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Smart Energy Resources Guide

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Foreword

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

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

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

Sally Gutierrez, Director
National Risk Management Research Laboratory

Notice

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The report contains information attained from a wide variety of currently available sources, including reports, periodicals, internet websites, and personal communication with both academically and commercially employed sources. No attempts were made to independently confirm the resources used. It has been reproduced to help provide government (federal, state, and local), industry and other end users, with information on methods to reduce GHGs and diesel emissions at waste cleanup and redevelopment sites.

All links in this document are active as of February 26, 2008.

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About the Regional Applied Research Effort

The Regional Applied Research Effort (RARE) Program promotes collaboration between the EPA regional offices and the EPA Office of Research and Development (ORD). The goals of the program are to:

- Provide the regions with near-term research on high-priority, region-specific science needs,
- Improve collaboration between regions and ORD laboratories and centers, and
- Build a foundation for future scientific interaction.

ORD provides $200,000 per year to each region to develop a research topic or topics, which are then submitted to a specific ORD laboratory or center as an extramural research proposal. Once approved, the research is conducted as a joint effort with ORD researchers and regional staff working together to meet region-specific needs. Each region's Regional Science Liaison (RSL) coordinates RARE Program activities and is responsible for ensuring the research results are effectively communicated and utilized in the region.

Past RARE research topics have touched upon all aspects of environmental sciences, from human health concerns to ecological effects of various pollutants. However, the RARE Program can be used as a tool to address any type of issue or problem that a region identifies as a high priority research need and for which ORD has the necessary expertise and capability to address.

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Acronyms and Abbreviations

AC	Alternating current
AFO	Animal feeding operations
AFV	Alternative fuel vehicles
AH	Amp-hours
ASTM	American Society for Testing and Materials
AWEA	American Wind Energy Association
BACT	Best available control technologies
bhp-hr	Brake horsepower - hour
BIPV	Building-integrated photovoltaic
BTU	British thermal unit
C	Carbon
CARB	California Air Resources Board
CCA	Cleanup-Clean Air Initiative
CEC	California Energy Commission
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cf	Cubic foot
cfd	Cubic foot per day
CFDA	Catalog of Federal Domestic Assistance
cfm	Cubic foot per minute
CFR	Code of Federal Regulations
CH_4	Methane
CHP	Combined heat and power
CIG	Conservation Innovation Grants
CMAQ	Congestion Mitigation and Air Quality
CMP	Carl Moyer Memorial Air Quality Standards Attainment Program
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
CREBs	Clean Renewable Energy Bonds
CSI	California Solar Initiative
CSP	Concentrated solar power
CT	Combustion turbine
DC	Direct current
DCA	Dichloroethane
DOC	Diesel oxidation catalyst
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DPF	Diesel particulate filter
EERE	DOE Office of Energy Efficiency and Renewable Energy

EGR	Exhaust gas recirculation
EIA	DOE Energy Information Administration
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
EPBB	Expected performance base buydown
EQIP	Environmental Quality Incentives Program
ERP	Emerging Renewables Program
ERRS	Emergency and Rapid Response Service
FEMP	Federal Energy Management Program
FPPC	Farm Pilot Project Coordination, Inc.
FY	Fiscal year
GAC	Granulated activated carbon
GCW	Groundwater circulation wells
GHG	Greenhouse gas
GRO	Greater Research Opportunities
GSA	General Services Administration
GSFC	Goddard Space Flight Center
GW	Gigawatt
H_2	Hydrogen
HC	Hydrocarbons
hp	Horsepower
HRT	Hydraulic retention time
IC	Internal combustion
IEA	International Energy Agency
IRS	Internal Revenue Service
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
kWh/m^2	Kilowatt-hour per square meter
lfg	Landfill gas
LFGE	Landfill gas-to-energy
LMOP	Landfill Methane Outreach Program
LNG	Liquefied natural gas
lsd	Low-sulfur diesel
µm	Micrometer
m	Meter
m^2	Square meter
m/s	Meters per second
MACRS	Modified Accelerated Cost-Recovery System
MSW	Municipal solid waste
mph	Miles-per-hour
MOA	Memorandum of agreement

MPO	Metropolitan planning organization
MW	Megawatt
NASA	National Aeronautics and Space Administration
NCDC	National Clean Diesel Campaign
NEG	Net excess generation
NETL	DOE National Energy Technology Laboratory
NMOC	Non-methane organic compounds
NNEMS	National Network for Environmental Management Studies
NO_x	Nitrogen oxides
NREL	DOE National Renewable Energy Laboratory
O&M	Operations and maintenance
OII	Operating Industries Incorporated
ORD	EPA Office of Research and Development
OTAQ	U.S. EPA Office of Transportation and Air Quality
P2	Pollution Prevention
P&T	Pump-and-treat
PBI	Performance based incentive
PCE	Perchloroethylene
PG&E	Pacific Gas and Electric Company
pH	Potential of hydrogen
PIER	Public Interest Energy Research
PM	Particulate matter
PPA	Power purchase agreement
ppm	Parts per million
PRP	Potentially responsible party
psig	Pounds-force per square inch gauge
PV	Photovoltaic
RAC	Response Action Contracts
RARE	Regional Applied Research Effort
RCRA	Resource Conservation and Recovery Act
RD&D	Research, development and demonstration
RD/RA	Remedial Design/Remedial Action
REC	Renewable energy credit/certificate
REPC	Renewable Electricity Production Tax Credit
REPI	Renewable Energy Production Incentive
RFP	Request for proposals
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RPM	Remedial project manager
RPM	Revolutions per minute
RSL	Regional science liaison
SARE	Sustainable Agriculture Research and Education
SCE	Southern California Electric Company

scfm	Standard cubic feet per minute
SDG&E	San Diego Gas and Electric Company
SERG	Smart Energy Resources Guide
SGIP	Self Generation Incentive Program
SOW	Statement of work
SO_2	Sulfur dioxide
SO_x	Sulfur oxides
SVE	Soil vapor extraction
TCA	Trichloroethane
TCE	Trichloroethylene
TOU	Time-of-use
ulsd	Ultra-low-sulfur diesel
USDA	U.S. Department of Agriculture
VOCs	Volatile organic carbons
W	Watt
W/m^2	Watts per square meter
WRAP	Western Regional Air Partnership
WURD	Western United Resource Development Corporation

EXECUTIVE SUMMARY

Remedial actions taken to clean up hazardous waste sites for environmental restoration and potential reuse are often sources of diesel and greenhouse gas (GHG) emissions. Many remediation systems, such as pump-and-treat (P&T), may operate for many years, demanding electricity from fossil-fuel powered utilities. Heavy-duty equipment used in construction during site remediation are usually diesel powered. Opportunities to lessen these emissions exist through innovative approaches and new technologies. The purpose of this guide is to provide information on available mechanisms to reduce these emissions at cleanup sites.

Reducing GHG and diesel emissions are important challenges facing this country. Executive orders have been issued and federal and state laws passed to address both concerns. GHG emissions from human activities are directly linked to global climate change. Diesel emissions are known to cause premature deaths and a wide variety of respiratory illnesses. The Cleanup-Clean Air Initiative (CCA) was established by the U.S. Environmental Protection Agency (EPA) Region 9 Superfund and Air Divisions to encourage GHG and diesel emissions reductions at cleanup sites. Through these efforts, CCA staff have engaged in pilot projects and changed Emergency and Rapid Response Service and Response Action Contracts to include language on renewable energy and clean diesel.

This document discusses many opportunities to reduce emissions due to energy use from remediation activities. Examples include energy efficiency upgrades, implementing on-site renewable energy projects, and carbon sequestration. An overview of renewable energy technologies is presented including costs, availability, applicability, estimated emissions reduction benefits, considerations, permitting, vendor information, funding resources and success stories. Renewable energy technologies covered in this guide are solar, wind, landfill gas, anaerobic digesters, and gasifiers. Additional methods for utilizing renewable energy are provided. Similar information is provided for diesel emissions reduction technologies and cleaner fuels. This document includes information on reducing diesel emissions through retrofitting diesel equipment, using cleaner and alternative fuels, and simple, low-cost practices such as idle reduction. Currently, there are approximately 15 EPA cleanup sites that are using cleaner diesel technologies and fuels or renewable energy to power their remediation systems.

The Smart Energy Resources Guide (SERG) is a tool for project managers to help them assess and implement these technologies and practices on Superfund sites as well as other cleanup sites. With this information, project managers may be better prepared to discuss emissions reductions strategies with contractors and/or developers. While resources cited in this document focus on Region 9 territories, many are applicable in other parts of the nation.

CHAPTER 1: INTRODUCTION

Chapter 1 Table of Contents

Remedial actions taken to clean up hazardous waste sites for environmental restoration and potential reuse at U.S. Environmental Protection Agency (EPA) Superfund Program sites are often also sources of harmful greenhouse gas (GHG) and diesel emissions. Region 9 Superfund's Cleanup – Clean Air Initiative (CCA) aims to encourage and facilitate emissions reductions at cleanup sites. The Smart Energy Resources Guide (SERG) was created as part of the initiative to provide information on emissions reductions opportunities for remediation project managers. This information can be useful for ascertaining emissions reductions opportunities at cleanup sites and as background information to facilitate communication with contractors and/or developers about cleaner energy.

1.1 OVERVIEW OF THE SMART ENERGY RESOURCES GUIDE (SERG)

The SERG was created for CCA to provide technical information to Region 9 Superfund remedial project managers (RPMs) and to help them make economic decisions about reducing GHG and diesel emissions from energy use in remediation activities at Superfund sites. An optimal phase in which to start considering these actions is during the Remedial Investigation/Feasibility Study (RI/FS) phase of a cleanup. The technical information in this document may assist in designing a remediation system during the Remedial Design/Remedial Action (RD/RA) phase as well. Efforts to reduce emissions can also be applied during remedy system optimization and evaluation, 5-year reviews, and Record of Decision (ROD) amendments. While some information presented in this guide is Region 9-specific, much of the information is also applicable for other parts of the nation. RPM

What the SERG Can Do for You

The SERG provides information on practices and technologies that can reduce emissions from electricity and diesel use at cleanup sites. This information can be used to:

- Assess possibilities of cleaner electricity and diesel at cleanup sites.
- Share information with contractors.
- Provide background information in order to better communicate with contractors and/or developers on emissions reductions strategies.
- Provide a starting point for implementing cleaner electricity and/or diesel projects.
- Reference guide for funding opportunities.
- Reference guide for tools to help estimate costs of technologies and emissions reductions.

counterparts, such as Resource Conservation and Recovery Act (RCRA) site and state project managers, may also find this guide useful.

See Chapter 2 for overviews on energy, conservation and efficiency, general renewable energy, purchasing clean energy, and carbon sequestration. Review Chapter 3 through Chapter 7 for more in depth information on renewable energy technologies that may be applicable for cleanup sites. Chapter 8 provides information on diesel emissions reduction practices and technologies. See Chapter 9 for funding and incentives for energy efficiency efforts, renewable energy projects, and cleaner diesel technologies. Find tools such as calculators, technical resources, and sources of further information for energy efficiency, purchasing clean energy, renewable energy and cleaner diesel in Chapter 10. Calculators to measure emissions and emissions reductions are also included in Chapter 10. In addition, Chapter 10 provides resources to help select a properly licensed renewable energy contractor. Appendix I includes an excerpt of contract language that incorporates CCA principles. Appendix II lists relevant executive orders and federal goals related to emissions reductions. Appendices III-VIII provide supplemental information on renewable energy technologies and cleaner diesel. Find the Region 9 Superfund Electricity and Diesel Emissions Inventory in Appendix IX. Appendix X includes resources to find local utility rate schedules on-line. Appendix XI provides a list of Green Pricing Programs in Region 9 states and territories. Last, Appendix XII provides a summary of some net metering programs in Region 9 states and territories.

The SERG focuses on cleaner energy and cleaner diesel technologies and practices. Although there are many other methods to reduce the environmental footprint of cleanup sites, those strategies extend beyond the scope of this guide.

1.2 THE CLEANUP-CLEAN AIR INITIATIVE (CCA)

The Cleanup – Clean Air Initiative is a cross-program partnership between the EPA Region 9 Air and Superfund Divisions. CCA aims to protect human health by reducing air pollution at Superfund sites during remedial action, construction and redevelopment. CCA seeks to encourage, facilitate and support implementation of diesel emissions and GHG reduction technologies and practices at Superfund cleanup and redevelopment sites. The use of cleaner fuels, retrofit technologies, and idle reduction practices on diesel equipment used at Superfund sites for purposes of construction is consistent with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) section 121(b)(1). In addition, CCA seeks to reduce GHG emissions through better energy management practices, such as the use of renewable energy technologies and improved energy efficiency.

To accomplish the emissions reductions goals, Cleanup – Clean Air:

- Raises awareness of the potential for GHG and diesel emissions reductions at Superfund site cleanup and redevelopment;
- Promotes Cleanup-Clean Air projects by providing coordination and facilitation support for potential projects that reduce diesel and GHG emissions;
- Creates an open forum for information sharing, and works to leverage significant new resources to expand voluntary emissions reductions; and

- Creates momentum for future GHG and diesel emission reduction efforts within the Superfund Program and elsewhere.

Visit the CCA website at www.epa.gov/region9/cleanup-clean-air.

1.3 INCORPORATING EMISSIONS REDUCTIONS INTO SITE CLEANUPS

Some of Region 9 Superfund contracts now include language on cleaner diesel and electricity. The Emergency and Rapid Response Services Contract (ERRS) strongly encourages contractors to use clean technologies and/or fuels on all diesel equipment to the extent practicable and/or feasible. The Response Action Contract (RAC) requires contractors, when directed by EPA, to use cleaner engines, cleaner fuel and diesel emissions control technology on diesel powered equipment where feasible and to evaluate all reasonably feasible renewable energy sources. See Appendix I (page 124) for the incorporated language.

GHG and diesel emissions reductions from cleanup activities can also be achieved through the following mechanisms:

- Modifying the Statement of Work under RAC (completed in Region 9)
- Developing Stand Alone Contract or Interagency Agreements with the Army Corps Of Engineers
    - Request for proposals (RFP) to energy providers
    - General Services Administration schedule

For fund-lead sites, RPMs have more control over which contractors are chosen. If it is lead by a potentially responsible party (PRP), it is best to encourage PRPs to make efforts to reduce diesel and GHG emissions and provide information on emissions reduction technologies and practices.

1.4 IMPORTANCE OF REDUCING THE SUPERFUND PROGRAM ENVIRONMENTAL FOOTPRINT

Reducing GHG and diesel emissions is a high priority for our nation. Presidential executive orders (EOs) and state and federal strategies have stressed the importance of GHG and diesel emissions reductions. For example, the EPA Administrator's Action Plan includes goals to promote diesel emissions reductions and renewable energy development. For a listing of some of the policies, regulations and executive mandates that are driving efforts to reduce emissions, see Appendix II (page 126).

Many remediation systems constructed for Superfund site cleanups operate for decades and/or have high energy consumption levels. Fossil fuel electricity generation is a major source of GHGs, (a primary cause of climate change) as well as other pollutants. Also, remediation activities often include the use of diesel equipment, which consumes fossil fuels and emits toxic diesel exhaust, potentially exposing site workers and surrounding communities.

In the U.S., most electricity is generated from coal or natural gas combustion. Power generation from fossil fuels releases carbon dioxide (CO_2), a GHG, as well as other air pollutants into the atmosphere. In 2005, more than 2.6 billion metric tons of CO_2 were emitted from electricity production in the U.S.[1] The U.S. population is about 300 million, so on average, the nation generated approximately 8.7 metric tons of CO_2 per person due to electricity production in 2005.

A survey conducted of half of Region 9 Superfund sites found that they will emit approximately 428,174 tons of CO_2 from remediation activities between 1990 and 2009 due to electricity consumption. This amount of CO_2 is equivalent to that from 84,000 cars on the road for one year or powering about 50,000 single family homes for one year. From 1985 to 2009, an estimated 3,140 tons of nitrogen oxides (NO_x), 848 tons of carbon monoxide (CO), and 105 tons of particulate matter (PM) will result from diesel equipment use at these sites (DeBoard, EPA GRO Fellow, 2007). See Appendix IX (page 154) for the full report.

CCA seeks to aid the Superfund Program to remediate sites in a manner that minimizes environmental impacts and to set positive examples for the public and other agencies. There are a variety of opportunities for Superfund to reduce GHG and diesel emissions including the following, which are discussed in this guide:

- Energy Efficiency
- Purchasing Clean Energy
- Carbon Sequestration
- Renewable Energy Technologies
- Cleaner Diesel Technologies
- Cleaner and Alternative Fuels

At the time of writing, 15 EPA cleanup sites were identified that currently use renewable energy to power some or all of their remediation activities (Dellens, EPA NNEMS Fellow, 2007).[2] The majority of these sites are utilizing groundwater extraction and treatment systems, one uses soil vapor extraction (SVE), and others are using renewable energy for powering irrigation and data collection purposes. See the EPA publication *Green Remediation and the Use of Renewable Energy Sources for Remediation Projects* (http://cluin.org/s.focus/c/pub/i/1474/) for more details.

CHAPTER 2: ENERGY BASICS, ENERGY CONSERVATION AND EFFICIENCY, RENEWABLE ENERGY INTRODUCTION, PURCHASING CLEAN ENERGY AND CARBON SEQUESTRATION

This section begins with a refresher of electrical and fuel energy basics. It includes information on options to reduce electricity and fuel use and associated environmental impacts. Conservation and energy efficiency opportunities as well as renewable energy are discussed. Purchasing clean electricity is another strategy discussed in this chapter to reduce the unwanted impacts of site cleanups. The end of this chapter includes an overview of carbon sequestration on contaminated lands which may be considered to mitigate GHG emissions.

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2.1 UNDERSTANDING ELECTRICAL ENERGY AND KEY TERMS

Think of a faucet with a hose to help understand amps, voltage, and watts. Electricity running through a wire is analogous to water running through a hose (Fig. 1).

