United States
Environmental Protection
Agency

EPA/600/R-08/049
March 2008

Smart Energy Resources Guide

EPA/600/R-08/049
March 2008

Smart Energy Resources Guide

Prepared By

Jennifer Wang

for

Penny McDaniel, Superfund Project Manager
Michael Gill, Hazardous Substance Technical Liaison
Superfund Division
Region 9
U. S. Environmental Protection Agency
San Francisco, CA 94105

Steven Rock
Land Remediation and Pollution Control Division
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

APPENDIX I: ERRS AND RAC CONTRACT LANGUAGE

ERRS Language

Region 9 Emergency and Rapid Response Service (ERRS) contracts include the following diesel emissions reduction language.

> CLEAN TECHNOLOGIES
>
> The contractor will use clean technologies and/or fuels on all diesel equipment to the extent practicable and/or feasible. The preference is for clean diesel technologies, but alterative fuels, such as biodiesel or natural gas-powered vehicles are also acceptable. These alternative fuels will be used where they are available and within a reasonable distance to sites. For equipment retrofits, the contractor will employ the Best Available Control Technology (BACT) on non-road and on-road diesel powered equipment used at a site. Examples of clean diesel technologies include diesel particulate filters (DPFs), and diesel oxidation catalysis (DOCs). For alternative fuel usage, the contractor will use at least a B20 blend (e.g., 20 percent biodiesel and 80 percent petrodiesel) or higher in the equipment engines that are used at a site.

RAC Language

Region 9 Response Action Contracts (RAC) include the following diesel emissions reduction and renewable energy use language.

> Clean Air
>
> In the performance of all activities performed under this contract, the contractor shall where directed by EPA use cleaner engines, cleaner fuel and cleaner diesel control technology on diesel powered equipment with engines greater than 50 horsepower whether the equipment is owned or rented. Direction will be provided on a Task Order by Task Order basis. The contractor shall provide a break-out cost for each task order in accordance with the instruction in contract clause addressing submission of cost proposal.
>
> Cleaner engines include non-road engines meeting Tier I or cleaner standards and on-road engines meeting 2004 On-Highway Heavy Duty Engine Emissions Standards or cleaner, whether the equipment is owned or rented. Cleaner fuels include biodiesel blends or ultra low sulfur diesel. Cleaner diesel control technology includes EPA or California Air Resources Board ("CARB") verified diesel particulate filters ("DPFs") or diesel oxidation catalysts ("DOCs"). The contractor shall track emissions reduced (i.e., tons of diesel particulate matter reduced) associated with using cleaner diesel equipment and fuels.
>
> Renewable Energy
>
> The contractor shall evaluate all reasonably feasible renewable energy sources when conducting work related to selecting a cleanup remedy, constructing a cleanup remedy, and when optimizing an existing cleanup remedy. Sources of renewable energy include solar, wind, and biomass and biogas. Examples of renewable energy technologies include photovoltaic panels, wind turbines, digesters, gasifiers, and micro turbines. Part of evaluating renewable energy sources and technologies will involve a cost analysis, comparing the energy costs from renewable sources versus

traditional electricity sources provided by local utilities, over the expected life of the cleanup remedy. Similarly, an evaluation of the avoided emissions as a result of using renewable energy sources versus traditional energy sources provided by local utilities shall be performed. The contractor shall also evaluate the cost of purchasing green power from organizations that offer green power within the appropriate state.

APPENDIX II: FEDERAL REGULATIONS AND GOALS

The following are some federal regulations and goals that pertain to reducing GHGs and diesel emissions.

- Diesel Emissions Reduction Act of 2005 (DERA): DERA authorizes $200 million per year over five years in grants and loans for states and organizations to clean up existing diesel fleets.
- EPA Administrator's Action Plan:[280] This plan aims to provide certainty for consumers and protect the environment by seeking passage of Clear Skies (www.epa.gov/clearskies) legislation; expand the use of biofuels and promote diesel emissions reductions through retrofit and other technologies; promote clean air and energy security through voluntary conservation programs, such as Energy Star (www.energystar.gov) and SmartWay Transport (www.epa.gov/smartway); and make timely permitting decisions and foster technological innovations to support the clean development of domestic energy resources (oil, gas, nuclear, coal, wind, and solar).
- EPA Region 9 Energy and Climate Change Strategy:[281] Included in this strategy is the promotion of renewable energy production on contaminated sites by working with land owners and utilities to encourage the production/use of renewable energy on revitalized lands.
- Energy Independence and Security Act of 2007:[282] Signed into law by President George W. Bush on December 17, 2007, this act increases renewable fuel standards and raises fuel economy standards for cars, trucks, and SUVs. It also aims to further develop carbon capture technology.
- Energy Policy Act (EPAct) of 2005:[283] The EPAct 2005 was passed by Congress on June 29, 2005 and signed into law by President George W. Bush on August 8, 2005. It addresses growing energy problems, provides tax incentives and loan guarantees for energy production of various types. Each federal agency is required to increase renewable energy use and reduce energy intensity. Federal agencies are also required to purchase products that are Energy Star-qualified (www.energystar.gov) or designated by the Federal Energy Management Program (FEMP) (www1.eere.energy.gov/femp/procurement/index.html).
- Executive Order (EO) 13134 "Developing and Promoting Bio-based Products and Bioenergy":[284] Issued August 12, 1999, EO 13134 develops a comprehensive national strategy, including research, development, and private sector incentives, to stimulate the creation and early adoption of technologies needed to make bio-based products and bioenergy cost-competitive in large national and international markets.
- Executive Order 13148 "Greening the Government Through Leadership in Environmental Management":[285] Issued April 22, 2000, EO 13148 encourages integrating environmental accountability into agency day-to-day decision-making and long-term planning processes, across all agency missions, activities, and functions. It stresses that environmental management considerations must be a fundamental and integral component of Federal Government policies, operations, planning, and management.

- Executive Order 13221 “Energy-Efficient Standby Power Devices”:[286] Signed on July 31, 2001, EO 13221 calls for Federal agencies to purchase products that use minimal standby power when possible.
- Executive Order 13423 “Strengthening Federal Environmental, Energy, and Transportation Management”:[287] Signed on January 24, 2007, EO 13423 mandates new sustainability goals for the federal government that match or exceed previous statutory and EO requirements. It mandates an annual 3 percent reduction and cumulative 30 percent reduction in energy intensity by 2015 (compared to a fiscal year 2003 baseline) and requires that 50 percent of current renewable energy purchases come from new renewable sources—sources that have been developed after January 1, 1999. This requirement seeks to reduce GHG emissions and achieve in 10 years the same level of energy efficiency improvement that federal agencies achieved in the last 20 years. EO 13423 is 50 percent more stringent than the requirements of EPAct of 2005.
- Executive Order 13432 “Cooperation Among Agencies in Protecting the Environment With Respect to Greenhouse Gas Emissions From Motor Vehicles, Nonroad Vehicles, and Nonroad Engines”: Signed on May 14, 2007, EO 13432 requires EPA to protect the environment with respect to GHG emissions from motor vehicles, non-road vehicles, and non-road engines. The Order calls for EPA to work in collaboration with the U.S. Department of Transportation (DOT) and the DOE in conducting research and developing policy. Key considerations in developing policy include sound science, analysis of costs and benefits, public safety, and economic growth.
- Greening EPA:[288] EPA continuously works to reduce the environmental impact of its facilities and operations, from building new, environmentally sustainable structures to improving the energy efficiency of older buildings. EPA is striving to significantly reduce its reliance on energy sources that emit GHGs. For more information, go to www.epa.gov/greeningepa. The EPA purchases Green Tags to offset 100 percent of its energy use in EPA facilities nationwide. The EPA strives to acquire alternative fuel vehicles, reduce its use of petroleum fuel, (improving its own fleet fuel efficiency by 3 percent annually) and encourage private sector organizations to follow its lead. Go to www.epa.gov/greeningepa/greenfleet for more information.
- National Clean Diesel Campaign (NCDC): The NCDC is a public-private partnership that collaborates with businesses, government and community organizations, industry, and others to reduce diesel emissions. NCDC is a program within EPA’s Office of Transportation and Air Quality (OTAQ); contacts are in each EPA region. For more information, go to www.epa.gov/cleandiesel.

APPENDIX III: SOLAR POWER

MORE SOLAR PV TERMS AND DEFINITIONS

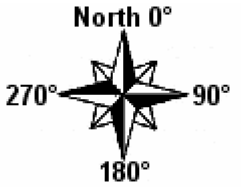


Figure 50 Azimuth. Image courtesy CSI[289]

Azimuth Horizontal angle between a point in the sky and true north (Fig. 50). To optimize annual energy production, solar arrays should be oriented to face true south, i.e., with an azimuth of 180°.

Insolation Amount of solar energy received on a given area over time measured in kilowatt-hours per square meter (kWh/m^2).[290]

Irradiance The direct, diffuse, and reflected solar radiation that strikes a surface. Usually expressed in kilowatts per square meter (kW/m^2). Irradiance multiplied by time is insolation.[291]

Peak Sun Hours Peak sun hours are the hours equivalent to the number of hours per day with solar irradiance equaling 1,000 W/m^2. To determine peak sun hours, determine the energy from total sunlight throughout the day. Next, determine how many hours with solar irradiance equaling 1,000 W/m^2 this equates to. This is equal to peak sun hours. In other words, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the sun shone for six hours with an irradiance of 1,000 W/m^2.[292]

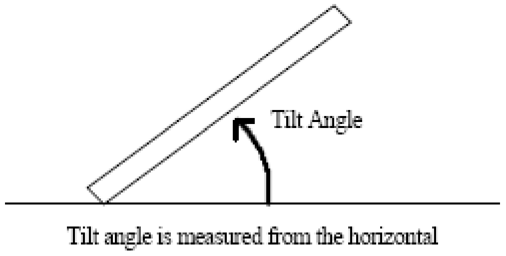


Figure 51 Tilt angle. Image courtesy Solar On-Line[293]

Tilt Angle Angle between the horizontal and the solar panel (Fig. 51). For maximum average annual insolation for a fixed-tilt PV system, the tilt angle should be equal to the latitude of the site. For maximum average insolation in summer months, the tilt angle should be equal to the latitude minus 15°. For maximum average insolation in winter months, the tilt angle should be equal to the latitude plus 15°.

For more solar energy terms, go to EERE's Solar Glossary (www1.eere.energy.gov/solar/solar_glossary.html).