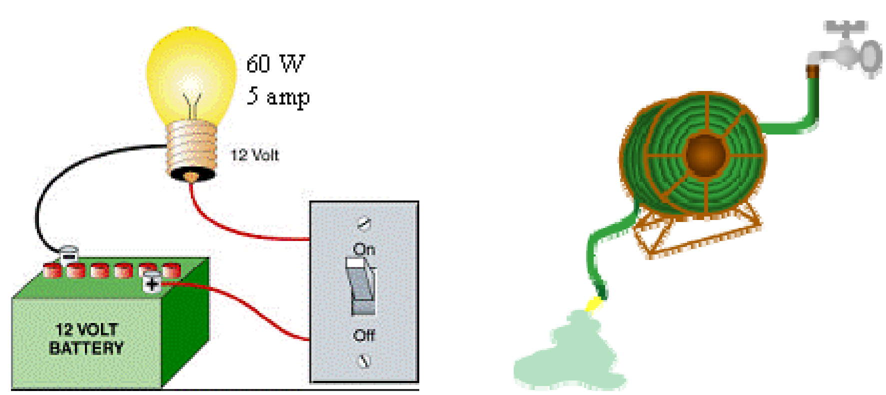

Figure 1 Electric circuit and hose. Image courtesy Solar On-Line and NDT[3]

Voltage Voltage is the "pressure" that pushes electrons along in a wire. This "electrical pressure" is analogous to water pressure in a garden hose. The greater the pressure, the more energy each parcel of water in the hose has and the greater the force with which it is pushed along. Voltage is measured in volts, usually abbreviated "V."[4]

Amperes (Amps) An ampere is a unit of measure of electrical current. An electrical current is the rate at which electrons flow past a given point in a wire. This electrical flow rate is analogous to a volume of water flowing per second. Amperes is usually abbreviated "amps" or "I."[5]

Power (Watts) The rate at which electricity is produced or consumed is referred to as power. It measures how much energy is needed to start a device or operate a piece of equipment per unit time. Using the water analogy, power is the combination of water pressure (voltage) and rate of flow (current) that allows work to be done (e.g., lighting a light bulb, water turning a turbine). This rate of energy use or production is measured in watts (W). It can also be measured in horsepower (hp). One hp is equivalent to 745.7 W. The power rating is usually found on the specifications of a piece of equipment.

Power (watts) = voltage (volts) x current (amps)

One can see the relationships among voltage, amperage and power by returning to the garden hose analogy. A high-pressure garden hose with a pinhole opening will shoot a tiny stream of water far into the air. The water has high energy, but there is very little water actually flowing (high voltage, low amperage). In contrast, consider a large pool of water slowly exiting a very large pipe. There is a large amount of water moving, but it has low energy (low voltage, high amperage). Most modern energy production systems generate both high voltage and high amperage electricity.

Energy Usage The actual energy used is measured in watt-hours (Wh). A 60-watt light bulb needs 60 watts of power to operate. If it operates for 3 hours, this light bulb will use 60 W x 3 hours = 180 Wh of energy.

Electrical Energy (Wh) = Power (W) x Time Operated (hours)

You most often see kWh on an energy bill and it stands for kilowatt-hours. One kilowatt is 1,000 watts, and so a kilowatt-hour is 1,000 watt-hours. A megawatt (MW) is 10^6 watts and a gigawatt (GW) is 10^9 watts. A typical 3 bedroom house will use about 600 kWh a month.[6] Another energy unit, the British Thermal Unit (BTU), is usually used to describe the energy content in fuels like natural gas. One kWh is equivalent to 3,414 BTUs.

Load A load is the general term for the power demanded by any device, equipment, or appliance that consumes electricity.

Alternating and Direct Current Electricity needs a complete circuit to flow. Electricity flowing in one direction is referred to as direct current (DC) and is typically found in batteries and solar modules. Electricity that cyclically reverses direction is referred to as alternating current (AC). Most appliances and equipment use this type of power and utility companies provide power as AC. Some renewable energy sources such as solar power and small wind turbines generate electricity as DC and an inverter is used to convert it to usable AC power.[7]

2.2 UNDERSTANDING ENERGY IN FUELS AND KEY TERMS

Different types of fuels are used to run construction equipment and vehicles, and to produce heat and electricity from renewable energy projects. Heavy-duty equipment like excavators, dozers, drills, and back hoes are used at cleanup sites during removals and construction. Most heavy-duty equipment runs on diesel fuel. Alternatively biogas or syngas fuels are used to generate electricity. Common energy terms associated with fuel include the following:

Biogas Gas produced from the decomposition of organic matter which can be used for heating or electricity generation. Biogas is produced in a landfill or anaerobic digester. See Chapter 5 for information on landfill gas and Chapter 6 for information on anaerobic digesters.

bhp-hr (Brake horsepower – hour) Net power after frictional power losses in the engine are subtracted from the maximum theoretical output power is the brake horsepower. Often seen as g/bhp-hr (grams per brake horsepower-hour) when assessing emissions.

$$\text{Emissions (g)} = \frac{\text{g}}{\text{bhp-hr}} \times \text{bhp} \times \text{hours of operation}$$

BTU (British Thermal Unit) The amount of heat (energy) required to raise the temperature of one pound of water one degree Fahrenheit.[8] Usually refers to energy content in fuels. 3,414 BTU = 1 kWh.

Combined Heat and Power (CHP) Practice of generating electrical and thermal energy and utilizing both, also known as cogeneration. When generating electricity, excess heat is produced and this valuable energy is often wasted. Capturing the thermal energy for heating dramatically increases efficiency.[9]

Energy content The amount of energy that can be released by burning a fuel. See “BTU.”

Fuel efficiency/fuel economy Measure of how well chemical energy in a fuel is converted into kinetic energy to operate equipment.

Heat rate Calculated as the fuel energy input divided by the electricity output of prime movers. It is closely related to the efficiency of the electricity generation system. Higher heat rates indicate lower efficiency.

Horsepower (hp) Like watts, a measure of the power required to operate a device or piece of equipment. One hp is equivalent to 0.7457 kW.

Prime Mover Devices that convert fuels to mechanical energy (e.g., gas turbines, reciprocating engines, steam turbines). Biogas or syngas can fuel prime movers to generate mechanical energy which in turn can drive a generator to produce electricity and heat.[10]

Syngas Gas composed of CO and hydrogen (H_2) produced by gasification technologies that can be used for heating and/or electricity generation. See Chapter 7 for information on gasifiers.

2.3 ENERGY CONSERVATION AND ENERGY EFFICIENCY

Conserving energy and improving energy efficiency are the first steps to reducing electricity and fuel use. Energy efficiency efforts reduce pollution and demand on resources, and can save money in many cases. There are many opportunities to improve energy efficiency at cleanup and redevelopment sites.

Conservation and Increasing Efficiency in Equipment

While preserving the priority of remediating a contaminated site to cleanup levels specified in the ROD, energy conservation may be considered during remedy selection. In long-term remedial action, remediation equipment may operate for years and even decades. In order to reduce energy demand as well as wear, equipment should be purchased and maintained for maximum efficiency. Although a piece of equipment may be over-sized in order to compensate for infrequent unexpected loads, note that the piece of equipment may not run at its maximum efficiency for the majority of operation. For example, a 50-hp pump engine may be very inefficient running at 30 percent of its full power. Installing a 15-hp engine instead can reduce energy bills compared to running the 50-hp engine at low power.[11] Properly sizing and maintaining pumps will prevent electricity and money from being wasted and will reduce pollution. Compare efficiency curves of pumps and purchase/rent a motor that is just powerful enough to meet what is required.

See *Introduction to Energy Conservation and Production at Waste Cleanup Sites* (www.epa.gov/swertio1/tsp/download/epa542s04001.pdf), a May 2004 EPA Engineering Forum Issue Paper for details on opportunities to make your pumps more efficient.

The same concept applies to diesel engines used during cleanup. Diesel fuel is wasted when oversized equipment is used to perform a job that a smaller piece of equipment is better suited to complete.

Optimizing Electricity Use Schedules

Utilities often resort to alternate, more expensive, polluting sources of energy during times of high-demand such as summer daytime hours. Time-of-use (TOU) rate schedules often categorize these times as "on-peak" hours. Under TOU schedules, electricity prices during on-peak hours are often significantly higher than during mid-peak or off-peak hours. Reducing electricity use at your site during on-peak hours can help to minimize the need for utilities to operate beyond their base loads and can reduce your utility bill. If available, contact an account manager at your utility to help compare different rate schedules to see which one best suits the electricity demands of your site in order to reduce costs. See Appendix X (page 172) for a list of web pages where you can find rate schedules for many utilities providing service in Region 9 states and territories.

2.4 RENEWABLE ENERGY INTRODUCTION, NET METERING AND UTILITY BILLS

Renewable energy is obtained from sources that are essentially inexhaustible (e.g., solar, wind, biomass). While fossil fuels are being depleted, renewable energy technologies provide a lasting source of energy. This document includes information on solar power, wind power, landfill gas-to-energy projects, anaerobic digestion and biomass gasification. Other renewable energy technologies such as hydropower, geothermal, tidal power, and biomass direct-combustion and pyrolysis are not covered in this guide. See Table 1 for a chart that summarizes applications and costs of some of these technologies. Cleanups may require a high electricity demand. Using renewable energy can avoid many of the pollutants emitted from fossil fuel use, including GHGs. Renewable energy use also reduces the demand to extract fossil fuels. Solar and wind power are widely available resources and the technologies are well established. Cleanup sites that are near landfills may consider capturing landfill gas if available. Sites that have potential biomass resources nearby may consider anaerobic digesters or gasifiers to produce electricity. Solar and wind options also require less maintenance and operational costs compared to digesters and gasifiers.

Additionally, implementing a renewable energy project can reduce energy bills. Some utilities have net metering programs which can increase monetary savings. Net metering programs allow grid-tied utility customers who generate electricity in excess of their consumption to credit that amount for later use.[12] For example, when a wind turbine produces more electricity than is consumed on-site, excess electricity is sent to the grid. For net metered systems, the utility acts like a giant battery. When wind power is unavailable, the site can use the energy credits from the utility. Some utilities may purchase excess power generated from renewable energy projects. Not all utilities have a net metering program. See Appendix XII (page 176) for net metering programs in Region 9 territory.

Also, review the cleanup site's energy bill to become familiar with how it is charged for electricity use. Commercial and agricultural customers are often charged per kWh (the electricity actually consumed), as well as per kW (the power the utility needs to have available). This kW charge is based on the highest level of power demanded during the month. This charge is often a large portion of the bill and may also be difficult to avoid. It may be worth sizing a renewable energy system for the purpose of reducing the demand charge.

Table 1 Summary of Some Renewable Energy Applications and Costs[13]

Energy Source	Applications	Cost (Generating Capacity)	Cost (Use)	U.S. Production
Solar	P&T, SVE, data collection, general energy production	\$8-\$10 per watt	\$0.04-\$0.07 per kWh	120 MW (PV)
Wind	P&T, SVE, general energy production	\$2-\$4 per watt	\$0.20-\$0.30 per kWh	11,961 MW
Landfill gas	General energy production	\$2-3 per watt	\$0.07-\$0.09 per kWh	1,195 MW

2.5 PURCHASING CLEAN ELECTRICITY

While it may not be feasible for a cleanup and redevelopment site to produce its own renewable energy, there are other options for a site to offset its carbon emissions from energy use. Options include buying Renewable Energy Credits and participating in green pricing programs. To estimate emissions reductions from purchasing clean electricity, go to EPA's Power Profiler listed in Chapter 10 (page 112.)

Renewable Energy Credits

Renewable Energy Credits (RECs), also called Renewable Energy Certificates or Green Tags, represent the environmental benefit from producing energy from renewable resources separate from the actual electricity. A REC puts a dollar value on the environmental benefits of clean energy that can be traded and sold independently of any actual electricity. After the REC is sold, the clean energy producer sells renewable electricity at the market price for conventional electricity. For example, producers of renewable energy, such as wind farm owners, register the amount of electricity they produce and can receive RECs. They can in turn sell two different products, electricity and RECs, to two different customers. REC owners can claim that they have offset their emissions from fossil fuel electricity consumption with cleaner renewable energy. The EPA purchases RECs to offset 100 percent of its energy use in EPA facilities nationwide. For a list of REC retailers, go to www.eere.energy.gov/greenpower/markets/certificates.shtml?page=1.

Green Pricing Programs

Some utilities provide green pricing as an optional service. These options provide an opportunity for customers to support the utility company's investment in renewable energy technologies. Participating customers pay a premium on their electric bills to cover the additional cost of renewable generation relative to conventional generation. More than 600 utilities in the nation, including investor-owned, municipal utilities, and cooperatives, offer a green pricing option. The price premiums charged in green pricing programs range from 0.7 cents per kWh to as much as 17.6 cents per kWh. Contact your utility to see if they offer a green pricing program. See Appendix XI (page 174) for some green pricing opportunities in EPA Region 9 states and territories.

Power Purchase Agreement

Another option for using renewable energy is to enter into a power purchase agreement (PPA). A PPA is a long-term agreement to buy electricity from a power producer. A company that provides PPA services will use its own funds to install a renewable energy system on your site. The company will own the system and sell the produced power to provide the needed power for your remediation system. This type of agreement may be applicable for the renewable energy technologies discussed in this document. PPAs may also be considered if a renewable energy project on a cleanup site produces a surplus of energy that can be sold to another party. For more information, go to EPA's *Guide to Purchasing Green Power* pages 22-23 (www.epa.gov/greenpower/documents/purchasing_guide_for_web.pdf).

2.6 CARBON SEQUESTRATION

Carbon sequestration is the process of removing CO_2 from the atmosphere and storing it in another form. Carbon can be stored in plant-life, soils, and geologic formations. While CO_2 can be sequestered in geologic formations such as oil and gas reservoirs, un-mineable coal seams, and deep saline reservoirs, this section focuses on carbon sequestration in plants. Restored lands may provide space for carbon sequestration in plant matter. Plants remove CO_2 from the atmosphere and store it in biomass (Fig. 2).[14] Plants store CO_2 in their tissues and also release some CO_2 back into the atmosphere. Soils also store and release CO_2. Net sequestration results if the rate of removal is higher than the rate of release. Young, fast-growing trees in particular will remove more CO_2 from the atmosphere than they will release.[15] An informational and technical resource is the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) which is currently researching carbon sequestration on mined lands[16] (www.netl.doe.gov/technologies/carbon_seq/index.html).

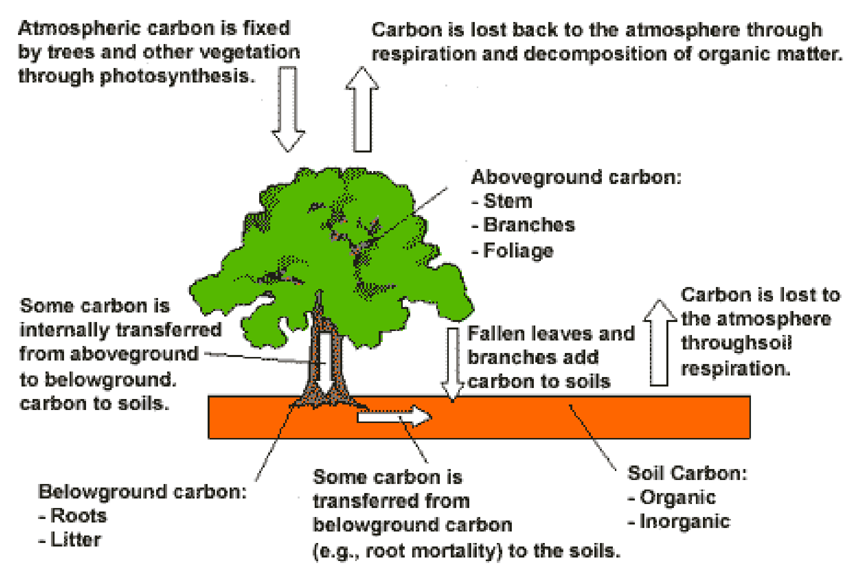

Figure 2 Carbon sequestration in plant-life. Image courtesy EPA[17]

Carbon sequestration rates vary by tree species, soil type, regional climate, topography and management practice. In the U.S., fairly well-established values for carbon sequestration rates are available for most tree species. Soil carbon sequestration rates vary by soil type and cropping practice and are less-well documented but information in this area is growing.[18]

Planting trees on lands previously not forested is called *afforestation*, which may be feasible for some cleanup sites. Afforestation can sequester about 0.6–2.6 metric tons of carbon per acre per year for approximately 90-120 years.[19] Carbon accumulation in vegetation and soils eventually reaches a saturation point. This happens, for example, when trees reach maturity, or when the organic matter in soils builds back up to original levels before losses occurred. Even after saturation, the trees or agricultural practices need to be sustained to maintain the accumulated carbon and prevent subsequent losses of carbon back to the atmosphere.[20]

Use the following document to estimate the amount of carbon sequestered in trees at your site: *Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings* by the DOE, Energy Information Administration (EIA) published in April 1998 (ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/sequester.pdf).

For more information go to:

- EPA Carbon Sequestration Web Pages: General information on carbon sequestration in agriculture and forestry. www.epa.gov/sequestration
- DOE Carbon Sequestration Web Pages: Information on DOE carbon sequestration efforts. www.fossil.energy.gov/programs/sequestration
- NETL Carbon Sequestration Web Pages: Information on current carbon sequestration research. www.netl.doe.gov/technologies/carbon_seq
- *The Contribution of Soils to Carbon Sequestration* (Plains CO_2 Reduction Partnership, August 2005): Document detailing soil carbon sequestration. www.netl.doe.gov/technologies/carbon_seq/partnerships/phase1/pdfs/ContributionSoils.pdf
- West Coast Regional Carbon Sequestration Partnership: This partnership is a collaborative research project bringing together dedicated scientists and engineers at 70 public agencies, private companies, and nonprofits to identify and validate the best regional opportunities for keeping CO_2 out of the atmosphere. www.westcarb.org/

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CHAPTER 3: SOLAR POWER

Various technologies are available to capture energy from the sun. Photovoltaic (PV) technology converts solar energy directly to electrical energy. In addition, heat from the sun can be used in solar hot water heaters or in concentrated solar power modules (see Appendix III page 134). While other forms of solar power are available, this guide focuses on PV technology. The Pemaco Superfund site in southern California is currently augmenting some of its grid-power consumption with a 3-kW solar PV system (see Section 3.7). PV systems typically require little maintenance depending on the complexity of the system.

Chapter 3 Table of Contents

3.1 SOLAR POWER TERMINOLOGY

The following are some solar power terms and definitions. See Appendix III (page 128) for more terms.

Photovoltaic (PV) Solar power technology that converts light energy into electrical energy.[21]

PV Cell Smallest semiconductor element within a PV module to perform the immediate conversion of light into electrical energy. They are also referred to as solar cells (Fig. 3).[23]

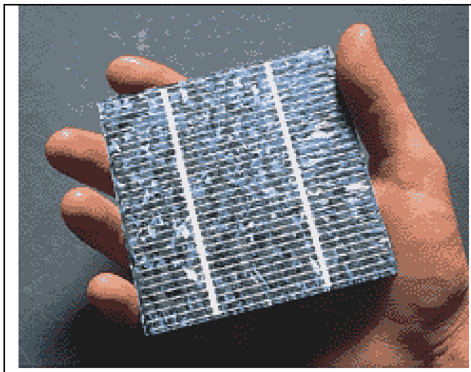

Figure 3 Multi-crystalline solar cell. Image courtesy Lawton Ltd[22]

PV Module Individual PV cells wired together in a sealed unit is called a module. It is the smallest assembly of solar cells and additional parts, such as interconnections, intended to generate DC power.[24]

PV Panel A group of modules wired together.[25]

PV Array PV system component composed of one or more PV modules or panels wired together. The array is an interconnected system of PV modules that function as a single electricity-producing unit.[26]

Battery A device that stores electricity for use when the PV system is not providing enough energy to meet the demand.[27] Typical batteries for PV systems last for 5-10 years.[28] See Appendix III (page 130).

Charge Controller A device that prevents overcharging of the batteries and the batteries from overly discharging electricity.[29] See Appendix III (page 132).

Inverter A device that changes direct current (DC) power to alternating current (AC). Electricity produced by the PV system is DC, and stored as DC if batteries are used, but appliances and equipment usually use AC power. The inverter converts DC electricity to AC either for stand-alone systems or to supply power to an electricity grid.[30] See Appendix III (page 132).

Balance of System Term used to describe PV system parts that include all hardware such as wiring and safety equipment that keep the system functional.[31]

Net Metering Net metering programs allow grid-tied utility customers who generate electricity in excess of their consumption to credit that amount for later use.[32] See Appendix XII (page 176) for some net metering programs in Region 9 states.

3.2 SOLAR POWER TECHNOLOGY BASICS

Sunlight hits PV cells and creates an electrical current. PV systems generate electricity without noise nor pollution (although production of PV systems results in some emissions, see Section 3.6) and are widely available. PV systems have a useful life of at least 25 years until the unit produces power at 80 percent of its original power rating.[35] PV technology can be installed in areas with sufficient space and solar resource. The core component of a solar panel is a PV cell. A PV module is made up of individual PV cells wired together in a sealed unit. An array is made up of interconnected modules (Fig. 4).

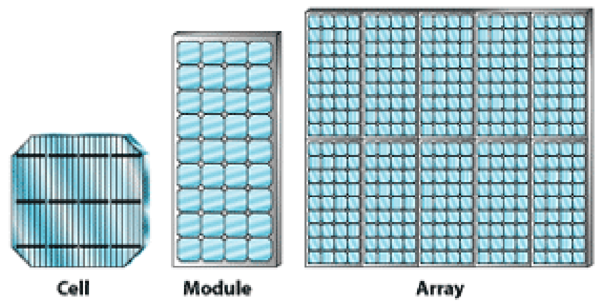

Figure 4 PV cells are interconnected into a module, and modules are interconnected to form an array to increase power output. Image courtesy EERE[33]

PV cells are composed of at least two layers of semiconductor material, commonly silicon. Sunlight hitting the cell causes electrons to flow in a single direction, generating DC electricity (Fig. 5). An inverter is then needed to convert the electricity to AC. See Appendix III (page 128) for more information on PV technology. You can view a short video by DOE's Office of Energy Efficiency and Renewable Energy (EERE) at the following link to see how a solar cell converts sunlight into electricity: www1.eere.energy.gov/solar/animations.html.

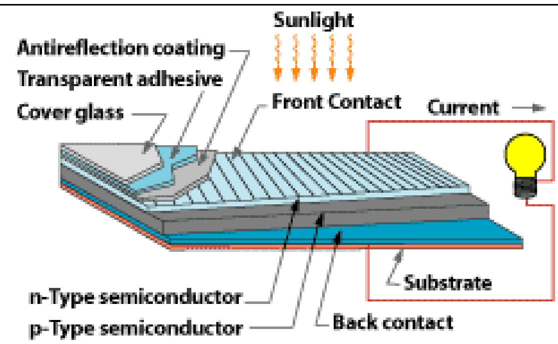

Figure 5 Inside a solar PV cell. Image courtesy EERE[34]

Crystalline and Amorphous Modules

Current cutting-edge PV technology can convert up to 40 percent of solar energy that hits a PV panel into electricity. Most readily available crystalline PV systems have solar cells with efficiencies of around 10-15 percent. Amorphous PV cells, or thin-film technology, have maximum efficiencies of about 10 percent. They are ideal for building-integrated uses such as roof tiles or shingles (Fig. 6).[36] Advancing technologies show that they may soon produce electricity at rates almost as high as crystalline modules and may drastically bring down the cost of solar power.[37]

Estimating Solar Power Emissions Reductions Using FindSolar.com and EPA's Power Profiler
www.epa.gov/cleanenergy/powerprofiler.htm

Consider the Pemaco Superfund site as an example. FindSolar.com estimates that a 3-kW solar system in southern California produces about 375 kWh per month. Then, go to the Power Profiler and enter the required information. Under "Make a Difference," select "My Emissions." Enter 375 kWh into the "Average Monthly Use" option. The Profiler estimates that about 4,311 pounds of CO_2 are released annually from producing 375 kWh of conventional electricity each month. This means that the 3-kW PV system at Pemaco prevents an estimated 4,311 pounds of CO_2 from being released into the atmosphere every year.

Single-crystalline PV devices are made from a single large silicon crystal. Multi-crystalline modules are made from multiple crystals grown together and are slightly less efficient than single-crystal modules. Amorphous modules are manufactured by depositing semi-conductor material onto a sheet of glass or plastic. Crystalline modules are delicate and need to be mounted on a rigid frame. Amorphous modules are flexible and their efficiency is not as affected as crystalline varieties by high temperatures, shading or cloudy days. While 100 ft^2 of crystalline cells produce roughly 1 kW, 100 ft^2 of amorphous cells will produce about 0.60 kW.[39]

Figure 6 Building integrated PV (BIPV) shingles. Image courtesy Kyocera[38]

Tracking or Fixed Tilt

Tracking units point the modules at the optimal angle to the sun throughout the day (Fig. 7). They can increase efficiency by 15 percent in the winter and 40 percent in the summer and thus can reduce the size of the system but require significant additional costs. They may need more frequent maintenance due to moving parts. They are best used at sites with long hours of sunlight and with no shading. Fixed tilt units do not move; they are tilted at an angle equal to the degree of latitude of the site to capture the greatest amount of energy over the year without using a tracking system.[41]

Figure 7 Solar tracking unit. Image courtesy Northern Arizona Wind and Sun[40]

3.3 ASSESSING SOLAR POWER POTENTIAL AND SIZE OF A PV SYSTEM

Sites that receive direct sunlight without shading from 9 am to 3 pm have good solar power potential. The following DOE National Renewable Energy Laboratory (NREL) website provides maps of solar radiation (sunlight availability) based on location and solar mounting type (fixed tilt or tracking) (Fig. 8): http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/. Keep in mind that this website gives the actual total solar radiation hitting earth's surface. Solar modules are 10-15 percent efficient at capturing this energy.

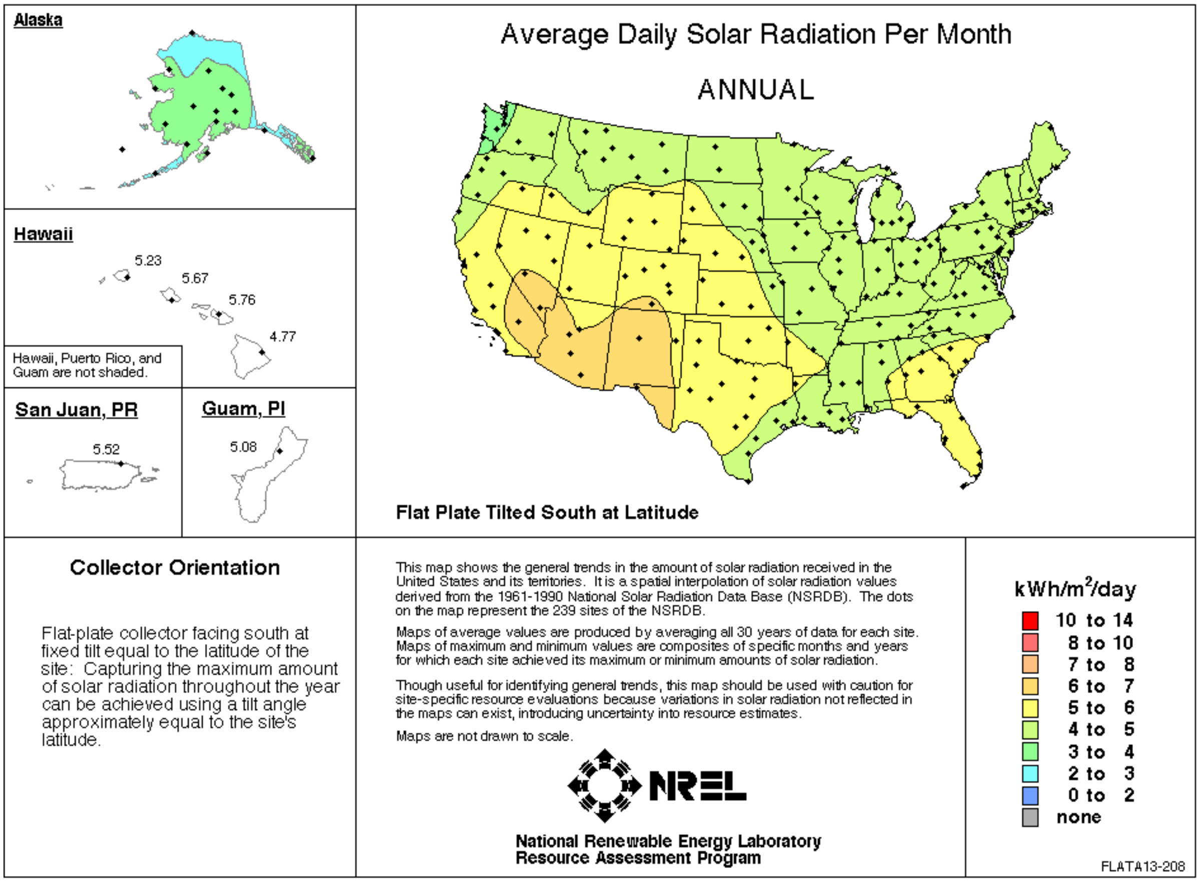

Figure 8 Solar radiation map. Image courtesy NREL[42]

PV panels can provide power to cleanup site remediation systems (1) that are off-grid; (2) that utilize low-flow pump systems; and (3) to augment grid-power for sites with high electricity demand. In general, PV systems will be most suitable for sites with an expected long-term need for power to operate equipment.

Completely shading just one cell can reduce efficiency by 75 percent for crystalline systems.[43] On moderately cloudy days, arrays can produce 80 percent of electricity compared to a bright sunny day, and on highly overcast days they can produce 20 percent.[44] For sites in the northern hemisphere, PV panels should be south-facing for maximum sunlight exposure. East or west facing panels may also be acceptable.[45] Panels can be mounted on roofs or poles or directly on the ground.

A PV system can be sized to meet all or a portion of your site's energy consumption. The size of the PV system needed for a site depends on the energy demands of the remediation system and available solar energy at a particular site. PV modules have two efficiency ratings. One measure is the Standard Test Conditions Rating set by the manufacturer which represents the maximum power output in laboratory conditions. A more accurate efficiency rating is the PV-USA Test Conditions rating which reflects the output under day-to-day conditions. A PV system rated for 1-kW in Region 9 sites will typically produce between 135 and 150 kWh per month. See EERE's *A Consumer's Guide: Get Your Power from the Sun* page 9 for a map of estimated site-specific annual solar energy production (www.nrel.gov/docs/fy04osti/35297.pdf). Rated kW is the maximum output capacity of the PV system. The actual energy produced depends on the solar resource at the site and efficiency of the PV equipment. Use the following equation (Box 1) to estimate the size of a PV system needed. To estimate your energy needs per month for a remediation system that is already operating, look at the site's energy bill for the number of kWh used per month. See Section 10.5 (page 114) for calculators to help size a solar PV system for the needs of your site.

Box 1 Size Calculation for a Simple PV System
S = E ÷ O
S = PV System Rated Power Output (kW)
E = Site Energy Needs per Month (kWh per month)
O = Average PV Energy Output (kWh per kW per month); Estimate 135 kWh/kW/month

3.4 GRID-TIED OR STAND-ALONE SYSTEMS

As previously discussed, grid-tied systems are connected to a utility grid. Stand-alone systems are not connected to a grid and may need battery backup or another source of power (e.g., clean diesel generator or wind turbine hybrid system) if a constant source of energy is necessary. Batteries add a substantial cost to a PV system but may be economical considering the cost of extending power lines. Evaluate the available electricity infrastructure in addition to solar energy availability.

Stand-Alone Day Use with DC Load

These systems are the simplest and least expensive. This configuration is applicable for remote sites that do not require a steady supply of power, especially at night. Examples include solar powered remote water pumps and solar powered fans used to circulate air in the daytime. Remediation equipment, devices or appliances that operate on DC power can directly use the electricity produced from the solar panels (Fig. 9).[47]

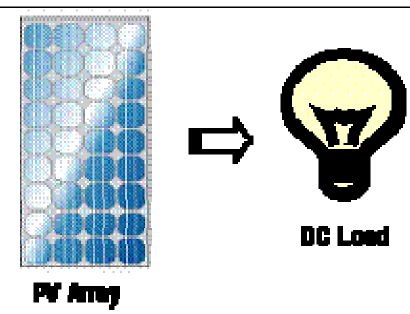

Figure 9 Day use DC load. "PV Array" image courtesy Solar On-Line[46]

Stand-Alone DC Load with Batteries

In many cases, electricity is needed in the day as well as at night and during cloudy weather. Excess energy produced during the day is stored in a battery to be used when the solar resource is not available. Battery power can also be used to provide high surge currents for short amounts of time which may be useful to start large motors. To prevent the battery, or batteries, from being overcharged or overly discharged, a device called a charge controller must be installed (Fig. 10).[49] See Appendix III (page 132) for more information on charge controllers. PV systems with batteries cost about $15,000-$20,000 per kW.[50]

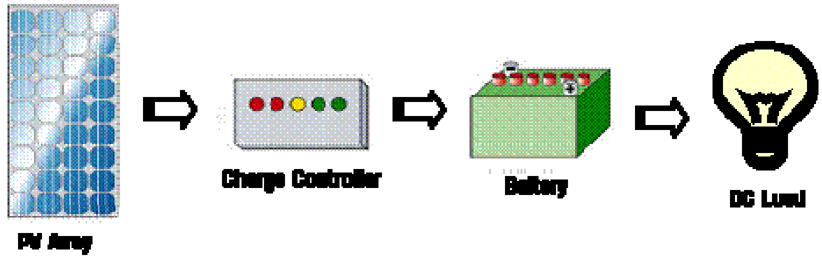

Figure 10 Stand-alone DC load with batteries. Separate images courtesy Solar On-Line except "DC Load"[48]

Stand-Alone AC Load with Battery

When solar panels are used to power AC loads, an inverter is installed to convert solar DC power to AC power (Fig. 11). Though inverters add complexity and cost, their use usually cannot be avoided. AC appliances are mass produced and more reliable than DC appliances. To see if your load is AC or DC, check manufacturer specifications.[51]

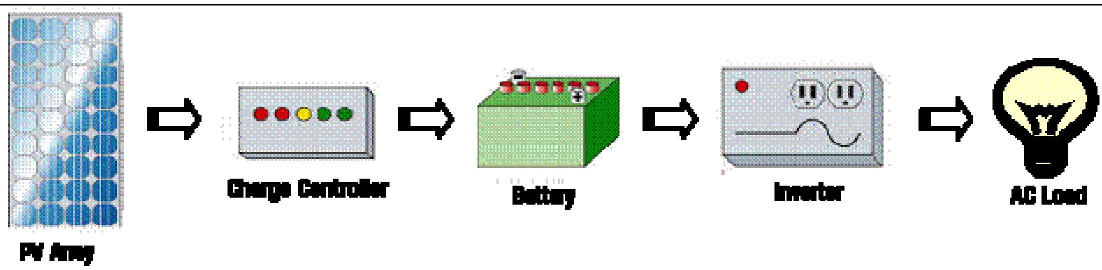

Figure 11 Stand alone AC load with battery. Separate images courtesy Solar On-Line except "AC Load"[52]

Grid-Tied AC Load

Grid-tied systems are interconnected with the utility grid (Fig. 12). When energy consumption exceeds energy production, the grid provides the remaining electricity needed. At times when electricity production is greater than consumption, excess energy is sent to the utility grid. Utilities may have a net-metering program that gives credits for electricity sent to the grid. See Appendix XII (page 176)

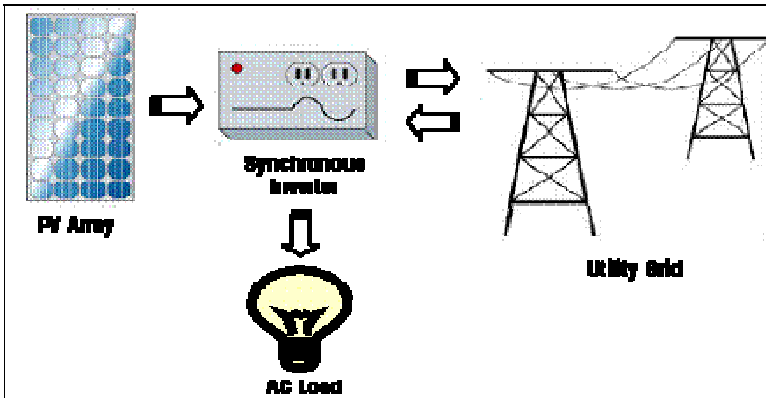

Figure 12 Grid-tied AC load without battery. Image courtesy Solar On-Line except for "AC Load"[53]

for net metering rules in your area. Also, without a battery, if the grid goes down, the site will not be able to get electricity from your solar PV system. They are disconnected at these times so utility employees are not at risk from an unexpected "live" wire.[54] Contact the local utility for more information on connecting to the grid.

Grid-Tied AC Load With Battery

Grid-tied systems can still have battery backup to help reduce demand from the grid. Excess energy generated will charge the battery, or batteries. If there is more energy left over, it will run back to the grid. In case the PV and battery system cannot meet the demand, the grid will provide necessary electricity. Also, these systems can operate when grid electricity is unavailable.

3.5 CAPITAL COST, O&M, INSTALLERS AND WARRANTIES

Estimate Capital Cost

The capital costs of a PV system with battery backup is $15,000-$20,000 per rated kW ($15-$20 per watt). PV systems without batteries cost $8,000-$10,000 per rated kW ($8-$10 per watt) (Box 2).[55] See Section 10.5 (page 114) for calculators to estimate initial costs, cash flow, and energy production.