SOLAR PV TECHNOLOGY

Solar Cell[294]

PV cells are composed of at least two layers of semiconductor material, commonly silicon. Silicon has a valence of four, meaning that there are four electrons in its outer orbital. Each silicon atom shares one of its valence electrons with each of its closest neighboring atom in a covalent bond.

These electrons can be knocked loose by a photon, creating an electron-hole pair. The "hole" refers to the positive charge created by the loss of the freed electron. Electrons and holes can migrate given an electric field within the material. The strength of the current depends on the concentration density of free electrons and holes. A small fraction of the silicon atoms can be substituted with a different element, a process known as doping. An "n" type semiconductor is doped with an element having 5 valence electrons, usually phosphorus, making the layer negatively charged (Fig. 52).

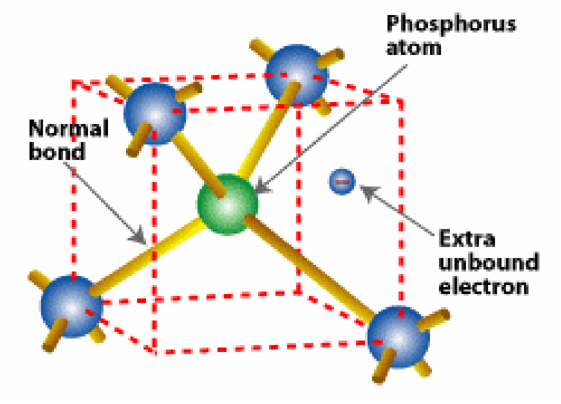


Figure 52 Substituting a phosphorus atom (with five valence electrons) for a silicon atom in a silicon crystal leaves an extra, unbonded electron that is relatively free to move around the crystal. Image courtesy EERE[295]

A "p" type semiconductor is doped with boron which has three valence electrons to create holes. A small amount of these impurities in the silicon does not alter the lattice structure but allows electrons on the n-type to be more easily freed and creates holes on the p-type semiconductor. Photons striking the cell releases electrons from the negative layer and they flow towards the positive layer (Fig. 53). A metal wire is placed separately on the p and n side to power a load with the induced current.

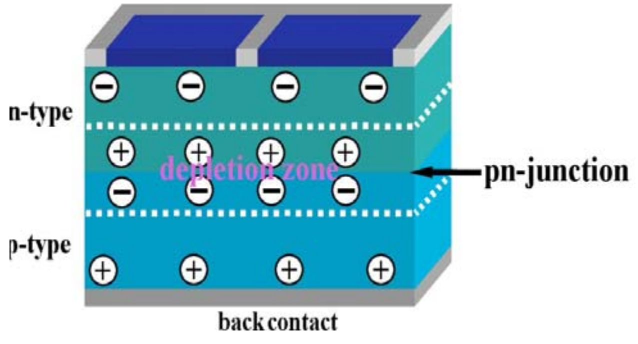


Figure 53 The pn-junction of a solar PV cell. Image courtesy Special Materials and Research Technology[296]

Series and Parallel Circuits

Each PV module is rated at a certain voltage and amperage. A 50-watt PV module is nominally 12 volts (DC) and three amps in full sun.[297] PV modules can be wired together to obtain different volts and amps to better suit the electricity needs of the site (Fig. 54). By wiring modules or batteries in series, voltage additively increases while amps do not change. Wiring modules or batteries in parallel will increase amps additively but voltage stays the same. To obtain required amps and voltages, modules and batteries may be wired with a combination of series and parallel circuits.[298]

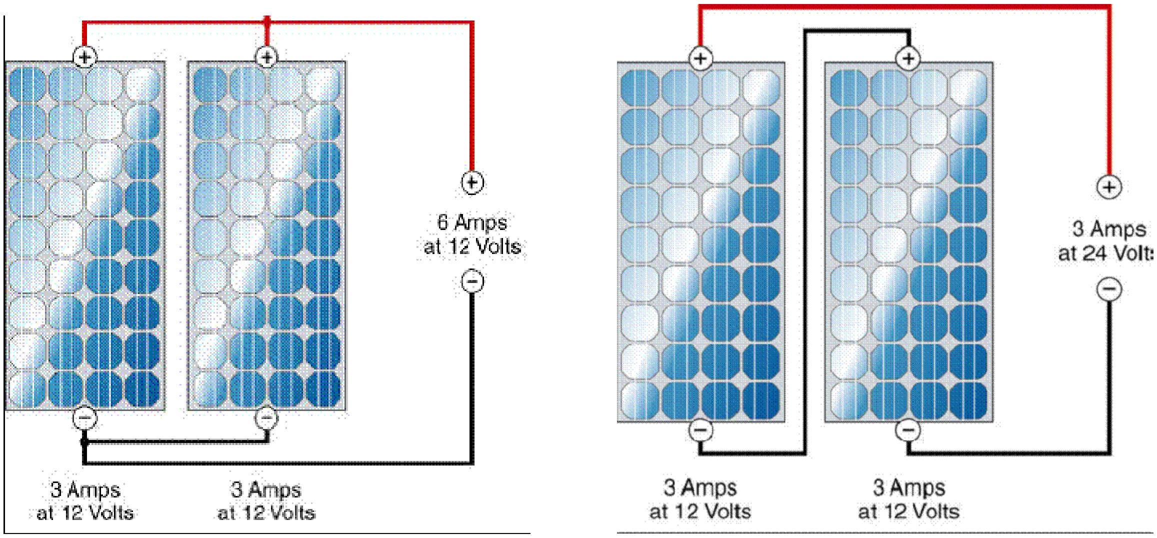


Figure 54 Parallel circuit (left) and series circuit (right). Images courtesy Solar On-Line[299]

Batteries

A battery is defined as two or more electrochemical cells enclosed in a container and electrically interconnected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels. [300] Batteries can be used with any renewable energy system to store electricity for later use when the renewable energy system is not generating enough energy for a cleanup site's operations. For sites that are not grid-tied, batteries should be included in the renewable energy project if a constant electricity source is necessary. In these cases, the renewable energy system must be sized to provide enough electricity to power your site as well as charge the battery. Sites that are grid-tied can still consider including a battery to reduce reliance on the grid. There are many types of rechargeable batteries that can be used with your project. The two main categories of battery technology are lead-acid and alkaline. Lead-acid batteries are used with most renewable energy projects.[301]

Lead-Acid: Lead-acid batteries are rechargeable, widely available, relatively inexpensive compared to alkaline batteries, easily maintained, and has comparable longevity for the price. Lead-acid batteries are distinguished between deep cycle and shallow cycle batteries. [302]

Deep cycle: Lead-acid deep cycle batteries may be discharged for an extended amount of time up to 80 percent of their rated capacity and are compatible with renewable energy projects. Two types of deep cycle lead acid batteries are liquid electrolyte and captive electrolyte batteries.

Lead-acid deep cycle liquid electrolyte: Liquid electrolyte batteries are found on golf carts and forklifts. Most renewable energy systems use these batteries (Fig. 55). They vent hydrogen gas that is produced as the battery nears full charge. Some batteries may require periodic filling as water is lost through the vent. A properly sized and maintained deep-cycle liquid electrolyte lead-acid batter will last 3-10 years. The life of a battery depends on temperature and how deeply the batteries are discharged. A battery cycle is one complete discharge and charge. Batteries that operate on a cycle that discharges to 50 percent of capacity will last about twice as long as batteries that are discharged to 80 percent.[304]

Lead-acid deep cycle captive electrolyte: Captive electrolyte batteries do not have a vent for electrolytes to escape. Therefore they require minimal maintenance though they are about twice as expensive as liquid electrolyte batteries. Less power is available in cold temperatures and high temperatures decrease battery life.

Shallow Cycle: Shallow cycle batteries, like car batteries, are discharged for a very short duration and are not recommended for renewable energy system use.

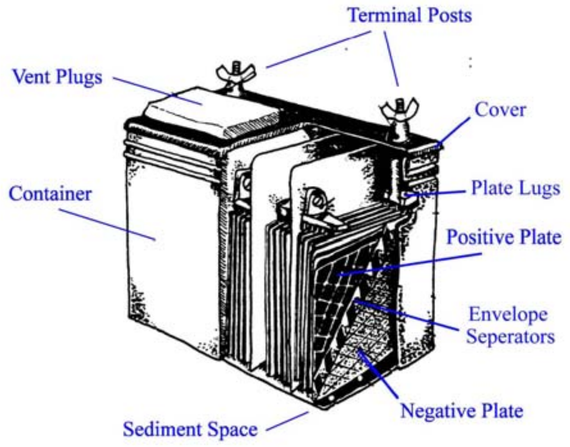


Figure 55 Liquid electrolyte lead-acid battery. Image courtesy Solar On-Line[303]

Alkaline Batteries: Alkaline batteries have higher voltages compared to lead acid batteries. They are not as effected by temperatures, can be deeply discharged, and have a useful life of about 30 years. They are significantly more expensive than lead-acid batteries. These are recommended for remote areas with extreme temperatures in cases where costs are not the most important issue.**[305]**

To properly size a battery for a renewable energy system, one must consider the following:[306]

Days of autonomy This refers to the number of days a battery system will provide enough energy for a load without recharging

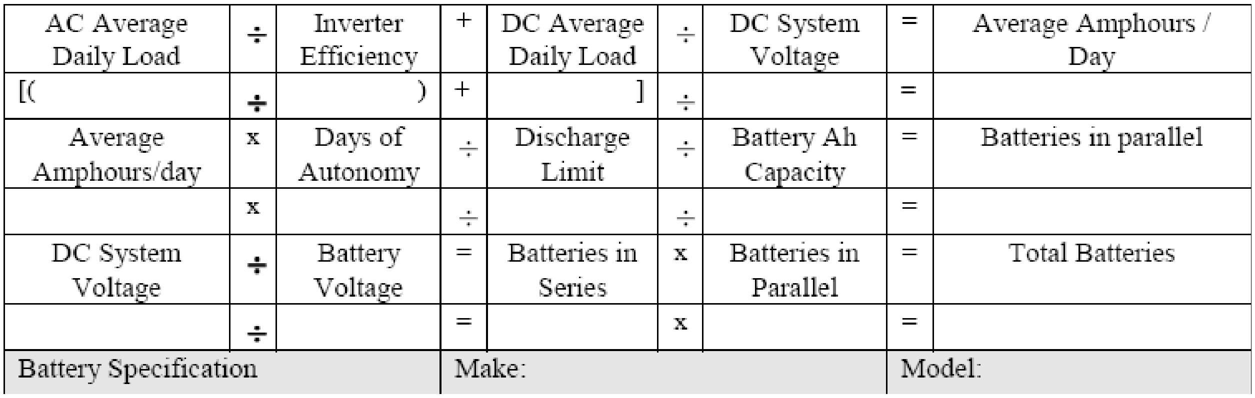
Battery capacity Battery capacity is rated in amp-hours (AH). Theoretically, a “100 AH battery” will deliver one amp for 100 hours or roughly two amps for 50 hours before the battery is considered fully discharged.

Rate and depth of discharge The rate at which a battery is discharged directly affects its capacity. Discharging a battery over a shorter amount of time decreases its capacity. The depth of discharge refers to how much electricity is withdrawn from the battery. Shallow depths of discharge, which is to draw little energy from the battery compared to the battery capacity, prolongs battery life.

Life expectancy Life expectancy for batteries is measured in number of cycles (one discharge and one charge). Batteries lose capacity over time and are considered to be at the end of their lives when 20 percent of their original capacity is lost.

Environmental conditions Battery capacity is reduced at extreme temperatures.

To estimate the number of batteries you would need, look at the specifications offered for a battery and use the following equations (Fig. 56).



AC Average Daily Load	÷	Inverter Efficiency	+	DC Average Daily Load	÷	DC System Voltage	=	Average Amphours / Day
[(	÷	)	+	]	÷		=	
Average Amphours/day	x	Days of Autonomy	÷	Discharge Limit	÷	Battery Ah Capacity	=	Batteries in parallel
	x		÷		÷		=	
DC System Voltage	÷	Battery Voltage	=	Batteries in Series	x	Batteries in Parallel	=	Total Batteries
	÷		=		x		=	
Battery Specification			Make:				Model:	

Figure 56 Estimate number of batteries needed. Image courtesy Solar On-Line[307]

Controllers[308]

Controllers prevent batteries from being overcharged by the PV system and overly discharged by the load. The size of the controller is measured by its amps. Controllers can be wired in parallel if high currents are necessary. There are four different types of PV controls:

- Shunt Controllers -- Shunt controllers are designed for small systems and prevent overcharging by “shunting” or by-passing the batteries when they are fully charged. Excess power is converted into heat.
- Single-stage Controllers – Single-stage controllers switch the current off when the battery voltage reaches a certain pre-set value and reconnect the array and battery if the voltage falls below a certain value.
- Multi-stage Controllers -- Multi-stage controllers establish different charging currents depending on the battery’s state-of-charge.
- Pulse Controllers – Pulse controllers rapidly switch the full charging current on and off when the battery voltage reaches the pre-set charge termination point.

Inverters[309]

Inverters are necessary to change DC electricity produced by PV modules and stored in batteries to alternating current for use in AC loads. They are also needed to feed electricity into the utility grid. For grid-tied PV systems, contact the utility for inverter requirements.

Optimal features of an inverter:

- High efficiency – converts 80 percent or more of direct current input into alternating current output
- Low standby losses – highly efficient when no loads are operating
- High surge capacity – able to provide high current often required to start motors or run simultaneous loads
- Frequency regulation – maintains 60 Hertz output over a variety of input conditions

- Harmonic distortion – can “smooth out” unwanted output peaks to minimize harmful heating effects on appliances
- Serviceability – easily field-replaced modular circuitry
- Reliability – provide dependable long-term low maintenance service
- Automatic warning or shut-off – protective circuits which guard the system
- Power correction factor – maintains optimum balance between power source and load requirements
- Lightweight – to facilitate convenient installation and service
- Battery charging capability – allows the inverter to be used as a battery charger
- Low cost – inverters are about $700 per kW

Inverter Types

Inverters can be sorted into two categories. Synchronous (also known as line-tied) inverters are used with grid-tied PV systems. Static inverters are used with non-grid-tied PV systems. Inverters also produce different wave forms:

- Square Wave Inverters – appropriate for small resistive heating loads, some small appliances and incandescent lights
- Modified Sine Wave Inverters – appropriate for operating motors, lights, and standard electronic equipment
- Sine Wave Inverters – appropriate for sensitive electronic hardware

MORE QUESTIONS TO ASK YOUR POTENTIAL SOLAR INSTALLER[310]

- Is the company a full service or specialty firm?
- How long has the company been in business?
- 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?
- What can they tell you about local, state and national incentives?
- How much do they know about zoning and electrical requirements and codes?
- Do they offer adequate warranties?
- Does the company carry workers’ compensation and liability insurance? Do their subcontractors, if applicable, carry liability insurance? Can they show you a copy of their policy?
- What permits are needed for this project? Who is going to obtain and pay for them?
- If applicable, will the city require a structural review of the roof by an architect or professional engineer? Who will pay for this service?

- Will they provide written guarantees on all materials and workmanship?
- What is the exact schedule of payments to be made? Besides materials and labor, does the estimate include sales tax, permit fees, structural analysis fees, interconnection fees, and shipping costs?
- How soon can they respond to a service call if the PV system is not working properly? Would they be the one to repair the system?
- What service do they offer after installation? Do they offer updates of manuals and catalogues?
- Ask for a cost estimate. Do they include the type of mounting requested, type of solar PV, etc? Ask for peak and average kW output estimates for specific conditions and seasons (sunny, summer, etc.) to be included in the bid. For battery systems, ask for specifications on battery capacity, recharging times, and the recharging cycle that will be used. Less expensive estimates may not include a service or device or may have hidden costs.

CONCENTRATED SOLAR POWER (CSP)[312]

Concentrated solar power technology can also convert solar power into electricity. Mirrors are oriented to focus heat from the sun to heat a liquid or gas in a tube to very high temperatures (Fig. 57). Energy from the liquid or gas can then be utilized in steam engine generators. CSP technology is less expensive than PV. However, current concentrated solar power projects are usually constructed at a large scale of greater than one MW, and may exceed the electrical needs of a cleanup. Companies that tailor CSP projects for industrial sectors are emerging. Go to www.nrel.gov/learning/re_csp.html for more information.

Figure 57 Parabolic-trough concentrating solar power system. Image courtesy NREL[311]

APPENDIX IV: WIND POWER

WIND TECHNOLOGY

Extracting Energy from Wind

The theoretical maximum efficiency for a wind turbine is 59 percent (the Betz limit). It is not possible to extract all the energy from wind. If total kinetic (motion) energy were extracted, there would be no wind passing through the turbine. You would need a solid disk to trap all the wind. But if this were the case, the wind would blow around the solid disk and no energy would be captured. Thus, wind blades can extract only a portion of the total wind energy.[313]

When air passes over a wind turbine's blade, it travels faster over the top of the blade than it does below. This makes the air pressure above the blade lower than it is underneath. Due to the unequal pressures the blade experiences a lifting force, causing the blades to spin. Since the wind turbine captured some kinetic energy from the wind, wind blows more slowly downwind of the turbine.[314]

Towers[315]

A general rule of thumb is to install a wind turbine on a tower with the bottom of the rotor blades at least 30 feet (9.1 meters) above any obstacle that is within 300 feet (91 meters) of the tower. Relatively small investments in increased tower height can yield very high rates of return in power production. For instance, a 10-kW turbine on a 100-foot tower costs 10 percent more than a 10-kW turbine on a 60-foot tower, but it can produce 29 percent more power.

There are two basic types of towers: self-supporting (free standing) and guyed. Most small wind power systems use a guyed tower. Guyed towers, which are the least expensive, can consist of lattice sections, pipe, or tubing (depending on the design), and supporting guy wires (Fig. 58). They are easier to install than self-supporting towers. However, because the radius of the circle created by guy wires must be one-half to three-quarters of the tower height, guyed towers require enough space to accommodate them. You may also opt to install tilt-down towers (Fig. 59), which lower the system to the ground for maintenance or during hazardous weather such as hurricanes. Although tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller light-weight turbines, usually 5-kW or less.

Figure 58 A 10-kW wind turbine with guyed lattice tower. Image courtesy NREL[316]

Aluminum towers are prone to cracking and should be avoided. Most turbine manufacturers provide wind energy system packages that include towers. Mounting turbines on rooftops is not recommended since vibrations from the turbines may damage buildings. This can lead to noise and structural problems with the building. Rooftops can also cause excessive turbulence that can shorten the life of a turbine.

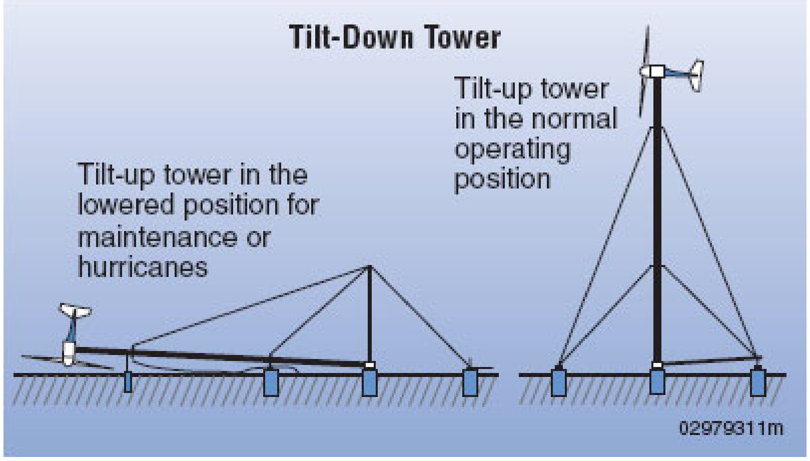


Figure 59 Tilt-down tower schematic. Image courtesy EERE[317]

CALCULATING WIND TURBINE OUTPUT POWER

See Box 11 for equations on estimating wind turbine output power with assumptions of blade length.