Box 2 Capital Cost Calculation for a Simple PV System
C = S ∗ P
C = Capital Cost of PV System ($)
S = PV System Rated Power Output (kW)
P = Price per kW of PV System ($ per kW); Estimate $10,000/kW

Operations and Maintenance

Panels should be cleaned once a year if the cleanup site receives little rain and/or wind or has substantial bird populations. The PV equipment manual should provide more information on maintenance of the system and its components. Inverters should be stored in a cool and dry location out of direct sunlight if possible. Dust and cobwebs on the inverter unit inhibit it from cooling properly. Inverters usually need replacement after about 15 years of operation. Cost for inverter replacement is about $700 per rated kW.[56] If your system has batteries, they need to be replaced every 5-10 years.[57] It is important to allow air flow under and over the modules to remove heat and avoid high cell temperatures. A module will lose approximately 0.5 percent efficiency per degree centigrade temperature rise between 80˚C and 90˚C.[58] The output of a PV module degrades by about 0.5 percent per year.[59] Annual operations and maintenance costs are around 0.25-1.5 percent of the initial capital cost.[60] Estimate total operations and maintenance costs for the life of the solar system with the equation in Box 3.

Box 3 Lifecycle Operation and Maintenance Costs
O&M = P ∗ C ∗ Y
O&M = Total Lifecycle O&M Costs ($)
P = 0.0025 for low estimate; 0.015 for high estimate
C = Capital Cost of PV System ($)
Y = Years of operation (years); Estimate 25 years

Solar Installers

Setting up a PV system on a cleanup site is usually done through a solar installer or contractor. They will design and size the PV system, and acquire and install the appropriate panels, inverters, wiring, batteries, mounting, and any other equipment for a full running system. Here are a few websites that provide information on solar installers:

- Findsolar.com: Pre-screened, customer reviewed installers. www.findsolar.com Select "Find a Solar Pro."
- Solar Energy Industries Association Members: National solar trade association. www.seia.org
- General Services Administration Contracts Schedule: www.gsaelibrary.gsa.gov Search "206 3" for solar businesses.
- Source Guides: Renewable energy businesses and organizations directory. www.sourceguides.com

Start with contractors local to the site since they would be familiar with the weather, sun availability, and permitting processes for the area. Make sure that they are licensed (Section 10.4 page 114). Research or interview the companies with some of the following questions. [61] For a more extensive list of questions for your potential installer, see Appendix III (page 133).

- How many projects like yours have they completed in the past year? In the past three years?
- Can they provide a list of references for those projects?
- What PV training or certification do they have?
- Do they offer adequate warranties?
- Can you communicate effectively with the contractor?

Warranties[62]

More expensive solar panels may include a 20-25 year warranty. However, this warranty will not likely apply to all system components. The parts and labor warranty will usually cover two years, in addition to the regular manufacturer's warranty. Batteries typically have limited warranties ranging from 8-10 years. Inverters will usually have a two year warranty.

Be sure of the following:

- Is your warranty included in the cost of the bid, or do you know its cost?
- Does the warranty cover all aspects of the removal, shipping, repair and reinstallation of components?
- Who is responsible for all aspects of the system--is it the installer, the manufacturer, the dealer?

3.6 PERMITS AND ENVIRONMENTAL CONCERNS

Permits

Installers are usually responsible for garnering permits from city and/or county offices and will pass on these costs to the customer.[63] Among these are building permits and electrical permits. Permit fees may cost up to $1,500 although some cities have eliminated the fee for solar installations.[64] Sometimes, additional drawings or calculations must be provided to the permitting agency. Be sure the permitting costs and responsibilities are addressed with your PV contractor before installation begins.

Environmental Concerns

The following addresses some PV system environmental concerns.

How long does it take for a PV system to recover the energy that went into producing it?

DOE estimates that today's multi-crystalline silicon PV systems have about a four year energy payback period while it takes three years for current thin-film modules, two years for future multi-crystalline modules, and one year for anticipated thin-film modules.[65]

What happens to panels after their useful life?

PV systems have about a 25-30 year useful life so there currently is little issue with its disposal. PV products are generally safe for landfills because PV materials are usually encased in glass or plastic, and many are insoluble. Some modules, however, may be classified as hazardous waste due to small amounts of lead solder, selenium and cadmium.[66] This is prompting the PV industry to develop recycling processes for modules. Recycling processes may even allow some PV components to be recovered intact. This in turn would allow companies to produce recycled PV modules at a lower cost and with lower energy use.[67]

3.7 SUCCESS STORIES

The following are three success stories of Region 9 Superfund sites that are using solar PV systems.

Pemaco Superfund Site, Maywood, CA, Region 9

Pemaco is a fund-lead Superfund site located in southern California in the city of Maywood. It is a former chemical mixing plant and EPA determined that the soil and groundwater on site were contaminated with volatile organic

Figure 13 3-kW solar PV system at Pemaco. Image courtesy Caraway[68] compounds (VOCs) including perchloroethylene (PCE), trichloroethylene (TCE), trichloroethane (TCA), dichloroethane (DCA), and vinyl chloride. A 3-kW solar system was installed on the roof of the building that houses remediation equipment (Fig. 13). It will provide some of the electricity demanded for the site. The PV panels were installed and operational as of June 29, 2007, and power was being directed back into the utility grid. The PV system will produce an estimated 375 kilowatt hours per month (4,506 kilowatt hours per year) and will avoid 4,311 pounds of CO_2 per year, four pounds of NO_x per year, and three pounds of sulfur dioxide (SO_2) per year.

Site Contact:
Rose Marie Caraway
RPM, EPA Region 9
Phone: (415) 972-3158
E-mail: caraway.rosemarie@epa.gov

Apache Powder Company Superfund Site, St. David, AZ, Region 9

The Apache Powder Company Superfund site is a former industrial chemicals and explosives manufacturing plant. Contaminants identified on-site include high concentrations of heavy metals in ponds, arsenic, fluoride and nitrate in perched groundwater, dinitrotoluene in a drum disposal area, and nitrate in shallow wells. The perched groundwater zone is pumped and treated by forced evaporation (brine concentrator). The shallow aquifer is pumped and treated with the use of constructed wetlands. The treated water is then pumped back into the aquifer. Solar power is used on site to power a pump that recirculates water through the wetlands when the water cannot be discharged to the aquifer (when water exceeds nitrate discharge limit of 30 parts per million [ppm]). The PV system consists of twelve PV panels with a 1,440 watt total capacity and one solar powered centrifugal pump. The system is capable of pumping five gallons per minute through 100 feet of two inch fire hose with an elevation rise of about 10 feet. The system is only used when sunlight is available.

Site Contacts:
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Greg Hall
Apache Nitrogen Products, Inc.
E-mail: ghall@apachenitro.com

Lawrence Livermore National Laboratory Site 300 Superfund Site, Eastern Altamont Hills near Livermore, CA, Region 9

The Lawrence Livermore National Laboratory Site 300 is an 11 square mile facility operated by the University of California System for DOE as a high explosives and materials testing site for nuclear weapons research, established in 1955. Groundwater contaminants released from various on-site activities include solvents, VOCs, tritium, uranium-238, highly explosive compounds, nitrate, and perchlorate. Sources of contamination include spills, leaking pipes, leaching from underground landfills and pits, high explosives testing and disposal of waste liquids in lagoons and dry wells. A groundwater P&T system is operating to treat contaminated groundwater at four locations. Solar power is used to pump water through four granulated activated carbon (GAC) systems. The systems were installed between June 1999 and September 2005. The low flow systems pump groundwater at about 5 gallons per minute from depths of 75-100 feet. Each system has a capacity of 800 watts (for a total of 3.2 kW) and costs about $2,000. These systems are not grid connected but they are equipped with batteries to store excess power to allow for some operation during non-daylight hours.

Site Contacts:
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CHAPTER 4: WIND POWER

Wind is a renewable energy resource that can be captured to produce electricity. Wind turbines convert kinetic energy from wind into mechanical energy (Fig. 15). Generators then convert this mechanical energy into electrical energy that can be used anywhere, including on a cleanup site. An average wind speed of at least 10 miles-per-hour (mph) at 33 feet above the ground is typically necessary to run a wind turbine. An example of a Superfund site utilizing wind power is the Nebraska Ordnance Plant Superfund Site. It currently has a 10-kW wind turbine powering its groundwater circulation wells (see Section 4.7).

Chapter 4 Table of Contents

4.1 WIND POWER TERMINOLOGY[69]

The following are some wind power terms and definitions (Fig. 14).

Anemometer Device on a wind turbine that measures wind speed and transmits wind speed data to the controller.

Blades Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Controller Component of a wind turbine that starts up the rotor in 8-16 mph wind and shuts it off when wind speeds exceed about 65 mph. Usually, turbines cannot operate in such high wind speeds because their generators could overheat.

Cut-in Speed Minimum wind speed needed to turn a wind turbine and produce electricity. Varies from turbine to turbine.

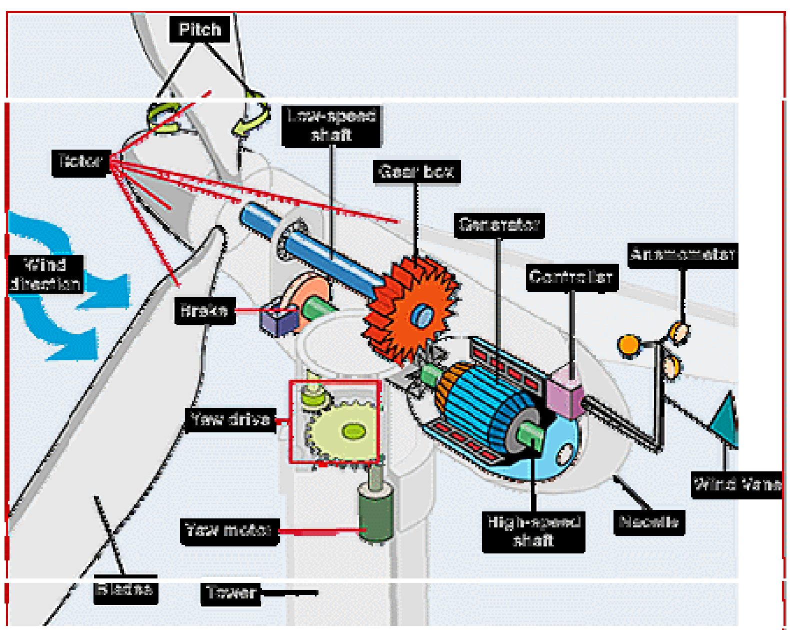

Figure 14 Parts of a wind turbine. Image courtesy DOE, EERE[70]

Cut-out Speed Maximum wind speed that a turbine can handle. Turbines automatically stop spinning at winds speeds greater than the cut-out speed to prevent damage to the turbine. Varies from turbine to turbine.

Figure 15 A 5-kW wind turbine.
Image courtesy ISET[71]

Generator Device that converts mechanical energy into electrical energy.

High-speed Shafts Drive the generator at 1,000-1,800 revolutions per minute (rpm).

Inverter Small wind turbines (20 W–100 kW) usually produce DC power. Inverters convert DC power to AC power so it can be used to power AC equipment.[72] See Appendix III (page 132) for more details.

Low-speed Shafts Drive the generator at 30-60 rpm.

Nacelle The nacelle sits atop the tower and encloses the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working.

Power Curve Graph showing the power output of a wind turbine at various wind speeds.

Swept Area Space that turbine blades travel through. Larger swept areas capture more wind energy.[73] Swept Area = $\pi \times r^2$ (r = length of one blade; $\pi \approx 3.14$)

Tower Vertical structure made from tubular steel or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity than turbines mounted on shorter towers. See Appendix IV (page 135).

Wind Power Class NREL wind speed and corresponding wind power classification system (Table 2).

Wind Power Density Available power usually measured in watts per square meter (Table 2).

Wind Direction Figure 14 illustrates an "upwind turbine", so-called because it operates with the blades facing into the wind. Other turbines are designed to run downwind, with the blades facing away from the wind.

Wind Map Map showing average annual wind speeds at a specified elevation (Fig. 20 page 30).

Wind Vane Component of a turbine that measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind. Also known as the tail.

Yaw Drive Component of a turbine that keeps the rotor facing into the wind as wind direction changes.

4.2 WIND POWER TECHNOLOGY BASICS

Kinetic energy in wind can be captured by wind turbines and converted to mechanical energy. Generators produce electricity from the mechanical energy. Simply, wind turbines work like a fan operating backwards. Instead of electricity making the blades turn to blow wind from a fan, wind turns the blades in a turbine to create electricity (Fig. 16). Remediation systems used to pump groundwater may consider windmills that directly draw water, rather than turbines for producing electricity. Windmills are commonly used on farms and have been utilized for hundreds of years.[76]

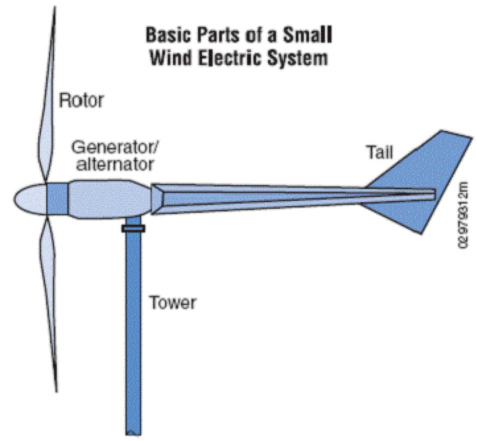

Figure 16 Main parts of a wind turbine. Image courtesy EERE[74]

Wind turbines range in size from a few hundred watts to as large as several megawatts (Fig. 17).[77] The amount of power produced from a wind turbine depends on the length of the blades and the speed of the wind. The faster the wind speed, the more kinetic energy it has. See Appendix IV (page 135) for more information on energy in wind. There is a cubic relationship between wind speed and power which means that a small change in wind speed will have a large effect on the power produced. Wind speeds vary with height and are generally weaker near the ground due to friction between earth's surface and air flow. To reduce turbulence and capture a greater amount of wind energy, turbines are mounted on towers (Appendix IV page 135). A common tower height is about 150 feet though it will depend on the length of the blades. A 10-kW turbine is usually mounted on a tower of 80-120 feet.[78]

Figure 17 3.6 MW turbine. Image courtesy EERE[75]

NREL divides wind speeds into wind power classes designated Class 1 (lowest) through Class 7 (highest) (Table 2). Class 2 and above wind speeds (at least 10 mph at 33 feet above ground) can provide sufficient energy to drive a small wind turbine. Utility sized turbines usually need at least Class 3 wind conditions to operate.

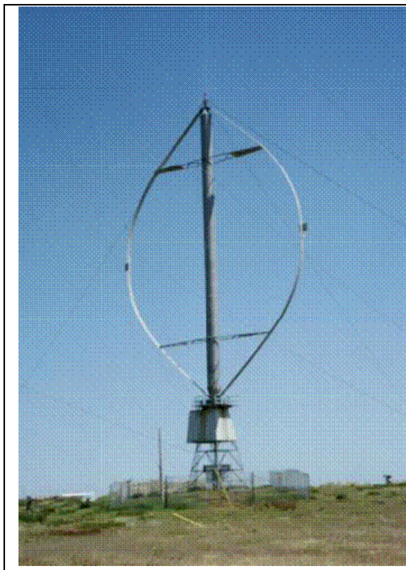

Figure 18 Darrieus style wind turbine. Image courtesy Solcomhouse[80]

Table 2 Wind Power Classes at 10 m (33 ft) Elevation*[79]

Power Class	Wind Speed mph	Wind Speed m/s	Power Density W/m^2
1	0-9.8	0-4.4	0-100
2	9.8-11.5	4.4-5.1	100-150
3	11.5-12.5	5.1-5.6	150-200
4	12.5-13.4	5.6-6.0	200-250
5	13.4-14.3	6.0-6.4	250-300
6	14.3-15.7	6.4-7.0	300-400
7	15.7-21.1	7.0-9.4	400-1,000

There are two basic groups of wind turbines. Horizontal axis turbines (propeller style) have two blades that face downwind or three blades that face upwind. Vertical axis turbines, such as the eggbeater-style Darrieus model, are less commonly used (Fig. 18). Blades for both types of turbines are made from fiberglass, carbon fiber, hybrid composites, or wood and will not interfere with television or radio waves.[81]

Wind turbines can be used in a wide variety of applications, from charging batteries to pumping water to powering a significant portion of a site. Large turbines are considered to be those rated greater than 100 kW and small turbines are considered to be 100 kW or less.[82] Turbines produce DC or AC power, depending on the generator.[83] Small turbines usually generate DC power.[84] Generators that produce DC power need an inverter to change the power to AC for use in most equipment. See Appendix III (page 132) for information on inverters. While variable speed turbines do not produce electricity at the voltage and frequency used in most equipment, these turbines are usually equipped with features to produce

Estimating Wind Power Emissions Reductions Using EPA's Power Profiler
www.epa.gov/cleanenergy/powerprofiler.htm

Consider the 10-kW wind turbine at the Nebraska Ordnance Plant Superfund site. It is estimated to produce about 817 kWh per month. Go to the Power Profiler and enter the required information. Under "Make a Difference," select "My Emissions." Enter 817 kWh into the "Average Monthly Use" option. The Profiler estimates that about 19,000 pounds of CO_2 are released annually from producing 817 kWh of conventional energy each month. This means that the 10-kW wind turbine prevents approximately 19,000 pounds of CO_2 from being released into the atmosphere every year.

* 1 meter per second (m/s) = 2.237 miles per hour (mph)

correct voltage and constant frequency compatible with the loads.[85]

Wind power will present an advantage for locations that are not easily accessible to local utility lines.[86] The expected wind turbine lifetime is about 20–30 years.[87] See Appendix IV (page 136) for a calculation of power output.

Wind Turbine Power Curve

A wind turbine power curve shows the power output of a turbine at corresponding wind speeds. Power curves are specific to different wind turbines. A wind turbine with the power curve shown in Figure 19 may be rated for a maximum output of 500 kW. What may not be stated upfront is that wind speeds of 14-24 m/s are necessary to reach a 500 kW output. Be sure to determine the power output of a turbine for wind speeds specific to your site. Wind turbine developers can properly install a turbine that is well-suited for each site. Higher altitudes usually have faster wind speeds because winds are more turbulent closer to the ground. Though it is more expensive to install a taller tower, it is often a good investment because of the greater return in energy production.