Box 11 Wind Turbine Output Power[318]

Step 1: Calculate swept area

$$\mathbf{A = 3.14 \ast r^2}$$

A = swept area

r = radius, length of one blade, one-half of the diameter of the rotor

Step 2: Calculate power in the swept area

$$\mathbf{P = 0.5 \ast \rho \ast A \ast V^3}$$

P = power in watts (746 watts = 1 hp) (1,000 watts = 1 kilowatt)

ρ = air density (about 1.225 kg/m^3 at sea level, less higher up)

A = swept area (m^2)

V = wind speed in meters/sec (20 mph = 9 m/s) (2.24 mph = 1 m/s)

Step 3: Calculate wind turbine power

$$\mathbf{P = 0.5 \ast \rho \ast A \ast C_p \ast V^3 \ast N_g \ast N_b}$$

P = power in watts (746 watts = 1 hp) (1,000 watts = 1 kilowatt)

ρ = air density (about 1.225 kg/m^3 at sea level, less at higher altitudes)

A = swept area (m^2)

C_p = Coefficient of performance (0.59 [Betz limit] is the maximum theoretically possible, 0.35 for a good design)

V = wind speed in m/s (20 mph = 9 m/s)

N_g = generator efficiency (0.50 for car alternator, 0.80 or possibly more for a permanent magnet generator or grid-connected induction generator)

N_b = gearbox/bearings efficiency (depends, could be as high as 0.95)

APPENDIX V: LANDFILL GAS-TO-ENERGY

PRELIMINARY EVALUATION WORKSHEET

Use the following worksheet to complete a preliminary feasibility evaluation of a LFGE project for an MSW landfill. (Worksheet created by LMOP)

Landfill Gas to Energy Project Preliminary Evaluation Worksheet[319]

A. Is your landfill a municipal solid waste landfill?

If not, you may encounter some additional issues in project development due to the presence of hazardous or non-organic waste in the landfill. Stop and consult an energy recovery expert.

B. Add your score for the next three questions:

1. How much MSW is in your landfill?

Tons	Score	
Greater than 3 million	40	
1-3 million	30	
0.75-1 million	20	
Less than 0.75 million	10	+Score____

2. Is your fill area at least 40 feet deep?

Yes = 5

No = 0 +Score____

3. Is your landfill currently open? If yes, answer 3(a). If no, answer 3(b).

(a) How much waste will be received in the next 10 years? For each 500,000 tons, score 5 points.

Total tons ÷ 500,000 tons x 5 points = +Score____

(b) If closed for less than one year, enter 0. If closed for one year or more, multiply each year since the closure by 5, and subtract that amount from the total score

Years since closure x 5 points = -Score____

Total your answers to questions 1-3: **Total Score**____

C. If your score is:

≥ 30: Your landfill is a good candidate for energy recovery (go to section D).

20-30: Your landfill may not be a good candidate for conventional energy recovery option. However, you may want to consider on-site or alternative uses for the landfill gas.

D. If your landfill is a good candidate, answer the following two questions:

1. Are you now collecting gas at your landfill (other than from perimeter wells), or do you plan to do so soon for regulatory or other reasons? If yes, your landfill may be an excellent candidate for energy recovery.

2. (a) Is annual rainfall less than or equal to 25 inches a year?

    (b) Is construction and demolition waste mixed into the municipal waste or is it a large portion of total waste?

If YES to questions D.2(a) or (b), your annual landfill gas production may be lower than otherwise expected. Your landfill may still be a strong candidate, but you may want to lower your estimated gas volumes slightly during project design and evaluation.

COMBINED HEAT AND POWER (CHP) [320]

Combined heat and power, also known as cogeneration, is an approach that increases efficiency from prime movers by generating and utilizing both electricity and heat. In conventional electricity generation, the electricity produced is utilized but the co-produced heat is often wasted. About 75 percent of fuel energy input into an engine is output as heat. In CHP applications, this waste heat is captured for space heating, water heating, steam generation to run a steam turbine, and cooling. Heat exchangers can recover up to 7,000 BTUs of heat per hour for each KW of the generator load. Utilizing waste heat can increase efficiency to 40-50 percent.

Go to EPA's Combined Heat and Power Partnership website (www.epa.gov/chp/) and see the EPA's Combined Heat and Power Partnership *Catalogue of CHP Technologies* (www.epa.gov/CHP/basic/catalog.html) for more information.

ELECTRICITY GENERATION

Details are provided below for the prime movers mentioned this guide. These include reciprocating engines, gas turbines, microturbines, boilers and steam engines, and fuel cells.

Reciprocating Engines / Internal Combustion (IC)Engine

Reciprocating engines, also called internal combustion engines, are a widespread and well-known technology. They require fuel, air, compression, and a combustion source to function. The two categories they generally fall into are (1) spark-ignited engines, typically fueled by gasoline, natural gas or landfill gas, and (2) compression-ignited engines, typically fueled by diesel fuel.[322]

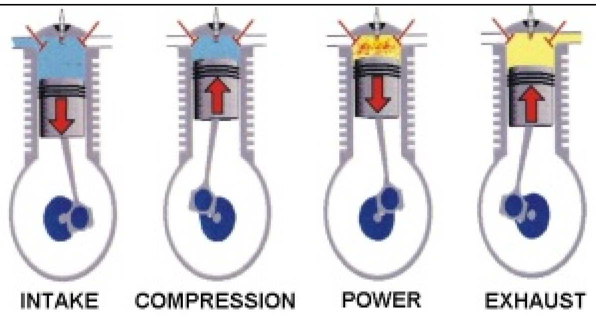


Figure 60 Reciprocating engine cycle. Image courtesy EERE[321]

How Does a Reciprocating Engine Work?

Four-stroke spark-ignited reciprocating engine process (Fig. 60):[323]

Intake: As the piston moves downward in its cylinder, the intake valve opens and the upper portion of the cylinder fills with fuel and air.

Compression: When the piston returns upward in the compression cycle, the spark plug emits a spark to ignite the fuel/air mixture.

Power: The piston is forced down, thereby turning the crank shaft and producing power.

Exhaust: The piston moves back up to its original position and the spent mixture is expelled through the open exhaust valve.

Applicability

Reciprocating engines can be used for landfill gas or biogas and are used in a wide variety of applications because of their relatively small size, low unit costs, and useful thermal output. For power generation, reciprocating engines are available in sizes ranging from a few kilowatts to over 5 MW.[324] The main advantage of reciprocating engines as compared to other power generation technologies is a better heat rate at lower capacities. Heat rate is the amount of gas needed to generate one kWh of electricity, and is closely related to system efficiency. The heat rate for a typical reciprocating engine plant is 10,600 BTU/kWh.[325] Another advantage of reciprocating engines is that the units are available in different incremental capacities, which makes it easy to tailor the IC engine size to the specific gas production rates of a landfill or digester.

Reciprocating engines are the most widely used prime movers for LFG-fired electric power generation.[326] Worldwide, there are more than 200 LFG-fired reciprocating engine power plants.[327] Reciprocating engines with power output from 0.1 MW to 3.0 MW have been proven suitable with landfill gas.[328]

Disadvantages of Reciprocating Engines

An important disadvantage of reciprocating engines is that they produce higher emissions of NO_x, CO, and NMOCs than other electric power generation technologies. However, significant progress has been made in reducing NO_x emissions in recent years. A second disadvantage to reciprocating engines is that their operation/maintenance costs on a per kWh basis are higher than for other power generation technologies. In general, reciprocating engines require a relatively simple LFG or biogas pretreatment process consisting of compression and removal of free moisture.[329] Water droplets are removed by the use of simple moisture separators (knockout drums), cooling of the biogas in ambient air-to-gas heat exchangers, and coalescing-type filters. Through compression and cooling, some of the NMOCs in the LFG are removed. The reciprocating engines can require 3-60 pounds per square inch gauge (psig) of fuel pressure.[330]

Information Resources

- ☐ EERE Distributed Energy Program Web Page: More information on gas-fired reciprocating engines. www.eere.energy.gov/de/gas_fired/
- ☐ *The California Energy Commission's Distributed Energy Resource Guide*: More information on performance, costs, strengths and weaknesses, and vendors of electricity generation equipment. www.energy.ca.gov/distgen/equipment/equipment.html

Combustion (Gas) Turbine (CT)

Landfill gas, digester biogas, and gasifier syngas can be used in gas turbines to produce heat and electricity. Gas turbines are heat engines that use high-temperature, high-pressure gas as the fuel. A portion of the heat supplied by the gas is converted directly into mechanical work.

How Does a Gas Turbine Work?

High-temperature and high-pressure gas rushes out of the combustor and pushes against the turbine blades, causing them to rotate. Gas turbines are often referred to as "combustion" turbines because in most cases, hot gas is produced by burning a fuel in air. Gas turbines are used widely in industry, universities and colleges, hospitals, and commercial buildings because they are compact, lightweight, quick-starting, and simple to operate.[331] Simple-cycle gas turbines convert a portion of input energy from fuel to electricity. The remaining energy produces heat which is normally expelled into the atmosphere. Simple-cycle turbines have efficiencies of 21-40 percent.[332] Combined-cycle gas turbines utilize high-quality waste heat to generate steam to power another turbine. The waste heat can also be used for cooling (e.g., absorption chillers), space or water heating, and other power applications. When taking advantage of the normally wasted heat, efficiencies increase to nearly 90 percent in some cases.[333]

Advantages and Disadvantages of a Gas Turbine

The main advantages of a CT as compared to a reciprocating engine are its lower air emissions and lower operation/maintenance costs. The main drawback to the combustion turbine is its high net heat rate. Combustion turbine net heat rates vary from 12,200 BTU per kWh to 16,400 BTU per kWh. Larger, new combustion turbines are more fuel efficient. Combustion turbines require a higher pressure fuel supply than reciprocating engines of 150-250 psig. Two stages of LFG compression are employed. Particles in the LFG have sometimes caused problems with the combustion turbine's fuel injection nozzles. A small water wash scrubber is normally provided in the pretreatment process to prevent this problem. [334]

For more information performance, costs, strengths and weaknesses, and vendors of electricity generation equipment, see *The California Energy Commission's Distributed Energy Resource Guide* (www.energy.ca.gov/distgen/equipment/equipment.html).

Microturbines

Microturbines are a relatively new technology. They are small combustion turbines, approximately the size of a refrigerator, with outputs of 30-250 kW.[335] Microturbines are best suited for relatively small applications that are less than 1 MW and for on-site electricity use or distribution to sites in close proximity.[336] They can be powered using landfill gas, digester biogas, or natural gas. Microturbines are ideal for LFGE or digester projects with low gas production or low methane concentration. A 30-kW microturbine can power a 40-hp motor or supply energy to about 20 homes.[337]

How do Microturbines Work?

Landfill gas, biogas, or other fuel, is supplied to the combustor section of the microturbine at 70-80 psig of pressure. Air and fuel are burned in the combustor, releasing heat that causes the combustion gas to expand. The expanding gas powers the gas turbine that in turn operates the generator; the generator then produces electricity. To increase overall efficiency, microturbines are typically equipped with a recuperator that preheats the combustion air using turbine exhaust gas. A microturbine can also be fitted with a waste heat recovery unit for auxiliary heating applications. They are different from traditional combustion turbines because they spin at much faster speeds.[338]

Applicability[339]

Microturbines provide advantages over other electrical generation technologies for landfills in cases where:

- LFG or biogas flow is low.
- LFG or biogas has low methane content.
- Air emissions, especially NO_x, are of concern (i.e., in NO_x nonattainment areas where the use of reciprocating engines might be precluded).
- Electricity produced will be used for on-site facilities rather than for export.
- Electricity supply is unreliable and electricity prices are high.
- Hot water is needed on-site or nearby.

Advantages

Compared to other IC engines, gas turbines and boiler steam-engine sets, microturbines have the following advantages.

- Portable and easily sized.
- Compact and fewer moving parts.
- Require minimal operation and maintenance.
- Use of air bearings coupled with air-cooled generator eliminates the need for lubrication and liquid cooling systems.
- Lower pollutant emissions (e.g., NO_x emissions levels from microturbines are typically less than one-tenth of those best-performing reciprocating engines and lower than those from LFG flares).
- Ability to generate heat and hot water.

Microturbine Concerns[340]

Microturbine long-term reliability and operating costs are not yet confirmed. They also have lower efficiencies than reciprocating engines and other types of turbines, by as much as 55 percent. Microturbines are more sensitive to siloxane contamination, so LFG needs more pretreatment measures to be used in a microturbine than in conventional engines.

For More Information on Microturbines

☐ EERE Distributed Energy Program Web Page : General information on microturbines. www.eere.energy.gov/de/microturbines/

☐ *“Powering Microturbines with Landfill Gas” (*EPA, LMOP): LFG-powered microturbine factsheet. www.epa.gov/lmop/res/pdf/pwrng_mcrtrbns.pdf

□ *The California Energy Commission's Distributed Energy Resource Guide*: More information on performance, costs, strengths and weaknesses, and vendors of electricity generation equipment. www.energy.ca.gov/distgen/equipment/equipment.html

Boilers and Steam Engines

Boilers and steam engines may use landfill gas, biogas, or syngas to produce electricity. They are often most applicable for projects that can produce enough fuel for more than 10 MW of power. Since the steam cycle power plant emit lower air emissions than either reciprocating engines or combustion turbines, steam cycles have been preferred in regions with stringent air quality regulations, even when the size of the plant was relatively small.[341] While landfills usually produce less than 10 MW, more than 60 organizations in the U.S. are operating their boilers with LFG.[342] The steam cycle is at an economic disadvantage when compared to reciprocating engines and combustion turbines although the steam cycle power plant becomes more cost competitive as the size of the plant increases.[343] Net heat rates for the steam cycle are in the range of 11,000 BTU per kWh to 16,500 BTU per kWh. Steam cycles with higher temperature (1,000˚F) and pressure (1,350 psig), air preheaters, and up to five stages of feedwater heating, increase efficiency. The least efficient units operate at low temperature (650˚F) and pressure (750 psig), and are not equipped with air preheaters or feedwater heaters.[344]

See LMOP's factsheet, "Adapting Boilers to Utilize Landfill Gas" for more information (www.epa.gov/lmop/res/pdf/boilers.pdf).

Fuel Cells

Similar to a battery, fuel cells create electricity through the process of an electro-chemical reaction. This clean technology's byproducts are water and heat. The applicability of fuel cell use for is not widely established for landfill gas, biogas, and syngas. See the California Energy Commission website on fuel cells for more information: www.energy.ca.gov/distgen/equipment/fuel_cells/fuel_cells.html.

APPENDIX VI: ANAEROBIC DIGESTION

PRELIMINARY EVALUATION CHECKLIST FOR MANURE FEEDSTOCK

Checklist to Assess Digester Potential[345]

1. Facility Characteristics

a. Do you have at least 500 cows/steer or 2,000 pigs at your facility? Yes ☐ No ☐

b. Are the animals confined year-round? Yes ☐ No ☐

c. Is the animal population stable (varies less than 20% in a year)? Yes ☐ No ☐

If the answer is YES to all the above questions, your facility is in good shape. Proceed to the next section. If the answer is NO to one or more of the above questions, the production and utilization of biogas as a fuel may not be suitable for your facility. For biogas production and utilization to succeed, a continuous and relatively consistent flow of biogas is required.

2. Manure Management

a. Is manure collected as a liquid (solids less than 4%), a slurry (solids less than 10%), or a semi-solid (solids less than 20%)? Yes ☐ No ☐

b. Is the manure collected and delivered to one common point? Yes ☐ No ☐

c. Is manure collected daily or every other day? Yes ☐ No ☐

d. Is the manure relatively free of clumps of bedding, rocks, stones, and straw? Yes ☐ No ☐

If the answers are YES to all the above questions, manure management criterion is satisfied. If the answer is NO to any of the questions, you may need to change your manure management routine.

3. Energy Use

a. Are there on-site uses for the energy recovered such as for heating, electricity, or refrigeration? Yes ☐ No ☐

b. Are there nearby facilities that could use the biogas? Yes ☐ No ☐

c. Are there electric utilities in your area that are willing to buy power from biogas projects? Yes ☐ No ☐

If the answer is YES to any of the above questions, the energy use criterion is satisfied for initial screening purposes.

4. Management

a. Is there a person available on the farm who can operate and maintain the technical equipment? Yes ☐ No ☐

b. If YES, can this person spend about 30 minutes a day to manage the system and 1-10 hours on occasional repair and maintenance? Yes ☐ No ☐

c. Will this person be available to make repairs during high labor use events at the farm? Yes ☐ No ☐

d. Is technical support (access to repair parts and services) available? Yes ☐ No ☐

e. Will the owner be overseeing system operations? Yes ☐ No ☐

If the answers are YES to all questions, there are promising options for gas recovery. Review the AgStar Handbook Chapter 3 (www.epa.gov/agstar/pdf/handbook/chapter3.pdf) to determine technical and economic feasibility of the project. If the answer was NO to any of the questions, you may need to make some changes. Evaluate the cost of the required changes before proceeding.

CALCULATING ENERGY POTENTIAL IN DAIRY MANURE[346]

How Much Power Can be Generated from 1,000 Dairy Cows?

Step 1: How much biogas can be produced from a farm with 1,000 dairy cows?

Assumptions:

- One dairy cow weighing 1,000 pounds generates 10 pounds (dry weight) of volatile solids (VS) per day (Source: American Society of Agricultural Engineering Standard).
- 60% of VS can be degraded during anaerobic digestion process.
- 12 ft^3 of biogas can be generated per pound of VS destroyed.

Volume of biogas produced daily:

$$\begin{aligned} &= 1{,}000\,cows \times 10\,\frac{lbs(VS)}{cow-day} \times 60\%\,\frac{lb(VS)destroyed}{lb(VS)} \times 12\,\frac{ft^3 biogas}{lb(VS)destroyed} \\ &= 72{,}000\,ft^3 biogas/day \end{aligned}$$

Step 2: What is the BTU content for the biogas produced from a farm with 1,000 cows?

Assumptions:

- Methane content in biogas is about 50%.
- Energy content of methane is 1,000 Btu/ft^3

BTU content of the biogas produced:

$$\begin{aligned} &= 72{,}000\,\frac{ft^3 biogas}{day} \times 50\%\,\frac{ft^3 methane}{ft^3 biogas} \times 1{,}000\,\frac{BTU}{ft^3 methane} \\ &= 36{,}000{,}000\,BTU/day \end{aligned}$$

Step 3: How much power can be generated using the biogas produced from a farm with 1,000 cows?

Assumption:

- The efficiency of a biogas fueled engine is 24% (Engine-driven generator has a heat rate of ~14,000 BTU/kWh)

Power production from 1,000 cows:

$$\begin{aligned} &= 36{,}000{,}000\,\frac{BTU}{day} \times \frac{1kWh}{14{,}000BTU} \times \frac{1day}{24hours} \\ &= 107kW \end{aligned}$$

Step 4: What is the estimated capital cost to install an anaerobic digestion to electricity system for a farm with 1,000 cows?

Assumption:

- The capital cost for an anaerobic digestion to electricity system is: $2,500 per kW. Note: Does not account for economies of scale.

Total estimated capital cost to build an anaerobic digestion system for a farm with 1,000 cows:

$$\begin{aligned} &= 107kW \times \frac{\$2{,}500}{kW} \\ &= \$267{,}500 \end{aligned}$$

DIGESTER BIOLOGY

Anaerobic digesters produce methane from anaerobic bacteria breaking down organic material. Methane production in a digester is a three stage process (Fig. 61). First, bacteria decompose the organic matter into molecules such as sugar. Second, another group of bacteria convert the decomposed matter to organic acids. Finally, the acids are converted to methane gas by methane-forming bacteria.[347]

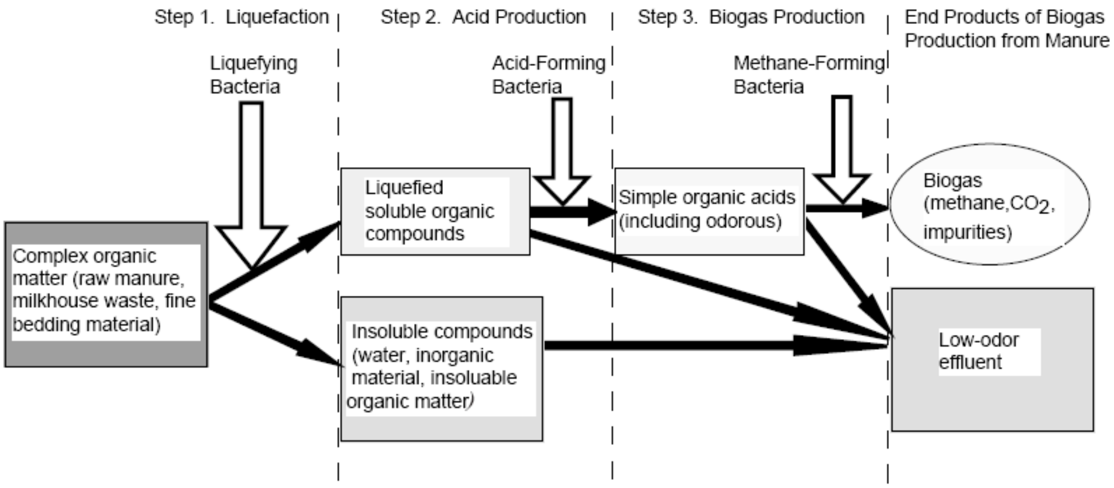


Figure 61 Stages of biogas production. Courtesy Penn State University[348]

Temperature is one of the most important factors in determining the rate of digestion and biogas production.[349] Anaerobic bacteria communities thrive best at temperatures of about 98°F (36.7°C) (mesophilic) and 130°F (54.4°C) (thermophilic).[350] Decomposition and biogas production occur faster in thermophilic conditions than in the mesophilic range. However, thermophilic bacteria are highly sensitive to disturbances, such as changes in feed materials or temperature. Mesophilic bacteria are less sensitive but the digester must be larger to accommodate for the longer HRT. Also, while all anaerobic digesters reduce the viability of weed seeds and pathogens, the higher temperatures of thermophilic conditions result in more complete destruction.[351] In most areas of the United States, anaerobic digesters usually require some level of insulation and/or heating if outdoor temperatures are too low. Digesters can be heated by circulating the coolant from the biogas-powered engines in or around the digester.