4.3 ASSESSING WIND POWER POTENTIAL AND SIZING A WIND TURBINE

Does My Site Have Wind Power Potential?

There is a space minimum as well as wind speed minimum for a wind power project to be feasible for your site. The potential site should be located on or near at least one acre of open, rural land. More importantly, it is necessary to have consistent wind at speeds of at least 10 mph (4.5 m/s) at an elevation of 33 feet (10 m) (Fig. 20). A common height for wind turbines is about 150 feet (45.7 m), where wind speeds are approximately 25 percent greater than at 30 feet.

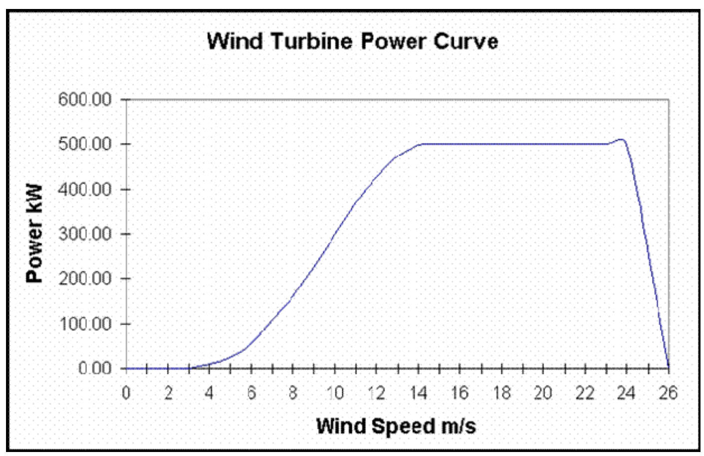

Figure 19 Sample wind Turbine Power Curve. Courtesy De Montfort University[88]

The turbine manufacturer can provide the expected annual energy output of a turbine as a function of annual average wind speed. A wind energy system, including rotor, transmission, generator, storage and other devices, will deliver approximately 10-30 percent of the energy available in the wind, depending on the manufacturer.[89] A 1.5-kW wind turbine will produce about 300 kWh per month in a location with a 14 mile-per-hour (mph) or 6.26 meters-per-second (m/s) annual average wind speed. A 10-kW turbine typically has a blade diameter of about 20-25 feet and would typically be mounted on a tower roughly 100 feet tall. If placed at a site with wind speeds of 10–15 mph, it will produce between 10,000 and 18,000 kWh per year.[90]

Wind speeds at a site can vary based on local topography and structural interference. Localized areas of good wind power potential such as a ridge-top may not show up on a wind map, so site-specific evaluations should be conducted to determine wind availability. Wind turbines should be sited in an area where obstructions or future obstructions, such as new buildings, will have minimal effect on the wind resource. Keep in mind that, depending on the manufacturer and/or model, some turbines run more efficiently at lower wind speeds and others are more efficient at higher speeds. Consult vendors to determine which turbines will operate efficiently with wind speeds available at your site.

To view average wind speed maps, visit:

- EERE: Provides annual average wind speed maps for individual states. www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp
- NREL: Provides annual average and seasonal wind speed maps for individual states and U.S. territories. http://rredc.nrel.gov/wind/pubs/atlas/maps.html
- Bergey Windpower: Provides wind maps for individual states and U.S. territories. www.bergey.com/wind_maps.htm

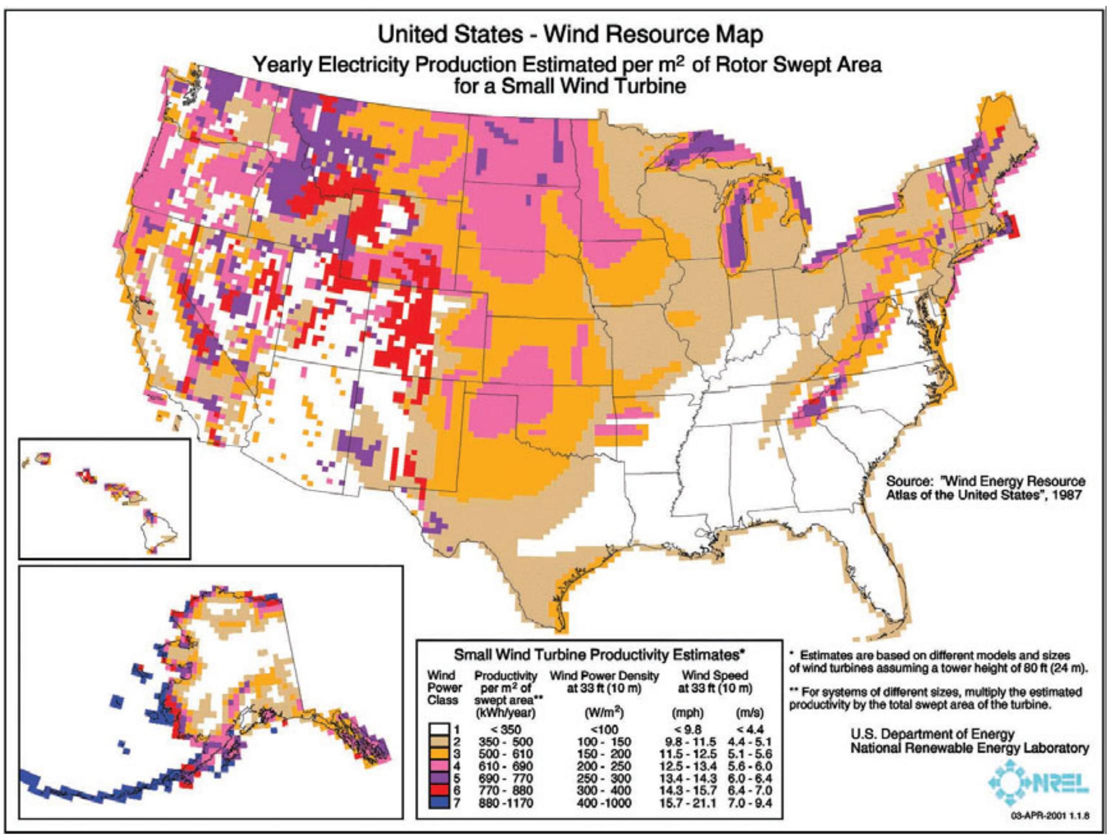

Figure 20 Wind resource map. NREL provides national wind maps and state-by-state maps.[91]

Location-specific wind speed data can be obtained using a recording anemometer, which generally costs $500-$1,500. Your local utility may provide services that lend assessment tools for renewable energy projects (See Section 10.6 page 115). The most accurate readings are taken at "hub height" (i.e., the elevation at the top of a potential wind turbine tower). This requires placing the anemometer high enough to avoid turbulence created by trees, buildings, and other obstructions.

Determining Size of Wind Power System

While solar panels are rated at an industry standard, there are no standards that apply to wind turbines. The electricity produced by a wind turbine depends on the following factors:

- Average wind speed of your site
- Length of blades (corresponds to swept area)
- Tower height
- Efficiency of system components

Use the equation in Box 4 for a rough estimate of the turbine size, in terms of rated power output (kW), needed to completely or partially provide electricity for your site.

Box 4 Estimate Turbine Rated Power Output (kW)[92]
P = E ÷ CF ÷ 8,760
P = Turbine Rated Power Output (kW) E = Site Energy Needs per Year (kWh) CF = Capacity Factor; Small Turbine Estimate ~0.25; Large Turbine Estimate ~0.30 8,760 = Hours in One Year

Box 5 Estimate Turbine Energy Production
G = P ∗ CF ∗ 8,760
G = Annual Energy Production (kWh) P = Turbine Rated Power Output (kW) CF = Capacity Factor; Small Turbine Estimate ~0.25; Large Turbine Estimate ~0.30 8,760 = Hours in One Year

Box 6 Estimate Length of Blades[93]
AEO = 0.01328 x D^2 x V^3
AEO = Annual Energy Output (kWh per year) D = Diameter of rotors (feet) V = Average wind speed (mph)

Consider a site that has an average wind speed of 7 m/s (15.6 mph) and consumes 87,000 kWh a year. Enter 87,000 kWh into the equation to find that your site would need about a 40-kW turbine to meet all the site's electricity needs, based on average electricity demand. You would need a wind turbine that outputs about 40 kW at 7 m/s wind speeds. To get a rough estimate of how much energy would be produced by this turbine at a certain speed, use the equation in Box 5. You can also use the equation in Box 6 to estimate the lengths of the blades your turbine would need to meet your site's energy demand**.**

These equations help to provide very rough estimates. Wind turbine manufacturers can help you more precisely size your system based a cleanup site's electricity needs and the specifics of local wind patterns.[94] They can factor in the particular wind turbine power curve, the average annual wind speed at the site, the height of the tower that you plan to use, and the frequency distribution of the wind (i.e., estimated number of hours that the wind will blow at each speed during an average year). They may also adjust this calculation for the elevation of your site.

4.4 GRID-TIED OR STAND-ALONE SYSTEMS

Grid-tied systems have access to electricity supplied by a utility. Sites that are interconnected can receive energy both from the utility and from a local wind turbine (Fig. 21). When the turbine produces more electricity than is consumed, excess electricity is sent to the grid. Net metering programs allow grid-tied utility customers who generate electricity in excess of their consumption to credit that amount for later use.[97] When wind power is unavailable, the site can use the energy credits from the utility. Some utilities may purchase excess power generated from wind turbines. For more information on utilities that have net metering programs, see Appendix XII (page 176).

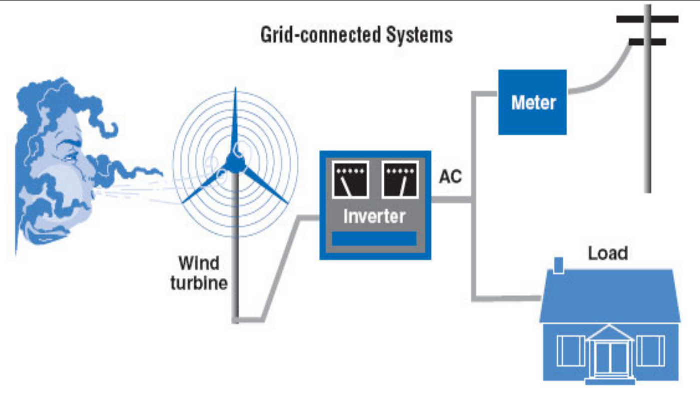

Figure 21 Grid-connected wind turbine. Image courtesy EERE[95]

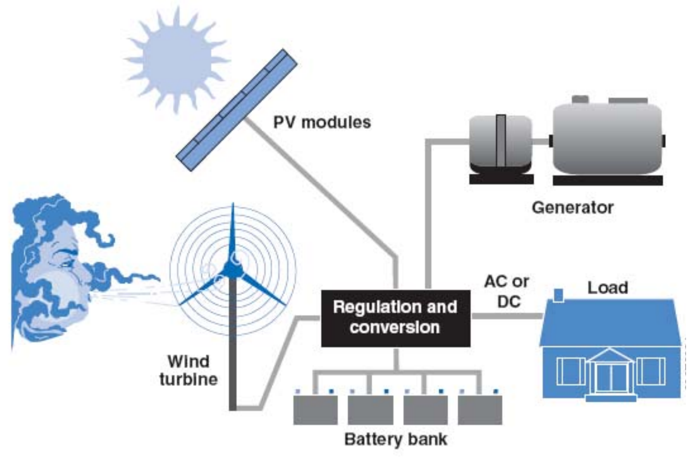

Figure 22 Stand-alone hybrid system of wind power, solar power, battery backup and clean diesel generator. Image courtesy EERE[96]

Wind power will be an even better investment if your site is not easily accessible to local utility lines.[98] The cost of extending utility lines to a remote location can cost as much as $20,000-$30,000 per quarter mile.[99] Stand-alone sites do not have access to grid-electricity. They must completely rely on wind power or a hybrid system with another renewable energy technology and/or a clean diesel generator (Fig. 22). If it is important to have a reliable, constant source of electricity, battery backup may be necessary. Battery systems can store power for use when the wind is not blowing. See Appendix III (page 130) for more information on batteries. Grid-tied systems can also consider a hybrid system to further reduce dependence on the grid.

4.5 CAPITAL COSTS, O&M, PERMITS, INSURANCE AND ENVIRONMENTAL CONCERNS

This section includes information on estimating wind turbine capital costs and payback times. It also discusses O&M costs and labor. Information on potential permit and zoning issues are also included. This section also addresses some insurance and environmental concerns.

Capital Costs

The Windfarmers Network estimates that the capital cost for a wind turbine is about $1,000 per kW of generation capacity, usually for utility-size turbines.[100] The American Wind Energy Association estimates that capital costs range from $3,000 to $5,000 per kW for smaller systems.[101] Costs may vary from project to project depending upon the size of the turbine(s), interconnection costs, permitting costs, installation and transportation costs, generator model, the type of tower and other components in your system such as batteries, inverters, and controllers. According to the American Wind Energy Association, a typical 10-kW wind turbine system will cost $25,000-$35,000. A 3-kW turbine mounted on a 60-80-ft tower costs about $15,000, including accessory components and batteries. Systems smaller than 1-kW are often used in stand-alone applications, or as part of a hybrid system with solar PV cells. A 400-watt system can be installed for $1,500.[102]

Used turbines will be much less expensive but should undergo remanufacturing by a qualified mechanic. Many parts should be replaced even if they are still functioning.[103]

Well-sited small wind turbines usually have a simple payback time of 15 years, about half of their serviceable lifetimes, if federal and state incentives are applied.[105] Installing a wind turbine is usually cost effective if electricity rates are more than 10-15 cents per kWh and there are sufficient wind resources. See Section 10.3 (page 111) for economic analysis calculations and Section 10.6 (page 115) for wind power calculators.

Operation and Maintenance

Annual operating and maintenance costs for a wind turbine are estimated to be about one percent of the capital cost. Alternator bearings need replacement after several years of operation. The same is true for yaw bearings given their significant loading. Check that bolts remain tight. Dust, debris, and insects will eventually erode the most durable blade materials, and leading edge tapes. Paint coatings, subjected to sunlight, moisture, and temperature extremes will eventually deteriorate. Also, the lubricant in the gear box, like oil in a car engine, will degrade over time. Maintain the turbine as recommended by the manufacturer to ensure that it will continue to operate properly for many years (Fig. 23).[106]

Figure 23 Repairing a wind turbine. Image courtesy Argonne National Lab[104]

Permits

Permitting requirements, procedures, and fees for wind turbines vary by county. Consider zoning issues in advance since local zoning codes or covenants may not allow wind turbines. You can find out about the zoning restrictions in your area by calling the local building inspector, board of supervisors, or planning board. They should be able to tell you if you will need to obtain a building permit and provide you with a list of requirements.[107]

Costs for building permits, zoning permits, and use permits may range from $100 to $1,600. Contact your county permitting agency or planning department for information on permitting issues. Find out if small wind energy systems (under 100 kW) are addressed by your local ordinance. Review the applicable standards and restrictions. They may include minimum land size, tower height restrictions, minimum distance from the edge of the property, and maximum noise levels. The turbine must comply with the Uniform Building Code and National Electric Code. Federal Aviation Administration approval may be necessary if your site is within 20,000 feet of a runway and your tower is taller than 200 feet. Wind turbines may be subject to local restrictions if they are near coastal regions, scenic highways or other specially designated areas.[108] In many cases, a building permit for a wind turbine tower will require that the zoning board grant you a conditional use permit or a variance from the existing code.[109] Also consult neighbors before installing a turbine on your site. This is recommended and sometimes required by county planners. You may need to appear at a public hearing for a conditional use permit or variance. For grid-tied systems, contact your local utility for more information on interconnection requirements and net metering programs if applicable.[110] Consultants can also help with permitting issues.

Contact the local municipality for more information on permitting requirements. For more information on permitting issues, go to www.awea.org/smallwind/toolbox/INSTALL/building_permits.asp.

Insurance

For grid-tied systems, some utilities require small wind turbine owners to maintain liability insurance in amounts of $1 million or more. Laws or regulatory authorities in some states, including California and Nevada, prohibit utilities from imposing any insurance requirements on small wind turbines that qualify for net metering.[111]

Environmental Concerns

There has been concern over the risk that wind turbines pose to birds and bats. While wind turbines may pose a danger to wildlife if not carefully sited, fatalities from turbines are minimal compared to deaths due to buildings, windows, power lines and radio towers. Tower design changes and careful siting of the turbine will mitigate this problem.[112] Consideration of migration patterns is an important step in the process. Look into legal and environmental limitations for your site's city and county and contact your local Audubon Society.

4.6 FINDING WIND TURBINE VENDORS AND INSTALLERS

Wind power companies may provide services from designing a wind energy system to acquiring equipment to system installation. Check the following websites for databases of wind energy professionals.

- American Wind Energy Association: Searchable member directory provides list of wind energy professionals. www.awea.org, http://web.memberclicks.com/mc/page.do?orgId=awea

- General Services Administration Contracts Schedule: www.gsaelibrary.gsa.gov Search "206 3" for wind power businesses.
- California Energy Commission (CEC): California registered wind turbine retailers. www.consumerenergycenter.org/erprebate/database/index.html
- Source Guides: Worldwide renewable energy directory. www.energy.sourceguides.com

Tips to choose among wind turbine manufacturers and installers[113]

- Obtain and review the product literature from several manufacturers.
- Ask the turbine manufacturer to suggest turbines that run most efficiently at speeds comparable to wind speeds at your site.
- Ask for references of past customers with installations similar to the one you are considering.
- Ask current system owners about performance, reliability, and maintenance and repair requirements, and whether the system is meeting their expectations.
- Find out how long the warranty lasts and what it includes.
- Find out if the installer is a licensed electrician (Section 10.4 page 114).
- A credible installer will help with permitting issues.
- Consider contacting the Better Business Bureau (www.bbb.org) to check the company's integrity.

4.7 SUCCESS STORY

Nebraska Ordnance Plant Superfund Site, near Mead, NE, Region 7

Figure 24 Installation of 10-kW turbine at Nebraska Ordnance Plant Dec 2003. Image courtesy EPA[114]

The Nebraska Army Ordnance Plant operated from 1942 to 1956 as a munitions production plant. The groundwater is contaminated with VOCs and explosives and soils are contaminated with polychlorinated biphenyls. P&T technology is utilized to address groundwater cleanup. A grid-tied 10-kW wind turbine powers a single relatively low energy groundwater circulation well (GCW), operating at a flow rate of 50 gallons per minute (Fig. 24). The GCW is equipped with air strippers used to treat TCE contaminated groundwater. The site has an average wind speed of 14.3 mph (6.4 m/s). The average monthly electricity demand by principal components of the GCW is 767 kWh. On average, the wind turbine generates 817 kWh each month; the excess electricity is sent to the grid. Over the initial five months of the project, the system treated more than 4 million gallons of water and an estimated 63 kilograms (kg) of TCE were removed from groundwater. This project was funded by the EPA's Office of Solid Waste and Emergency Response through a grant program of the Innovation Work Group, with additional support from University of Missouri-Rolla, the Kansas City District Corps of Engineers, Bergey Wind Systems, and Ohio Semitronics. Researchers estimate that the use of wind power, coupled with a well designed climate control system, may result in a present-worth energy cost savings of more than $40,000 over the 20 years of groundwater treatment anticipated at this site. Similarly-sized off-grid wind turbine systems, including installation, cost approximately $45,000. The wind turbine saved an estimated total of 17,882 pounds of CO_2 emissions over a period of 19 months.

For details, see www.clu-in.org/products/newsltrs/tnandt/view.cfm?issue=0904.cfm and www.epa.gov/oswer/docs/iwg/groundwaterFactSheet_final.pdf.

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CHAPTER 5: LANDFILL GAS-TO-ENERGY

Municipal solid waste (MSW) landfills can provide a source of energy. MSW landfills consist of everyday garbage generated from residences, businesses, and institutions. The decomposition of MSW creates landfill gas (LFG). This gas is primarily composed of CO_2 and methane (CH_4). CH_4, a GHG with high energy content, can be captured to produce electricity through the use of microturbines, boilers, or engines. As an example, Operations Industries Inc. Landfill Superfund Site in Southern California is currently powering about 80 percent of its operations buildings with landfill gas (See Section 5.7).

Chapter 5 Table of Contents

5.1 LANDFILL GAS-TO-ENERGY TERMINOLOGY

The following are some landfill gas-to-energy terms and definitions.

Boiler / Steam Turbine A boiler produces thermal energy from burning LFG. This heat is used in a steam turbine and generator to produce electricity. This configuration is best suited for landfills with gas production of greater than five million cubic feet per day.[115] It is the least used among LFG projects because it is more expensive than other gas power conversion technologies for the typical size of landfill projects.[116] See Appendix V (page 142).

Co-disposal landfill Landfill that may contain MSW as well as some hazardous wastes.

Collection Wells Wells strategically dug into a landfill to collect LFG. Gas collection system transports the gas to be treated and used to generate electricity or as a direct fuel.

Combustion (Gas) Turbine (CT) Energy generation equipment typically used in medium to large LFG projects, where LFG production is approximately two million cubic feet per day. This technology is competitive in larger LFG electric generation projects because of significant economies of scale. The electricity generation efficiency generally improves as size increases.[117] See Appendix V (page 139).

Compressor A device that changes the density of LFG to be compatible for use in an internal combustion engine, combustion turbine, or microturbine to generate electricity.

Condensate Liquid formed from water and/or other vapors in the LFG that condense as the gas travels through the collection pipes. Proper disposal of condensate is necessary.

Internal Combustion (IC) Engine / Reciprocating Engine Engine in which the combustion of fuel and air in a chamber produce expanding gas that can run a electricity generator. IC engines are the most widely used electricity generation technology for LFG.[118] They are typically used for generation projects greater than 800 kW.[119] See Appendix V (page 138).

Landfill gas (LFG) Gas generated when landfill waste decomposes. It is approximately 50 percent CO_2 and 50 percent CH_4.

Methane (CH_4) Highly combustible GHG that makes up about 50 percent of gas produced from a landfill. This gas can be used directly to generate heat or as a fuel to produce electricity. Methane makes up more than 90 percent of typical natural gas.

Microturbine Small combustion turbine with rated power outputs that range from 30-250 kW and can be combined with each other. They are better-suited to landfills where gas production is low (low concentrations of CH_4 and/or low flow) to economically use a larger engine and for sites with on-site energy use. Microturbine heat rates are generally 14,000-16,000 BTU per kWh. The total installed cost for a LFG microturbine project is estimated to be $4,000-$5,000 per kW for smaller systems (30 kW), decreasing to $2,000-$2,500 per kW for larger systems (200 kW and above). Operation and maintenance costs are about 1.5-2 cents per kWh.[121] The addition of a heat recovery system adds $75-$350 per kW.[122] The CA Energy Commission estimates annual maintenance costs to be 0.5-1.6 cents per kWh, which would be comparable to costs for small reciprocating engine systems.[123]

Municipal Solid Waste (MSW) Everyday garbage generated from residences and institutions.

5.2 LANDFILL GAS-TO-ENERGY TECHNOLOGY BASICS

Landfill gas is composed of about 50 percent CO_2, 50 percent CH_4, and traces of non-methane organic compounds (NMOC). In the U.S., landfills are one of the largest sources of anthropogenic (human-made) CH_4 released into the atmosphere.[124] One kilogram of CH_4 gas in the atmosphere creates 23 times the global warming effect as one kilogram of CO_2 over a 100 year period.[125] For more information on GHG

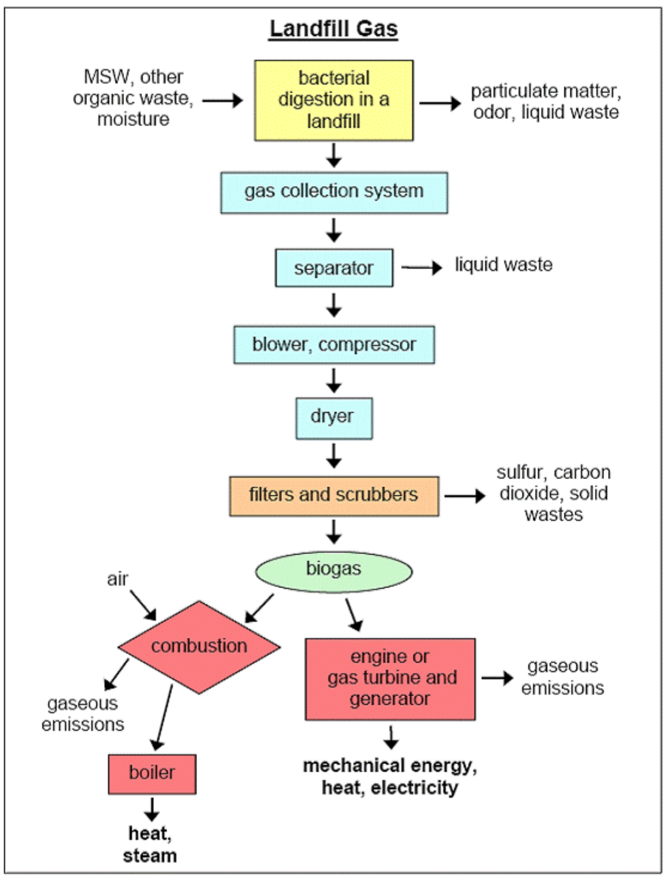

Figure 25 LFGE processes.
Image courtesy Oregon Department of Energy[120]

global warming potentials, go to www.eia.doe.gov/oiaf/1605/gwp.html. Methane is a high energy gas that is used to provide energy for homes, businesses and industries. Instead of wasting a valuable energy source by flaring LFG, it can be collected from landfills and used directly for heating and/or to generate electricity by implementing a landfill gas-to-energy (LFGE) project (Fig. 25). A series of wells drilled into the landfill can collect the gas and transport it through a system of pipes to be cleaned (Fig. 26) and then (a) used directly as a boiler fuel to produce hot water or steam to run a steam turbine or for other processes; (b) used as a fuel to power internal combustion engines or turbines to generate electricity; or (c) treated to become pipeline quality gas.[126] Landfill gas may also be sold as pipeline quality gas for direct use in heating applications such as for greenhouses, dryers, boilers, and many other industrial purposes.

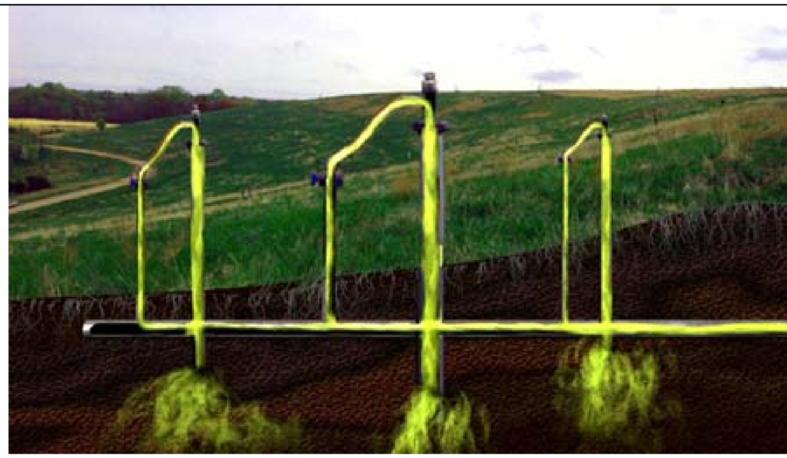

Figure 26 Landfill gas wells and collection piping. Image courtesy LMOP[127]

Co-disposal landfills usually produce less CH_4 because they are generally older and the LFG has already escaped to the atmosphere. They may also have more inert materials buried that do not produce CH_4. Co-disposal landfills tend to produce higher concentrations of NMOC and air toxics than MSW landfills and may be less suitable for renewable energy generation without engineering and waste disposal practices and controls. To help evaluate potential emissions from hazardous waste landfills, use EPA's *Guidance for Evaluating Landfill Gas Emissions From Closed or Abandoned Facilities* (www.epa.gov/nrmrl/pubs/600r05123/600r05123.pdf).

Estimating Emissions Reductions from a LFGE Project Using LMOP's LFGE Benefits Calculator
www.epa.gov/lmop/res/calc.htm

The Benefits Calculator estimates methane and CO_2 emissions reductions from a LFGE project. For example, a 3-MW LFGE project reduces about 6 tons of methane emissions per year and avoids 17 tons of CO_2 emissions due to fossil fuel energy generation per year. A project this size could power about 2,000 homes.

While burning LFG also generates CO_2, using LFG is considered to contribute a net zero effect to climate change because the gas came from recently living organisms that would have released the same amount of CO_2 from naturally decomposing.[128] However, note that all combustion devices, including LFGE systems, generate some NO_x emissions which are attributed to ground-level ozone and smog formation. Overall, the environmental benefit from landfill gas electricity generation projects is significant because of the large reductions in CH_4 emissions, hazardous air pollutants, and use of limited nonrenewable resources such as coal and oil.[129] Go to Section 10.7 (page 117) for the LFGE Benefits Calculator by EPA's Landfill Methane Outreach Program (LMOP).

5.3 ASSESSING LANDFILL GAS-TO-ENERGY PROJECT POTENTIAL AND SYSTEM COMPONENTS[130]

This section details the factors to consider when determining whether a landfill gas-to-energy system is appropriate for your site. Information on the components of a LFGE system is also included.

Assessing LFGE Project Potential

LMOP created a database of landfills in the country that have potential for LFGE projects (http://epa.gov/lmop/proj/index.htm). Arizona has 13 potential candidates, California has 40, Hawaii has eight, and Nevada has 5. LMOP can also help locate landfills within 20-25 miles of your site using their Locator Tool. Contact LMOP (www.epa.gov/lmop/contact) for assistance.

As a guide, 432,000 ft^3 of LFG is produced per day for every million tons of MSW in a landfill.[131] This is equivalent to 800 kW of power that could be generated. See Section 10.7 (page 117) to calculate LFG production. Site measurements are highly recommended, especially for co-disposal landfills, to more accurately quantify CH_4 flow rates. A flare may be installed to assess LFG flow before sizing energy recovery equipment.[132]

There are many factors to consider that effect the amount of gas produced at each landfill. Some of the most important factors are:[133]

Depth of landfill—a depth of at least 40 feet best-suits anaerobic conditions for producing LFG. However, LFGE projects have been successfully implemented in shallower landfills.

Amount of waste—a landfill with at least one million tons of MSW is optimal, although smaller ones may be applicable as well. Small landfills are good candidates if the gas will be used on-site or near by.

Type of waste—organic wastes such as paper and food scraps produce the most LFG. Landfills with a lot of construction and demolition, industrial, or hazardous wastes, such as co-disposal landfills, may not be as productive.

Age of landfill—as a landfill ages, the rate of CH_4 production decreases. Landfills that are still open or have recently closed have the best potential for a LFGE project.

Rainfall—the bacteria that break down the waste and produce LFG thrive best in moisture. An optimal site will have at least 25 inches of rainfall a year. Landfills in arid climates may have lower rates of LFG flow but are expected to produce LFG for a longer period of time.

For a LFGE project preliminary evaluation worksheet, go to Appendix V (page 137).

LFGE System Components

The following are components of a landfill gas-to-energy system.

1. Gas Collection and Backup Flare:

Gas collection typically begins after a portion of a landfill (called a cell) is closed. A collection well is drilled into the landfill to collect the gas. Each LFG wellhead is connected to lateral piping, which transports the gas to a main collection header. An aqueous condensate forms when warm gas from the landfill cools as it travels through the collection system. If the condensate is not removed, it can block the pipes and disrupt the energy recovery process. Sloping pipes and headers in the field collection system are used to drain condensate into collecting ("knockout") tanks or traps. Condensate could be recirculated to the landfill, treated on-site, or discharged to the public sewer system. Most landfills with energy recovery systems have a flare for combusting excess gas and for use during equipment downtimes (Fig. 27).

2. Gas Treatment:

The collected LFG must be treated to remove any condensate that is not captured in the knockout tanks. NMOC and air toxics must be properly treated. Removal of particles and other impurities depend on the end-use application. For example, minimal treatment is required for direct use of gas in boilers, while extensive treatment is necessary to remove CO_2 and other trace organic compounds for injection into a natural gas pipeline. Electricity production systems typically include a series of filters to remove impurities that could damage engine components and reduce system efficiency.

3. Energy Recovery:

Figure 27 LFGE treatment/blower/flare station. Image courtesy LMOP[134]

Prime movers such as internal combustion (IC) engines, combustion turbines (CT), and boiler/steam turbines combined with generator systems can convert energy in LFG into electricity. The IC engine is the most commonly used conversion technology in LFG applications. IC engine projects typically have higher rates of NO_x emissions than other conversion technologies which may cause a permitting issue. NO_x controls can usually be installed to meet local requirements. CTs are typically used in medium to large landfill gas projects, where landfill gas volumes are sufficient to generate a minimum of 3-4 MW. One of the primary disadvantages of CTs is that they require high gas compression levels. More energy is required to run the compression system, as compared to other generator options. However, CTs are much more resistant to corrosion damage than IC engines and have lower NO_x emission rates. They are also relatively compact and have low operations and maintenance costs in comparison to IC engines. The boiler/steam turbine configuration is less often used as a LFG conversion technology compared to IC or CT. It is applicable mainly in very large landfill gas projects, where LFG flow rates support systems of at least 8-9 MW. The boiler/steam turbine consists of a conventional gas or liquid fuel boiler, and a steam turbine generator to produce electricity. This technology usually requires a complete water treatment and cooling cycle, plus an ample source of process and cooling water. Other technologies include microturbines and fuel cells. See Appendix V (pages 138-142) for details on electricity generation technologies. Use combined heat and power (CHP) applications along with these prime movers (heat engine[135]) to capture the thermal energy output which will improve energy efficiency. Go to Appendix V (page 138) for CHP resources. Lastly, note that LFG may be corrosive to LFG collection and electricity generation parts and equipment so proper maintenance is necessary to keep the system running safely and efficiently.

5.4 HOW MUCH ENERGY CAN A LANDFILL PRODUCE?[136]

Use the following equation to estimate the potential energy production from a landfill each year with more site specific information (Box 7). Keep in mind this is a rough estimate that does not account for losses in gas capture and transport and any efficiency losses from conversion to electricity.

See LMOP's *A Landfill Gas to Energy Project Development Handbook*, Section 2.2.1 "Methods for Estimating Gas Flow" (www.epa.gov/lmop/res/pdf/handbook.pdf) for more precise methods of estimating landfill gas production.

Box 7 Estimating Landfill Energy Production

$$G = F * EC * 365$$

G = Potential energy production from a landfill in one year (BTU per year)

F = LFG Flow per day (cfd); 1 million tons MSW ≈ 432,000 cfd LFG

EC = Energy content in LFG (BTU per cf); Estimate 500 BTU/cf

365 = Days in one year

. . .

BTU = British Thermal Unity (1 kWh = 3,414 BTU)

cfd = cubic feet per day

BTU/cf = energy content per cubic foot of gas

Consider the following example: Landfill gas typically contains about 500 BTUs per cubic foot. This can be used as a default if the BTU value of landfill gas at a specific site is not known. For a 5 million ton landfill with a gas flow of about 3 million cubic feet per day, the energy content would therefore be calculated as follows:

548 billion BTU per year = 3 million cfd x 500 BTU per cf x 365 days per year

5.5 CAPITAL COST AND POSSIBLE BUSINESS MODELS

Estimating Cost

Cost of a LFGE project varies depending on a variety of factors including size of the landfill, type of electricity generation technology, and site specific characteristics. Site preparation and installation costs vary significantly among locations though in general, electric generation equipment accounts for about 30-70 percent of the capital cost. Total capital includes the engine, auxiliary equipment, interconnections, gas compressor, construction, and engineering. Some landfills may already have a gas collection system in place.[137]

The California Energy Commission (CEC) estimated the following costs for LFGE projects in California in a report published in 2002 (Table 3).

Table 3 Estimated LFGE Project Costs[138]

	LFG Collection System	Blower / Flare Station	Reciprocating Engine	Combustion Turbine	Boiler / Steam Turbine
Construction Cost	$10,000 - $20,000 per acre of landfill	$350 - $450 per scfm*	$1,100 - $1,300 per kW (> 800 kW)	$1,000 - $1,200 per kW (> 3.5 MW)	$2,500 - $1,500 per kW (> 10 MW)
O & M	$400 - $900 per acre per year	$20 - $30 per scfm per year	1.6¢ - 2.0¢ per kWh	1.4¢ - 1.8¢ per kWh	1.0¢ - 1.4¢ per kWh

*Scfm: standard cubic feet per minute

In a 2005 draft document, the California Climate Action Team estimated total installed costs to range between $1,100 and $4,000 per kW of generating capacity.[139] Use software and documents listed in Section 10.7 (page 117) to estimate LFG production and costs for a MSW landfill gas project.