Other digestion rate and biogas production factors:

> pH: Optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7.[352] In most digesters, the pH is self-regulating. Bicarbonate of soda can be added to the digester to maintain a consistent pH.[353]
>
> Carbon-to-nitrogen (C:N) ratio: A C:N ratio ranging from 20:1 to 30:1 is considered optimum for anaerobic digestion. Organic materials with high C:N ratio could be mixed with those with a low C:N ratio to bring the average ratio of the influent to a desirable level (Table 11).[354]

Other factors that affect the rate and amount of biogas output include the liquid to solid ratio, mixing of the influent material, the particle size of the feedstock, and retention time. Pre-sizing and mixing of the feed material for a uniform consistency allows the bacteria to work more quickly. It may be necessary to add water to the feed material if it is too dry or if the nitrogen content is very high. Occasional mixing of the material inside the digester can aid the digestion process. Be aware that antibiotics in livestock feed may kill the anaerobic bacteria in digesters.[356]

Table 11 Carbon to Nitrogen Ratio of Various Organic Materials[355]

Organic Material	C:N Ratio
Cow manure	24:1
Swine manure	18:1
Chicken manure	10:1
Duck manure	8:1
Goat manure	12:1
Sheep manure	19:1
Straw (maize)	60:1
Straw (rice)	70:1
Straw (wheat)	90:1
Sawdust	>200:1

SLUDGE OR EFFLUENT

The digested organic material from an anaerobic digester is called sludge or effluent. It is rich in nutrients such as ammonia, phosphorus, potassium, and more than a dozen other trace elements.[357] Biomass digestion can also help reduce pathogens. For wastewater treatment sewage, operating digesters at mesophilic temperatures around 98-99˚F for 15 days results in 0.5-4.0 log reduction in fecal coliform, 0.5-2.0 log reduction in enteric viruses, and about 0.5 log reduction in protozoa and helminth ova. Operating digesters at thermophilic temperatures may reduce pathogens to non-detectable levels, depending on the solids-content and HRT (see 40 CFR 503.32(a) for calculations).[358] The digester sludge can then be used as a soil conditioner. Effluent has also been used as a livestock feed additive when dried. Be aware that toxic compounds (e.g., pesticides) that are in the digester feedstock material may become concentrated in the effluent. Therefore, it is important to test the effluent before using it on a large scale.[359]

APPENDIX VII: BIOMASS GASIFICATION

HOW DOES GASIFICATION WORK?[360]

The gasification process includes: (a) pre-treating the feedstock; (b) feeding it into the gasifier; (c) treating the generated syngas; (d) use of the syngas to produce electricity and heat; and (e) proper disposal of other byproducts. Inside the gasifier itself, biomass is added in either a dry form or mixed with water. The feedstock then reacts with steam and air or oxygen (O_2) at high temperatures (up to 2,600ºF) and pressure (up to 1,000 psig). To heat the gasifier, the char byproduct of gasification may be combusted.[361] The feedstock undergoes three thermal and chemical processes within the gasifier. There are a few types of gasifiers (updraft, downdraft, bubbling fluidized bed, circulating fluidized bed) but the following processes occur in each type:

1. *Pyrolysis*

   Pyrolysis is a chemical breakdown of complex compounds due to heat. It occurs as the organic matter heats up. Volatile substances such as tar, H_2, and CH_4 are released and a combustible residue resembling charcoal, called char, is produced.

2. *Oxidation*

   Then, volatile products and some char are burned in a controlled manner to form CO_2 and CO in a process called oxidation.

3. *Reduction*

   Last, in the reduction stage, the char reacts with the CO_2 and steam to produce CO and H_2, with some CH_4, which together make up syngas. The high temperature in the gasifier converts the inorganic materials left behind by gasification and fuses them into a glassy material, generally referred to as slag. The slag has the consistency of coarse sand. It is chemically inert and may have a variety of uses in the construction and building industries.

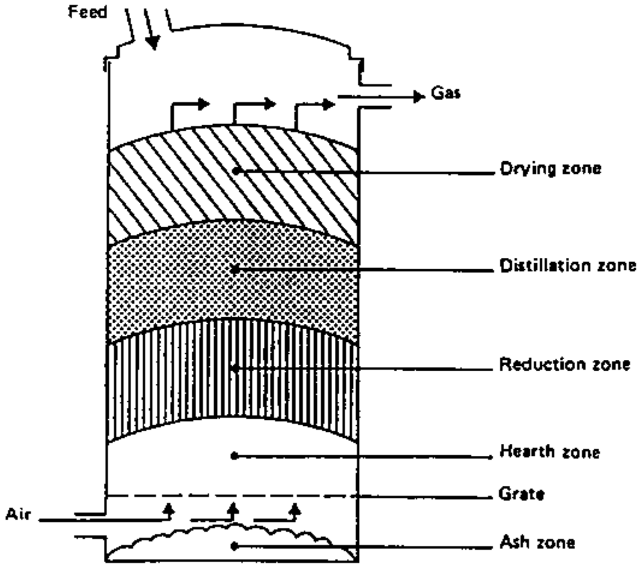


Figure 62 Updraft gasifier.
Image courtesy United Nations[362]

TYPES OF GASIFIERS[363]

Updraft Gasifier

The updraft gasifier is the oldest and simplest type of gasifier (Fig. 62). It is also known as counter-current or counter-flow gasification. Biomass is introduced at the top of the gasifier while air intake is at the bottom. Syngas leaves at the top of the gasifier.

Advantages:

- Proven technology, low cost process.
- Able to handle high moisture biomass and high inorganic content (e.g., municipal solid waste).
- Low gas exit temperatures and high equipment efficiency.

Disadvantages:

- Syngas contains 10-20 percent tar by weight, requiring extensive syngas cleanup before engine, turbine, or synthesis applications.

Downdraft Gasifier

The downdraft gasifier is also known as cocurrent-flow gasification (Fig. 63). Like the updraft gasifier, biomass is introduced at the top but in this case air is introduced at or above the oxidation zone in the gasifier. The syngas is removed from the bottom. The high-temperature syngas exiting the reactor requires a secondary heat recovery system.

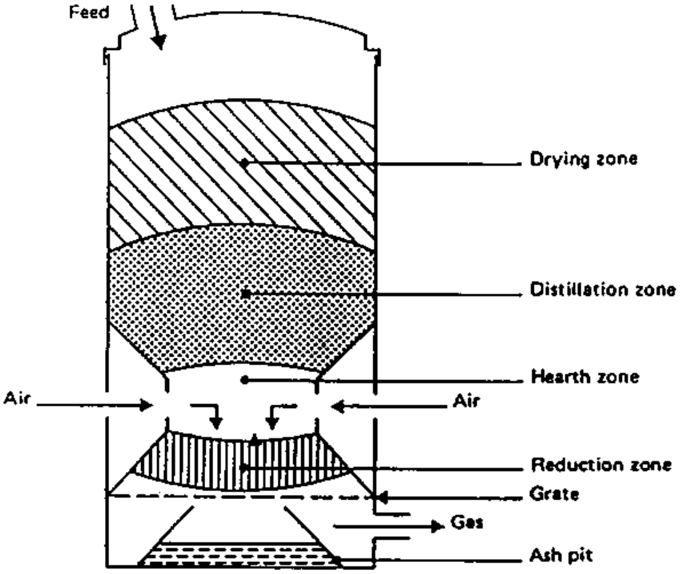


Figure 63 Downdraft gasifier.
Image courtesy United Nations[364]

Advantages:

- Proven technology, low cost process.
- Up to 99.9 percent of tar is broken down.
- Lower level of organic components in the condensate, less environmental objections than updraft gasifiers.

Disadvantages:

- Requires low moisture content feedstock (<20 percent) which necessitates a dryer.
- 4-7 percent of the carbon remains unconverted.
- Low density feedstock materials may cause flow problems and excessive pressure drop and the fuel may require pelletizing before use.
- May suffer from the problems associated with high ash content fuels (slagging) to a larger extent than updraft gasifier.

- The necessity to maintain uniform high temperatures over a given cross-sectional area makes it impractical to use downdraught gasifiers in a power range above about 350 kW.

Fluidized Bed Gasifier

In a fluidized bed gasifier, air, oxygen, or steam is blown through a bed of solid particles, such as sand or alumina, at a sufficient velocity to keep them in a state of suspension (Fig. 64). The "fluidized" particles can quickly break up and heat the biomass.

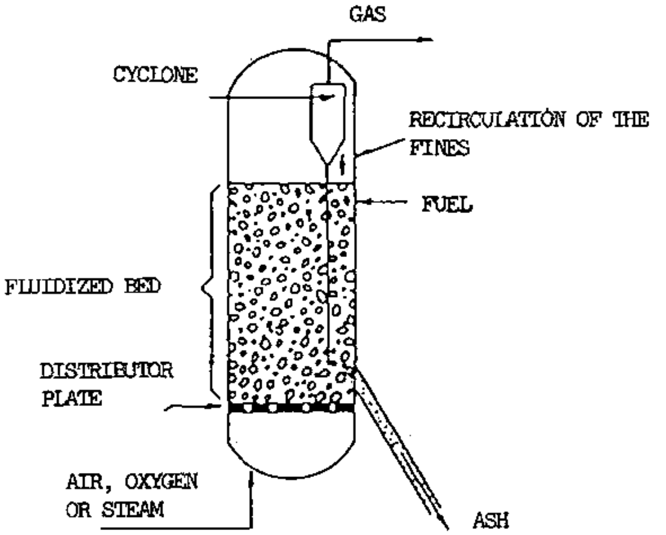


Figure 64 Fluidized bed gasifier. Image courtesy United Nations[365]

Advantages:

- Feedstock flexibility due to easy control of temperature.
- Can handle low density, fine grained feedstock (e.g., sawdust) without pre-processing.
- Yields uniform product gas.
- Suitable for rapid reactions.

Disadvantages:

- Poor response to load changes.

APPENDIX VIII: CLEANER DIESEL

VERIFIED TECHNOLOGIES

Use Table 12 to help evaluate which verified retrofit technologies are compatible with your off-road engines. Go to EPA's Verified Technologies List (www.epa.gov/otaq/retrofit/verif-list.htm) and CARB's Verified Diesel Emission Control Strategies List (www.arb.ca.gov/diesel/verdev/vt/cvt.htm) for technologies for on-road engines and stationary engines (e.g., electricity generators).

The EPA's Diesel Retrofit Program signed a memorandum of agreement (MOA) with CARB for the Coordination and Reciprocity in Diesel Retrofit Device Verification. The MOA establishes reciprocity in verifications of hardware or device-based retrofits, and further reinforces EPA's and CARB's commitment to cooperate on the evaluation of retrofit technologies.

Acronyms
*DPF: Diesel particulate filter
*DOC: Diesel oxidation catalyst
*EGR: Exhaust gas recirculation
*LSD: Low sulfur diesel. Diesel fuel with less than 500 ppm sulfur content.
*ULSD: Ultra-low-sulfur diesel. Diesel fuel with less than 15 ppm sulfur content.

Table 12 Non-Road Verified Retrofit Technology Options

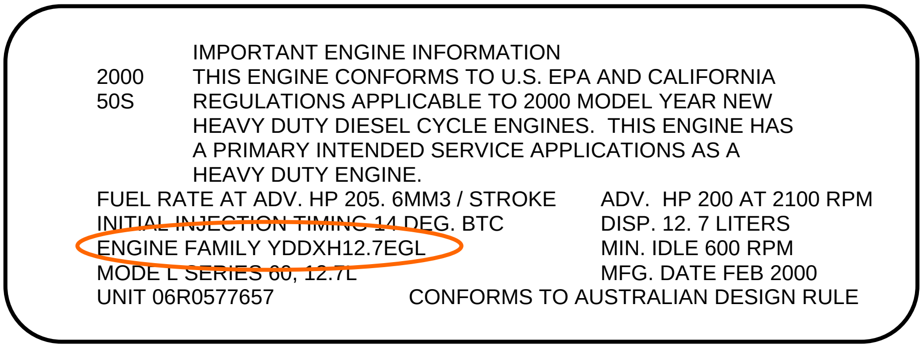
Verified Technology for NON-ROAD Engines	Minimum Engine Requirements	Potentially Applicable Engines
Caterpillar Inc. Passive DPF www.cat.com EPA verified http://www.epa.gov/otaq/retrofit/techlist-cat.htm#dpf	Model year 1996-2005 Turbocharged 130 kW-225 kW Exhaust temperature of 260˚C for 40% of the cycle for NO_x:PM ratios of less than or equal to 20:1 and for NO_x:PM ratios equal to or greater than 25:1, only 200˚C for 40% of the cycle is required Fueled with LSD Complete requirements: http://www.epa.gov/otaq/retrofit/documents/verif-letter-cat2.pdf	Any engine that meets "Engine Requirements"
Engine Control Systems Combifilter Active DPF http://enginecontrolsystems.com CARB verified http://www.arb.ca.gov/diesel/verdev/level3/level3.htm	Model year 2007 or older Engine displacement ≤12 liters Must be able to return to regeneration panel after 8-10 hours of operation Fueled with LSD Complete requirements: http://www.arb.ca.gov/diesel/verdev/level3/eo_de04012_01.pdf	Must NOT belong to engine families found at http://www.arb.ca.gov/diesel/verdev/level3/ef_eode04012_01.pdf

HUSS Umwelttechnik GmbH FS-MK Series Active DPF http://www.huss-umwelt.com/en/ CARB verified http://www.arb.ca.gov/diesel/verdev/level1/level1.htm	Model year 2006 or older Complete Requirements: http://www.arb.ca.gov/diesel/verdev/level3/eo_de06007_01.pdf	Must NOT belong to engine families found at http://www.arb.ca.gov/diesel/verdev/level3/ef_de06007_01.pdf
Paceco Corporation Mitsui Engineering and Shipbuilding DPF Passive DPF http://www.pacecocorp.com/ CARB verified http://www.arb.ca.gov/diesel/verdev/level1/level1.htm	Must be a rubber-tired gantry crane 225 kW - 450 kW Achieves exhaust temperature of 250˚C or greater at least 50% of the time. Maximum consecutive minutes operating below passive regeneration temperature: 120 mins Max exhaust temp: 550˚C Fueled with ULSD or ≤B20 Complete Requirements: http://www.arb.ca.gov/diesel/verdev/ltrs/pacecomesdpfeo.pdf	Any engine that meets “Engine Requirements”
Donaldson DCM DOC DOC http://www.donaldson.com/en/index.html CARB verified http://www.arb.ca.gov/diesel/verdev/level1/level1.htm	Yard tractor, large lift trucks, top picks, side picks or gantry crane Model year 1996-2003 150 hp-600 hp Complete Requirements: http://www.arb.ca.gov/diesel/verdev/eodonaldsondoc88_90.pdf	Manufactured by the following companies AND listed in attachment below: Case Corporation Caterpillar Cummins Detroit Diesel Komatsu http://www.arb.ca.gov/diesel/verdev/level1/ef_donaldson_offroad.pdf
Engine Control Systems AZ Purifier and AZ Purimuffler DOC http://enginecontrolsystems.com/home.aspx CARB verified http://www.arb.ca.gov/diesel/verdev/level1/level1.htm	Port, railway, or other intermodal/freight handling applications Model year 1996-2002 Tolerate 20% reduced peak engine power No optical/conductive fuel sensors nor water absorbing fuel filters Must not use Bosch fuel pump VP30 nor VP44 Certified at PM emissions between 0.01 g/bhp-hr and 0.4 g/bhp-hr Fueled with ULSD Complete Requirements: http://www.arb.ca.gov/diesel/verdev/ltrs/azpurifieandpurimuffleeo.pdf	Manufactured by the following companies AND listed in attachment below: Case Cummins Navistar Komatsu http://www.arb.ca.gov/diesel/verdev/ltrs/purifilterenginefamilies.pdf
Extengine Inc. Advanced Diesel Emission Control	Rubber tired excavators, loaders, dozers, or utility tractor rigs Model year 1991-1995	Must be manufactured by Cummins

System DOC and SCR www.extengine.com CARB verified http://www.arb.ca.gov/diesel/verdev/level1/level1.htm	5.9 liter 150 hp-200 hp Duty cycle w/average exhaust >180˚C for at least 55% of operating cycle Turbocharged Mechanically controlled Requires pressurized anhydrous ammonia Fueled with LSD May incur 1% fuel economy loss Complete Requirements: http://www.arb.ca.gov/diesel/verdev/eode05001.pdf	

ENGINE FAMILY NAME

The engine family name is an alphanumerical code designated to engines by the EPA. It identifies engines by make, year, displacement, and emissions characteristics. It is important to get the engine family name for each engine as well as the individual specifications to facilitate the process of finding the appropriate retrofit device. EPA and CARB verify retrofit technologies for certain engines and other requirements, such as minimum engine temperature. The engine family name can be found on a sticker on the engine itself (Fig. 65). If this code cannot be found, retrofit technology dealers may be able to determine the family name from the other engine information provided. Off-road engines manufactured before 1996 typically do not have an engine family name.



IMPORTANT ENGINE INFORMATION
2000 THIS ENGINE CONFORMS TO U.S. EPA AND CALIFORNIA
50S REGULATIONS APPLICABLE TO 2000 MODEL YEAR NEW
HEAVY DUTY DIESEL CYCLE ENGINES. THIS ENGINE HAS
A PRIMARY INTENDED SERVICE APPLICATIONS AS A
HEAVY DUTY ENGINE.
FUEL RATE AT ADV. HP 205. 6MM3 / STROKE   ADV. HP 200 AT 2100 RPM
INITIAL INJECTION TIMING 14 DEG. BTC   DISP. 12. 7 LITERS
ENGINE FAMILY YDDXH12.7EGL   MIN. IDLE 600 RPM
MODE L SERIES 60, 12.7L   MFG. DATE FEB 2000
UNIT 06R0577657   CONFORMS TO AUSTRALIAN DESIGN RULE

Figure 65 Sample engine emissions label with engine family name.[366]

ESTIMATING EMISSIONS FROM ON-ROAD TRANSPORT TRUCKS

Use the equations in Box 12 for a general estimate of NO_x, CO, and PM emissions from transport trucks to determine the approximate baseline emissions without pollution reduction measures.

Assumptions:

- Gas mileage of 6 miles per gallon
- Steady state operation of the trucks on interstate type roads

- Urban highway heavy-duty truck emission factors cited from *Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level: Final Report*, April 2005 by the DOT, Federal Highway Administration.

Box 12 Estimating on-road trucking emissions

Miles per Round Trip		Number of Trips		Emissions per Mile (g)		Total Emissions	
[ ]	x	[ ]	x	25.65	=	[ ]	Grams NO_x
[ ]	x	[ ]	x	2.48	=	[ ]	Grams CO
[ ]	x	[ ]	x	0.37	=	[ ]	Grams PM

APPENDIX IX: REGION 9 SUPERFUND ELECTRICITY AND DIESEL EMISSIONS INVENTORY

Superfund Electricity and Diesel Emissions Inventory
US EPA Region 9
Superfund

Prepared by:
Ashley DeBoard MacKenzie
Environmental Protection Agency GRO Fellow

August 16, 2007

Background and Goals

The Cleanup-Clean Air (CCA) initiative is a regional pilot program in US EPA Region 9. It is demonstrating the feasibility of using cleaner diesel vehicles and reducing greenhouse gases (GHG) in Superfund and developing tools to make it easier to do in the future. CCA is focused on encouraging, facilitating and supporting implementation of diesel emissions and greenhouse gas reductions technologies and practices at Superfund cleanup and redevelopment sites. Furthermore, the initiative strives to measure and reduce Superfund's environmental footprint, reduce exposure to Superfund communities, save energy costs in the long term, and serve as role model for other programs.