Possible Business Models

The following are examples of business models that outline LFGE operations and maintenance roles:

- Landfill owner owns and manages all LFGE equipment and sells electricity to the utility or directly to an end user.
- Landfill owner owns LFG collection system. Electricity generation equipment owned and operated by utility; the utility purchases LFG from landfill owner.
- Landfill owner provides LFG. Third party owns and operates LFG collection system and electricity generation equipment

Review LMOP's *A Landfill Gas to Energy Project Development Handbook,* Section 7 "Selecting a Project Development Partner" (www.epa.gov/lmop/res/pdf/handbook.pdf) for more information. Though the target audience of this document is the landfill owner, it may provide some insight on partnering with other stakeholders. Find a list potential clean energy investors at www.nrel.gov/technologytransfer/entrepreneurs/directory.html.

5.6 LANDFILL GAS ENVIRONMENTAL AND SAFETY CONCERNS AND PERMITS[140]

This section provides information on LFGE environmental and safety concerns and potential permits required for developing a LFGE project.

Environmental and Safety Concerns

Dioxins and furans are a group of toxic chemical compounds known as persistent organic pollutants. Combustion processes, such as incinerating municipal waste, burning fuels (e.g., wood, coal, or oil), and some industrial processes, can release dioxins and furans into the atmosphere. Relative to many of these combustion processes, landfill gas combustion is less conducive to dioxin/furan formation.

Batteries, fluorescent light bulbs, electrical switches, thermometers and paints are some sources of mercury in a MSW landfill. Mercury may be present in landfill gas but combusting the gas converts the organic mercury compounds to less toxic inorganic compounds.

LFG is potentially explosive, may pose an asphyxiation hazard, and may cause headaches and nausea due to odors. LFG collection systems minimize exposure. Always take precautions when handling LFG. For more information, see the following document by the Agency for Toxic Substances and Disease Registry: *Landfill Gas Primer: An Overview for Environmental Health Professionals* (www.atsdr.cdc.gov/HAC/landfill/html/toc.html).

LFGE Permits

LFGE projects must follow federal regulations related to both the control of LFG and air emissions from the electricity generation equipment. Emissions need to comply with the federal Clean Air Act and Resource Conservation and Recovery Act. States may have more stringent requirements. Permits can take more than a year to attain. No construction should begin until permitting issues are resolved since permits may affect the design of the project. Permits in the following areas may be required:

- Air Quality
- Building Permit
- Land use Permit
- Noise
- Wastewater
- Condensate
- Water
- Stack height

See LMOP's *A Landfill Gas to Energy Project Development Handbook,* Section 9 "Securing Project Permits and Approvals" for details (www.epa.gov/lmop/res/pdf/handbook.pdf). Contact LMOP for more information on permitting issues.

5.7 SUCCESS STORIES

Three examples of successful LFGE projects are presented below. Go to LMOP's website for more success stories (www.epa.gov/lmop/res/index.htm#4).

Operating Industries Inc.[141] (OII) Superfund Site, Monterey Park, CA, Region 9

OII is a Superfund site located in southern California. It was a 190-acre landfill that operated from 1948 to 1984. It accepted 38 million cubic yards of MSW and 330 million gallons of liquid industrial waste. Methane production at this landfill is about 2,500 ft^3 per minute. A LFGE project was constructed in 2002 (Fig. 28). The construction of the project cost $1.05 million and utility connection cost $105,000. It produces electricity from microturbines to save an estimated $400,000 annually by providing 80 percent of electricity needs for the operations and maintenance of the site.

For RPMs who are considering a LFGE project, OII project managers recommend briefing stakeholders early in the planning process, including local utilities, land use contacts, and federal, state and local environmental agencies. It is important to obtain a "power interconnection" application from the utility in the early stages of planning to sell power back to the grid. If using microturbines, ensure that the microturbine system can accept the LFG specific to your site. Research the microturbine vendor for experience and support for a LFGE project. An ideal situation would be to contract a turnkey system which provides a completely operational product upon delivery. It is also recommended to get a service contract for the microturbine system that includes details of the costs and time frame for implementation of the system.

Figure 28 LFG flares at OII. Image courtesy Chern[142]

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National Aeronautics and Space Administration (NASA)'s Goddard Space Flight Center (GSFC), Greenbelt, MD[143]

GSFC in Maryland is the first federal facility in the country to implement a LFGE project. Two of the five boilers at GSFC were modified in 2003 to run on LFG, and can use natural gas or fuel oil as backup. The LFG is supplied from the nearby county-owned Sandy Hill Landfill and fuels boilers to make steam that heats 31 GSFC buildings. The project illustrates a successful public-private partnership between Prince George's County, MD., Waste Management, Toro Energy, NASA and LMOP in pursuing the economic and environmental benefits of landfill gas energy. LMOP worked with NASA to assess the technical and economic feasibility of using gas from the Sandy Hill Landfill to fuel boilers at GSFC. This LFGE project will reduce 160,000 metric tons of CO_2 equivalents from being emitted over ten years. These emissions reductions are equivalent to taking 35,000 cars off the road per year or planting 47,000 acres of trees. NASA will save taxpayers more than $3.5 million over the next decade in fuel costs. Landfill gas provides 95 percent of all of the center's heating needs, with natural gas serving as the backup. Go to www.nasa.gov/centers/goddard/news/topstory/2003/0508landfill.html for details.

BMW, Green, South Carolina[144]

The BMW plant in Greer, South Carolina has a landfill cogeneration project. Landfill gas is transported through a 9.5-mile pipeline and provides 53 percent of the plant's energy needs by generating electricity with the use of gas turbines and direct use in heating water. The landfill is expected to be able to provide LFG for at least 20 years. For more information, go to www.bmwusfactory.com//community/environment/gastoenergy.asp.

CHAPTER 6: ANAEROBIC DIGESTION

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Anaerobic digestion is the natural process of decomposing organic materials by bacteria in an oxygen-free environment. Anaerobic digestion produces biogas, which is mainly CO_2 and CH_4. It can be used to produce heat and/or electricity. Anaerobic digestion can be manipulated in a controlled environment, such as inside an anaerobic digester, where biogas can be collected and utilized.[145] Digesters may be designed as plastic or rubber covered lagoons, troughs, or as steel or concrete tanks.[146] Organic material such as manure, wastewater treatment sewage sludge, agricultural wastes or food processing wastes are appropriate feedstock for anaerobic digesters. Regular maintenance is required to restock biomass as well as dispose of digester byproducts, which may be used as fertilizers. Cleanup sites that have biomass sources nearby may consider using an anaerobic digester to generate electricity and gas.

6.1 ANAEROBIC DIGESTER TERMINOLOGY[147]

The following are some anaerobic digester terms and definitions.

Anaerobic Absence of oxygen.

Anaerobic Digester Sealed container in which anaerobic bacteria break down organic matter and create biogas.

Biogas The gas produced from decomposition of organic matter in anaerobic conditions consisting of 60-80 percent CH_4, 30-40 percent CO_2, and other trace gases such as hydrogen sulfide, ammonia and H_2.

Effluent Organic liquid and solid material leaving a digester.

Hydraulic Retention Time (HRT) The average length of time the influent remains in the digester for decomposition.

Influent, or Feedstock Liquid and solid material fed to the digester.

Methane (CH_4) A combustible gas produced by anaerobic digestion and also the principle component of natural gas.

Mesophilic Range Temperature range between 95°F and 105°F in which certain methane-producing microbes thrive.

Thermophilic Range Temperature range between 125°F and 135°F where certain methane-producing bacteria are most active. In digesters, the greatest pathogen destruction occurs in this temperature range.

Slurry The mixture of biomass and water processed in the digester.

6.2 ANAEROBIC DIGESTER TECHNOLOGY BASICS

Figure 29 Plug-flow digester. Image courtesy Penn State University[148]

Anaerobic digestion is the natural process of decomposing organic materials by bacteria in an oxygen-free environment. One of the products of anaerobic digestion is biogas, which consists of 60-80 percent CH_4, 30-40 percent CO_2, and trace amounts of other gases. It typically has an energy value of about 600-800 BTU/ft^3.[149] This natural process can be manipulated in a controlled environment, such as in an anaerobic digester, where the biogas can be collected and used for heating and/or electricity production (Fig. 29).[150]

Organic material such as manure, wastewater treatment sewage sludge, agricultural wastes or food processing wastes are used in anaerobic digesters to produce biogas. Cleanup sites that have these sources nearby may consider using an anaerobic digester to generate electricity. Digesters are designed as plastic or rubber covered lagoons, troughs, or as steel or concrete tanks.[151] Carefully controlled nutrient feed, moisture, temperature, and pH in the digester make a habitable environment for the anaerobic bacteria, which are naturally occurring in manure (Fig. 30).

Digesters work best with biomass that is greater than 85 percent moisture by mass. Digesters operate at two ideal temperature ranges: mesophilic temperatures (95˚F-105˚F) which best host mesophile bacteria, and thermophilic temperatures (125˚F-135˚F) which best host thermophile bacteria.[152] See Appendix VI (page 145) for more information on digester biology. Thermophilic conditions decrease the hydraulic retention time, reducing the size of the digester needed compared to digesters operating under mesophilic temperatures.[153] However, thermophilic bacteria are also much more sensitive to changes in their environment, so digester conditions must be closely monitored and maintained. Digesters operating at thermophilic temperatures also need more energy to heat them. Excess heat from operating the electricity generators or direct combustion of the produced biogas may be able to provide enough thermal output to heat the digester. There is little change in the volume of the organic matter after it goes through the digester. The digested solids and liquids can be used as high-quality fertilizer (See Appendix VI page 146). The effluent can be spread on fields as a liquid fertilizer or liquids and solids can be separated to be sold individually.

The fiber in digested dairy manure can be used on farms as bedding or recovered for sale as a high-quality potting soil ingredient or mulch. Because anaerobic digestion reduces ammonia losses, digested manure contain more valuable nitrogen for crop production. The nutrient content of digested manure is the same as in raw manure. Some liquid content can be re-fed into the digester in the case that the moisture content needs to be increased.

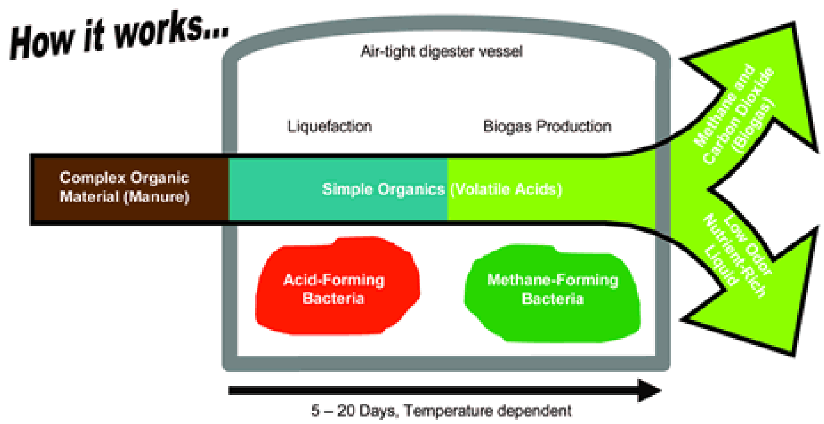


Figure 30 Bacterial processes within an anaerobic digester. Image courtesy Penn State University[154]

Benefits of an anaerobic digester include:

- Green energy production.
- In the case of manure digesters, reduced odor compared to conventionally stored liquid manure, reducing potential nuisance complaints.
- Digested material can be pumped long distances for use as fertilizer.
- Reduction of pathogens and weed seeds in digested material.
- Reduced fly propagation.
- Use of digested material as fertilizer, potting soil, or mulch.

6.3 BASIC DIGESTER COMPONENTS, TYPES OF DIGESTERS AND ASSESSING ANAEROBIC DIGESTER POTENTIAL

There are many types of digesters but all share similar components. This section discusses the various components of a digester system and various anaerobic digester types. Information on assessing the potential of a digester project for a site is also provided.

Basic Components of All Digesters[155]

The following are descriptions of the components of an anaerobic digester biogas recovery system.

The digester system components include (Fig. 31):

Nutrient Source Organic material including animal manure, wastewater treatment sewage sludge, food waste, food processing wastes. It is possible to combine different sources of organic matter to feed into the digester.

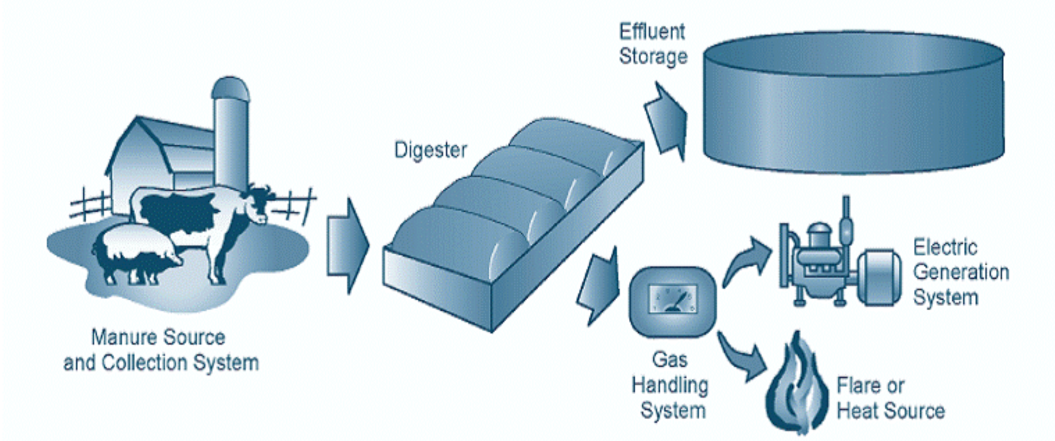


Figure 31 Components of an digester biogas recovery system. Image courtesy AgStar[156]

Transport System Most digesters are constructed on-site near the nutrient source. The organic matter must be collected and fed into the digester.

Pre-treatment Tank A pre-treatment tank is sometimes recommended. This tank is used to preheat the influent as well as settle out sand, grit, and other contaminants from the organic feedstock before transporting into the digester.

Digester Choose a digester that suits your site-specific characteristics.

Gas Handling System Biogas is collected and processed to remove moisture and contaminants to the degree necessary for end use.

Electricity Generation System Reciprocating engines, boilers/steam engines, or microturbines and generators can produce electricity from the biogas. See Appendix V (pages 138-142). The waste heat can be captured and recycled to heat the digester.

Flare or Heat Source Excess CH_4 is flared. Methane can also be used directly for heating the digester or other processes.

Effluent Storage Digested material is stored for later use. It can be spread on fields as a liquid fertilizer. Solids can also be separated for use as a solid fertilizer.

Types of Digesters

Choosing the most suitable digester depends on the moisture content of the influent and, in the case for covered lagoon, climate at the site. The digesters detailed below are conventional designs including complete-mix, plug-flow, and covered lagoon digesters. This section also includes information on where a digester project may be applicable.

Complete-Mix Digester

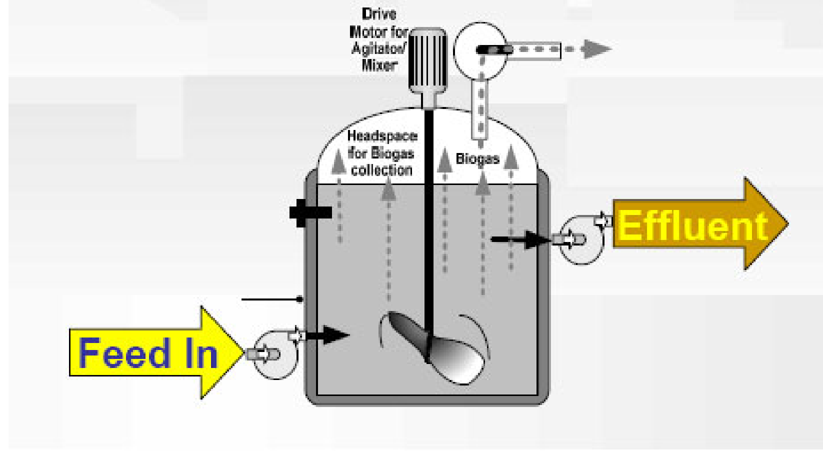
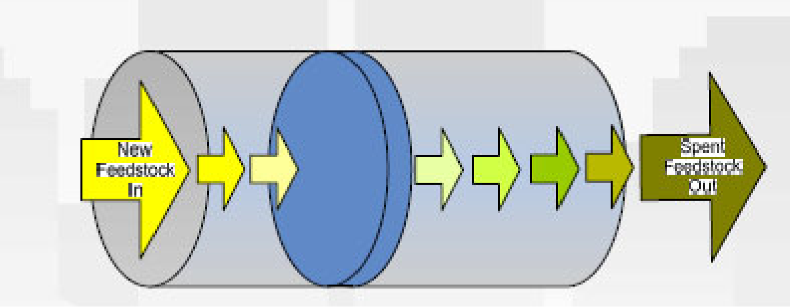


Figure 32 Schematic of a complete-mix digester.
Image courtesy Ohio State University [157]

The complete-mix digester is a vertical concrete or steel circular container that can be installed above or below ground (Fig. 32). It can handle organic wastes with total solid concentration of 3-10 percent, such as manure or food waste collected from a flush system. Complete-mix digesters can be operated at either the mesophilic or thermophilic temperature range with a HRT of 10-20 days. A mixer keeps the solids in suspension. For manure feedstock, cost estimates range from $200-$400 per 1,000 pounds of animal mass that contribute to the digester influent.[158]

Plug-Flow Digester



33 Schematic of a plug-flow digester.
Image courtesy Ohio State University[159]

The basic plug-flow digester design is a rectangular trough, often built below ground level, with an impermeable, flexible cover (Fig. 29 page 48). Organic material is added to one end of the trough and decomposes as it moves through the digester. Each day a new "plug" of organic waste is added, pushing the feedstock down the trough (Fig. 33). Plug-flow digesters are suitable for biomass with a solids concentration of 11-13 percent and have a HRT of about 20-30 days. Suspended heating pipes of hot water stir the slurry through convection. This type of digester has few moving parts and requires little maintenance. For manure feedstock, cost estimates range from $200-$400 per 1,000 pounds of animal mass that contribute to the digester influent.[160 n]

Covered Lagoon Digesters

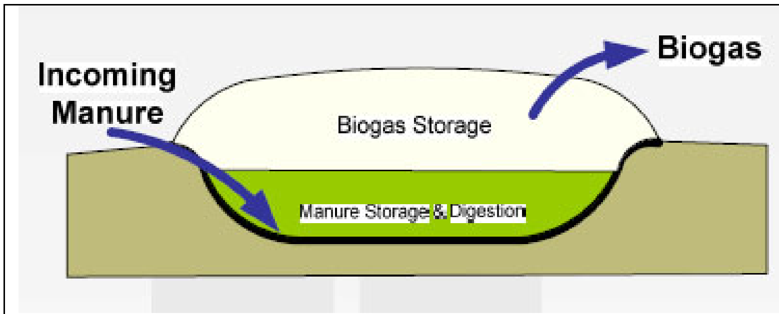


Figure 34 Covered lagoon digester.
Image courtesy Ohio State University[161]

A covered lagoon digester is a lagoon fitted with a floating, impermeable cover that collects biogas as it is released from the organic wastes (Fig. 34). An anaerobic lagoon is best suited for liquid organic wastes with a total solid concentration of 0.5-3 percent. Covered lagoon digesters are generally not externally heated so they must be located in warmer climates for them to produce enough biogas for energy production. This type is the least expensive of the three mentioned here. For manure feedstocks, cost estimates range from $150-$400 per 1,000 pounds of live animal mass that contribute to the digester influent.[162]

Other digester designs include advanced integrated pond systems, up-flow solids reactors, fixed-film (Fig. 35), temperature-phased, and anaerobic filter reactors.[163]

Siting Anaerobic Digesters

A suitable location for anaerobic digester energy project should be close to an organic waste source. It may be possible to collect organic wastes from a community, such as local farms and food processing facilities that have a need to dispose biomass. To consider a manure digester project for energy production, the manure influent supply should generally have at least 300 head of dairy cows or steers, 2,000 swine in confinement, or 50,000 caged layers or broilers (types of fowl) from which manure is collected regularly.[165] The influent source should be available year-round for a constant supply of biogas and energy production. Anaerobic digesters need material with high moisture content. The influent should be collected as a liquid, slurry, or semi-solid from a single point daily or every other day. Alternatively, water may be added after collection. Manure feedstock should have as little bedding materials as possible. It may be necessary to have at least one person who can manage the digester for daily and long-term maintenance. Consider uses for the digested material, both liquid and solid components, such as for fertilizers. See Appendix VI (page 143) for a preliminary evaluation checklist for manure feedstock.

Figure 35 Fixed-film digester. Image courtesy University of Florida[164]

6.4 ANAEROBIC DIGESTER ENERGY PRODUCTION

Producing biogas is just one step to harnessing energy from organic wastes. Once the gas has been collected, engines or boilers coupled with generators are utilized to convert the energy contained in the biogas to heat and/or electricity to be used on the cleanup site. The term "prime mover" is often used to refer to heat engines which generate mechanical energy that can drive electricity generation equipment. See Appendix V (pages 138-142) for more details.

Energy Generation Options

Internal Combustion Engine / Reciprocating Engine An internal combustion engine is the most commonly used technology for utilizing biogas. Natural gas or propane engines can be modified to burn biogas. In general, a biogas-fueled engine generator is 18-25 percent efficient at converting energy in biogas to electricity.[166] Optimize efficiency by using the co-generated heat energy for space heating, water heating, and/or heating the digester. When a reciprocating engine is used, the biogas must have condensate and particulates removed. [167]

Boiler / Steam Turbine A boiler can produce thermal energy from burning biogas. The heat is used in a steam turbine to generate electricity. This configuration is best suited for gas production that can generate 8-9 MW, which is very large for a digester project.[168] At smaller scales, it is generally more expensive than other gas power conversion technologies.

Combustion (Gas) Turbine Combustion turbines (CTs) are typically used in medium to large biogas projects rated from 3-4 MW. This technology is competitive in larger biogas electric generation projects because of significant economies of scale. The biogas must have most of the visible moisture and any particles removed and then must be compressed in order to be utilized in a gas turbine combustion chamber.

Microturbines Microturbines range in power rating from 30-250 kW and can be combined with each other. They are better-suited for digester projects for which low CH_4 concentrations or low flow rates prohibit the applicability of larger engines. Microturbines cost from $700 per kW to $1,100 per kW of generation capacity. The addition of a heat recovery system, which captures the otherwise wasted heat, adds between $75 and $350 per kW.[169] Microturbines require very clean biogas fuel, increasing the cost for biogas cleanup.

Potential Energy Production

The amount of energy a digester can produce depends upon the type of feedstock, type of digester, environment inside the digester, loading rate, and type of energy recovery technology. Table 4 includes electricity production rates compiled by the California Energy Commission (CEC) which provides a general estimate of the energy production potential of different manure feedstocks. Other influent sources including cheese whey (about twice as much biogas production as manure), animal and vegetable fats and oils (about 20 times as much biogas production as manure), crop and green wastes, and food processing waste, yield even greater amounts of biogas. Different feedstocks can be combined to increase biogas production.[170] If you are considering dairy manure as a feedstock for a digester, use the CEC Dairy Power Production Program's worksheet for estimating energy production (Appendix VI page 144). The heat generated from the engine or turbine generator is also a useful resource that can be harnessed instead of being released as waste heat. See Appendix V (page 138) for combined heat and power application information.

Table 4 Energy Potential of Various Animal Manures[171]

Anaerobic Digestion Feedstock	Volatile Solids per animal per day (lbs/day)	Energy Potential (kWh/animal/day)
Dairy Cows	6.2	1.24
Swine	1.64	0.328
Layer Poultry	0.048	0.0096
Broiler Poultry	0.034	0.0068
Turkey	0.091	0.0182
Sheep and Lamb	0.92	0.184

6.5 CAPITAL COST, O&M, DEVELOPERS AND POSSIBLE BUSINESS MODELS

This section includes information on estimating the capital cost for an anaerobic digester, associated operations and maintenance, resources to find digester developers and possible business models for an anaerobic digester project.

Estimating Cost

For a manure digester, the joint EPA, USDA, and DOE AgStar Program estimates the installed capital cost of a covered lagoon, complete mix, and plug flow digester to range between $200 and $450 per 1,000 pounds of animal mass that provide feedstock to the digester (Table 5). AgStar estimates a 3-7 year payback period when energy recovery is employed.[172] Contact digester developers for cost estimates for other feedstocks.

Table 5 Cost Estimates for Various Manure Management Options
(per 1,000 pounds of animal mass that contribute feedstock)[*173]

Aerated lagoons with open storage ponds (for comparison)[♣]	$200-$450
Covered lagoon digesters with open storage ponds	$150-$400
Heated digesters (e.g., complete mix and plug flow) with open storage tanks	$200-$400
Separate treatment lagoons and storage ponds (2-cell systems)	$200-$400
Combined treatment lagoons and storage ponds	$200-$400
Storage ponds and tanks	$50-$500

[*] Cost estimates are from a 2002 publication. Cost ranges do not include annual operation and maintenance costs.
[♣] Aerated lagoon energy requirements add an additional $35-50 per 1,000 live animal lbs/year.

Download FarmWare from www.epa.gov/agstar/resources/handbook.html to get preliminary feasibility and economic analyses of manure digesters.

Operations and Maintenance

Anaerobic digesters require daily maintenance checks and longer term maintenance. Daily maintenance includes checking proper digester and engine function (e.g., gas leaks in digester cover or piping, oil level in the engine, film buildup in the digester). Daily maintenance takes from 10 minutes to one hour per day. Oil in the engine may need changing every few months. Digesters may need to be cleaned out after several years of operation.

Finding a Developer

The following links provide listings of anaerobic digester consultants, developers, and equipment suppliers. Select businesses based on their previous biogas project experience, successful project track record, and in-house resources such as engineering, financing, operations and experience with environmental permitting and community issues.[174]

- The AgSTAR Industry Directory: Listing of consultants, project developers, energy services, equipment manufacturers and distributors, and commodity organizations. www.epa.gov/agstar/tech/consultants.html
- The California Integrated Waste Management Board: Listing of anaerobic digester vendors. www.ciwmb.ca.gov/Organics/Conversion/Vendors
- Penn State Department of Agriculture and Biological Engineering: Listing of digester consultants, designers, and vendors. www.biogas.psu.edu/listdigandequip.html

Partners and Possible Business Models

Purchasing and operating an anaerobic digester may involve many different parties. Consider the following:

- Appropriate level of involvement with the local utility if the digester is expected to produce a large excess amount of energy that can be net metered or sold to the utility.
- The need for a formal agreement with feedstock provider(s).
- Which party will own, operate and manage the digester.
- County, community, union organization involvement.

The following are possible business models that outline digester operations and maintenance roles:

- Producer of organic matter owns and manages digester and electricity generation equipment.
- Producer of organic matter owns and manages digester. Electricity generation equipment owned and operated by utility; the utility purchases the biogas from digester owner.
- Producer of organic matter provides influent. Third party owns and operates digester and electricity generation equipment.

Find a list potential clean energy investors at www.nrel.gov/technologytransfer/entrepreneurs/directory.html.

6.6 ENVIRONMENTAL BENEFITS AND CONCERNS, SAFETY AND PERMITS

This section includes information on the environmental benefits of a digester project, mainly emission reductions. It also highlights some environmental concerns and safety issues. Information on possible permit requirements is also included.

Emissions Reductions[175]

Use AgStar's *A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures* (www.epa.gov/agstar/pdf/protocol.pdf) to estimate GHG reductions from the use of a manure digester. Utilizing anaerobic digesters, rather than conventional manure management practices, can reduce CH_4 and nitrous oxide (N_2O) emissions, two highly potent GHGs. CO_2 emissions from livestock are not estimated because annual net CO_2 emissions are assumed to be zero – the CO_2 photosynthesized by plants is returned to the atmosphere as respired CO_2. A portion of the carbon is emitted as CH_4 and for this reason CH_4 requires separate consideration.[176] Methane emission reductions should not be based on CH_4 production from the digester. Methane generated from conventional manure practices often differ from the amount produced in an anaerobic digester. To estimate baseline emissions, calculate the CH_4 emissions from a conventional manure management method, or the method that would have been in place if a digester was not installed. The methodology described in the EPA Climate Leaders "Draft Manure Offset Protocol" is found at www.epa.gov/stateply/documents/resources/ClimateLeaders_DraftManureOffsetProtocol.pdf.

Estimating Digester Emissions Reductions with EPA's Power Profiler
www.epa.gov/cleanenergy/powerprofiler.htm

Consider Gordondale Farms (Section 6.7) which has a digester fueled with manure from their 860 cows. Their digester system produces about one million kWh per year. Go to the Power Profiler and enter the required information. Under "Make a Difference," select "My Emissions." Enter 83,000 kWh into the "Average Monthly Use" option. The Profiler estimates that about two million pounds of CO_2 are released from producing one million kWh of conventional electricity a year. This means that use of the digester gas prevents an estimated two million pounds of CO_2 from being released into the atmosphere every year.

While CO_2 emissions from manure management are usually not counted towards a carbon footprint as mentioned above, there is carbon savings if the biogas is used to produce electricity. Instead of using fossil fuel electricity, carbon is offset by using renewable biogas.

FarmWare may be used to help estimate the emissions from anaerobic lagoons with secondary storage and combined storage and treatment lagoons (www.epa.gov/agstar/resources/handbook.html).

Environmental and Safety Issues

NO_x emissions from combusting biogas may be of concern for a digester project. Naturally aspirated reciprocating internal combustion engines emit relatively high levels of NO_x. Fuel injected lean-burn reciprocating internal combustion engines provide greater engine power output and lower NO_x emissions compared to a naturally aspirated engine. Gas turbines emit even lower levels of NO_x.

Sulfur oxides (SO_x) may be produced from swine manure digesters and may necessitate the use of scrubbers. SO_x emissions are generally not a concern for other types of influent.

Since biogas is flammable and displaces breathable oxygen within the space it occupies, it is potentially dangerous and it is necessary to take safety precautions including, but not limited to, installing and monitoring gas detectors, eliminating ignition sources, posting warning signs and never entering an empty digester without extensive venting and a confined space entry permit in accordance with Occupational Safety and Health Administration regulations. Developers should train the owner to properly maintain and operate the system to ensure efficiency and safety. Go to http://www.biogas.psu.edu/Safety.html for more on digester safety.

Permits

It is essential to garner appropriate permits early in the digester design process as the design may need adjustment to comply with federal, state, and local rules. Anaerobic digester construction and operation may need permits in the following areas:

- Land use
- Confined Animal Facility Operation Permit
- Noise
- Wastewater
- Water
- Storm-water management
- Air

See *AgStar Handbook,* Chapter 8 "Permitting and Other Regulatory Issues" for more details (www.epa.gov/agstar/pdf/handbook/chapter8.pdf).

6.7 SUCCESS STORIES

Dairy Manure: Gordondale Farms, Nelsonville, WI[177]

Gordondale Farms is a 3,200 acre dairy farm located in Nelsonville, Wisconsin with a milking herd of about 860 Holstein-Friesian cows. They use a two-stage modified plug-flow mesophilic digester with vertical gas mixing. The captured biogas is used to fuel a modified 150-kW engine generator set. While the farm owns the digester, the local utility, Alliant Energy, owns and operates the electricity generation equipment and owns the electricity generated. Alliant Energy pays Gordondale Farms at the rate of $0.015 per kWh delivered and all electricity used by Gordondale Farms is purchased from the utility at retail rates. Biogas production was estimated to be 93,501 ft^3 per day with 860 cows. For each 1,000 ft^3 of biogas utilized, about 30 kWh are generated. Liquid and solid residuals are separated. Liquids are used as fertilizer and the solid portion is used on-site and sold as bedding for dairy farms. Cost for design, materials, and construction was estimated to total $650,000 (completed March 2002). The owners of this system partially constructed the digester themselves, reducing the capital cost. The installed cost of the engine-generator set was $198,000. The engine-generator itself and interconnection fees totaled $160,000 while the remaining $38,000 was the cost of generator installation, including labor and materials.

Dairy Manure: California Dairy Power Production Program, various locations, CA

The Dairy Power Production Program was funded by the CEC and contracted to the Western United Resource Development Corporation (WURD). The purpose of the Dairy Power Production Program was to encourage the development of biological-based anaerobic digestion and gasification electricity generation projects on California dairies. The overall goal of this effort was to develop commercially proven biogas electricity systems that can help California dairies offset the purchase of electricity, and may provide environmental benefits by potentially reducing air and ground water pollutants associated with storage and treatment of livestock wastes. Total funds allocated for this project was $9,640,000.[178] All funds have been granted and future funding for this program is uncertain. The following is a summary of many of the projects that were completed through this program (Table 6). From the data below, a covered lagoon and generator set costs about $3,500 per kW and plug-flow digesters and generator set costs an average of about $3,000 per kW of generating capacity.

Table 6 California Dairy Power Production Program Digester Projects[179]

Dairy Name	Cows	Type of System	kW	Total Cost
Hilarides Dairy	6,000 heifers	Covered Lagoon	250	$1,500,000
Gallo Cattle Company	5081	Covered Lagoon	300	$1,289520
Blakes Landing Dairy	237	Covered Lagoon	75	$135,800
Castelanelli Bros. Dairy	1600	Covered Lagoon	160	$772,925
Koetsier Dairy	1500	Plug Flow	260	$381,850
Van Ommering Dairy	600	Plug Flow	130	$489,284
Meadowbrook Dairy	1900	Plug Flow	160	$524,898
CA Polytechnic State University Dairy	175	Covered Lagoon	30	$75,000
Lourenco Dairy	1258	Covered Lagoon	150	$229,557
Inland Empire Utilities Agency	4700	Plug Flow	563	$1,546,350
Eden-Vale Dairy	770	Plug Flow	150	$661,923

See the CEC (www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/projects.html) and WURD (www.wurdco.com/) websites for more information on the CA Dairy Power Production Program.

Food Processing: Valley Fig Growers Biogas Project, Fresno, CA[180]

Valley Fig Growers is a grower-owned marketing cooperative with 35 growers. They installed an anaerobic digester at their processing facilities in Fresno, California to help mitigate their wastewater issues and to produce electricity. The digester and microturbine system began operations in May 2005.

The Fig Growers installed a covered lagoon and a 70-kW Ingersoll Rand microturbine. The lagoon is 26,500 ft^2 (0.6 acres) with a 1.8 million gallon capacity. The retention time is 45 days with gas production of 2,000–2,500 ft^3 per hour. In 2002, the CEC Public Interest Energy Research (PIER) Program awarded the Valley Fig Growers $476,000. Biogas from the digested fig processing wastewater is used to generate electricity and heat. The Fig Growers use a total of 40,000 gallons of fresh water daily for processing, seven days a week. With high levels of organic matter in their wastewater, the Valley Fig Growers were charged $100,000 a year to discharge their wastewater into city sewers.

Benefits

The digester reduced biochemical oxygen demand and suspended solids by 70-80 percent. The estimated cost savings from this reduction is $115,000 per year. They save $90,000 each year from reduced wastewater discharge fees. Electricity produced from the digester saves the Fig Growers $25,000 each year in energy costs.

Costs[181]

The digester system cost a total of about $1.1 million. See the breakdown of the costs below.

Digester	
Engineering and project management	$478,000
Earthwork	$210,000
Lagoon liner and cover	$219,000
Digester and aeration	$229,000
Gas collection, heating	$270,000
Microturbine	
70-kW microturbine	$163,000
Engineering and commissioning	$13,000
Freight and sales tax	$8,000
3-year maintenance contract	$38,000
Utility rebate	($70,000)
Other Costs	
Road surface, fencing, landscaping	$65,000
Interest	$65,000
Total	$1,676,000
PIER grant and utility rebate	($546,000)
Net total cost	$1,142,000

Permitting[182]

- San Joaquin Valley Air Pollution Control District—permit to operate, emissions requirements
- City of Fresno Building Permit—city inspectors may not be familiar with microturbines and may be unsure of the inspection process for microturbines
- CA Regional Water Quality Control Board—submit groundwater monitoring network plan and waste discharge permit
- CA State Water Resources Board—general permit to discharge storm water

Valley Fig Recommendations[183]

- Test biogas quality to ensure compatibility with engine/turbine.
- Ensure that all correct O rings are used.
- Ensure that gas line regulators are properly installed to prevent potential fires.
- Negotiate equipment maintenance in the early stages of contracting.
- For bacteria to start producing biogas quicker during early stages of digester use, find similar digester material from other digesters as seed material.
- Contact local utilities early to resolve any interconnection issues and net metering rules.
- Plan for alternative uses of excess biogas.
- Investigate the underground characteristics of the planned digester site before construction.
- Be warned that if the project receives a state grant of more than $1,000, prevailing wages must be paid, increasing construction costs. Be sure contractors are aware of these grants.
- Utilize heat produced by the microturbine to heat the digester.
- Look for simple solutions to minimize the complexity of operations and maintenance. Budget for automation only when needed.
- Address water quality, air quality and other permitting issues early in design phase and negotiate annual fees ahead of time.
- Find a project manager with experience in both construction and operation of anaerobic digesters.