There were two specific goals set forth for this project within Cleanup-Clean Air. First, the project was designed to attain a rough estimate of the emissions footprint associated with remediation activities at Superfund National Priorities List (NPL) sites in Region 9. The second goal was to establish a baseline of electricity and diesel emissions to which any future measurable changes can be compared. Emissions associated with diesel equipment use and electricity production evaluated in this study include Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), and particulate matter (PM). However, other pollutants such as Sulfur Dioxide (SO_2) and Polycyclic Aromatic Hydrocarbons (PAHs) are also present in diesel exhaust and combustion of fossil fuels for electricity production. Some of the associated health effects are listed below (EPA 2007a).

CO_2 : High concentrations of this greenhouse gas (GHG) are most significantly linked to global climate change.

PM: 90% of PM is $PM_{2.5}$. Exposure is linked to premature mortality, chronic bronchitis, chronic obstructive pulmonary disease (COPD), asthma aggravation, pneumonia, and heart attacks.

NO_x : Is a precursor causing ground level ozone (smog) through a series of atmospheric chemical changes. It contributes to global warming, acid rain, low visibility, deteriorated water quality, and a myriad of respiratory problems.

CO: Exposure affects human health in several ways. Depending on the concentration, CO can cause fatigue, flu-like symptoms, loss of brain function and even fatality. It affects the ability of blood to absorb oxygen. CO is also oxidized to form CO_2 in the atmosphere.

SO_2: Contributes to and aggravates respiratory illnesses; contributes to formation of acid rain; and it forms atmospheric particles that refract light and decrease visibility.

PAHs: Are highly carcinogenic compounds such as benzene and formaldehyde that are found in diesel emissions.

Methods

Information collected centered on construction activities (past, present, and projected future); specifications of treatment systems; past fuel and electricity use, and types of diesel equipment used for remediation activities (models and hours operating). Surveys were developed and distributed to Remedial Project Managers (RPMs) in two branches (Federal Facilities Branch and Site Cleanup Branch) of EPA Region 9's Superfund division. Data were collected through use of the surveys and personal meetings with each RPM, review of their associated site design documents, and contact with their contractors. *See Appendix E.*

The response rate for the surveys was roughly 50%, and therefore, emissions were only estimated for the sites that had completed surveys. Limited detail of information available for past remediation activities necessitated a method for creating rough estimates of emissions for sites with the incomplete information. Extrapolations and assumptions from the data were made and recorded, and consistent methods were applied across the data set when not otherwise specified. Assumptions involving site conditions, remedy design, construction and operations were made when the records were not available. A professional cost estimator from the Army Corps of Engineers was used to provide industry averages of typical equipment and associated operating times based upon the size and scope of the standard projects. *See Appendices A for a list of emissions assumptions regarding diesel and electricity, B for a list of assumptions that estimate equipment use for construction activities, and Appendix C for list of assumptions that encompass emissions estimates for diesel barges.*

To calculate the total mass of pollutants emitted (in grams), the following formula was used:

Pollutants Emitted = **hours x horsepower x EF (g/bhp-hr)**

where,

Hours: Hours were determined by assuming the amount of time each piece of equipment operated
Horsepower (hp): Assumed to be an average of 330 hp for all pieces of equipment unless otherwise specified. 330 hp represents a midsized piece of equipment and should even out with larger and smaller pieces of equipment used at each site.
Emissions Factors (EF): Were provided by Sacramento Air Resources Board for each standard assumed piece of equipment that was used in their emissions inventory model, ***Road Construction Modeler.Ver5.2.xls*** **(Christensen 2007)**. Units are measured in grams/brake-horsepower-hour (g/bhp-hr). EFs are also equipment specific (grader, off-highway truck, excavator, etc), model year specific, and operating year specific.

This formula was applied to each piece of equipment for individual construction activities conducted on sites, and the total grams for each individual pollutant (NO_x, CO, and PM) were aggregated and converted to tons. When unavailable, a model year was assumed for each piece of equipment to attain the EF. This was done by using the median use life of an equipment piece and subtracting it from the year construction commenced. (S*ee Appendix D*). It was also assumed that for the general estimating purposes of this project, bhp-hr and hp-hr were equal.

There were also certain construction activities that were omitted because there were no EFs available or because the information gaps in records regarding scale of projects made estimations impossible. Future projections, beyond 2009, were also estimated for known projected remediation activities.

Estimations of emissions associated with electricity consumption were conducted by gathering records of actual yearly kWh averages consumed at remediation sites. For sites without available electricity records, specifications of treatment systems were gathered that summarized the treatment facility type, number of extraction wells, flow rates, and dates of operation. These specifications were then inputted into the independent cost estimation software, Remedial Action Cost Engineering and Requirements (RACER), version 2006, developed by Earth Tech, Inc. and the Army Corps of Engineers (Earth Tech 2006.) Several assumptions about system conditions were made that are listed in *Appendix A.* This software provided an estimated amount of kWh needed to operate each specific treatment facility. Electricity amounts from both site records and RACER estimates were combined to get a total kWh consumed over time (1990-2009) for each site. Future projections were also established based on known treatment systems that will be operational for decades beyond 2009. EPA's database Emissions and Generation Resource Integrated Database (eGRID), released April 2007, was used to estimate tons of CO_2 associated with electricity production from the utility companies in the area (EPA 2007b). The database provided an average, "statewide" factor that was multiplied by kWh to attain CO_2 emissions.

Results

See Appendix F for Results Tables and Charts

Results pictured for emissions from both diesel exhaust and electricity production are approximately 50% of all Region 9 NPL sites surveyed. Although this information is not complete, data may be collected from the remaining sites in the future. Until that time, results for the whole region can be roughly estimated by multiplying these results by a factor of 2 and noting the assumption.

Total diesel emissions from 1985-2009 were estimated to be 3,140 tons NO_x, 848 tons CO, and 105 tons PM. The highest period of NO_x output was from 2000-2004 with 1,339 tons. The highest period of CO output was 1995-1999 with 268 tons. Lastly, the highest period for PM output was 2000-2004 with 38 tons. The lowest period of output for all pollutants was 1985-1989 with 186, 93, and 11 tons for NO_x, CO and PM respectively. It should be noted however, that although PM output was significantly lower in mass, the microscopic properties of the particles make this pollutant especially dangerous to human health by bypassing the body's natural defenses, such as cilia in the lungs.

Total CO_2 emissions associated with electricity consumption from 1990-2009 for Region 9 sites were estimated to be 428,174 tons. This is the equivalent of 84,000 cars on the road for one year or powering about 50,000 single family homes for one year. Future projections based only on known treatment facilities on grid as of 2007, Superfund is expected to use an additional 113.2 million kWh per year, equating to about 44,600 tons of CO_2. This would be equivalent to adding an additional 8700 cars or 5100 homes per year projected out for decades. (EPA 2005)

Discussion

As stated previously, the level of detail sought for emissions estimates was not always available from the RPMs when completing the surveys. This is because much of the information was tracked on a sub-contractor level, far from RPM involvement. It was especially difficult to obtain complete, detailed information of site remediation from the past, as many records were not preserved at a level regarding detail of fuel and electricity consumption or equipment associated with construction activities.

It is recommended that this information be tracked in the future. If specific information associated with emissions (i.e., gallons used, type of equipment used, and kWh consumed) is tracked throughout the life of the remediation activities, it is much easier to estimate the GHG emissions associated with each activity. Furthermore, the information gathered in this study, combined with detailed future tracking may help to normalize our data. In the future, it could be taken to the next step by putting it into a form that can be applied to all activities. For example, to achieve a baseline at any given point, we could calculate the emissions for each pound of contaminant removed during remediation.

The initial steps of tracking this information for Region 9 have already begun through inputting conditions into contract language. Regions 9 and 10 now have Emergency and Rapid Response contracts, and Region 9 is soon to have Remedial Action contracts in place that are or will soon require contractors to track use of cleaner diesel equipment, energy efficiencies, and renewable energy to power remediation on sites.

It is important to note that although results for diesel emissions are pictured within 5 year periods over the course of 25 years, the data is really a historical snapshot of past emissions rather than a trend. This is because the diesel work takes significantly less time in relation to electricity use for remediation. Generally, using heavy diesel equipment to complete construction activities on-site is accomplished on the time scale of several months to several years. In contrast, remediation that is tied into the electricity “grid” is conducted for decades or longer. It still may have fluctuations resulting from commencement or termination of treatment systems, but it is expected that these treatment facilities remain more stable in their electricity use and consequently the associated emissions. Therefore, fluctuations in diesel use over time may be a reflection of the phase of remediation at the Superfund site rather than a trend-like increase or decrease.

This emissions inventory also has applications beyond regional remediation. The process for collecting this data as well as the picture of our emissions footprint will help to inform larger Office of Solid Waste and Emergency Response (OSWER) efforts to estimate emissions across all regions. Furthermore, this data can likely be applied to EPA’s COBRA model to quantify health care costs (in dollar amounts) associated with human health exposure to pollutants resulting from remediation activities.

We have quantified measurable adverse impacts to air quality resulting from remediation activities. While the estimates are rough, they provide an idea of our emissions footprint and clarified the need to track this information in the future for more accurate emissions inventories.

Possible mitigation of these impacts to air quality includes the use of cleaner diesel equipment, energy efficiencies, and renewable energy technologies. The Smart Energy Resource Guide (SERG) is currently being developed as a “one stop shop” tool for RPMs to implement these mitigation techniques and gain insight into reducing their emissions footprint at each of their Superfund sites.

Citations

1. Christensen, Peter. Sacramento Air Resources Board. Emissions Factors for Diesel Construction Equipment. Road Construction Modeler.Ver5.2.xls. Provided August 2007.

2a. Environmental Protection Agency. Air Pollutants. Updated May 2, 2007. http://www.epa.gov/air/airpollutants.html Accessed August 10, 2007.

2b. Environmental Protection Agency. eGRID (Emissions and Generation Resource Integrated Data Base). Released April 2007.

3. Environmental Protection Agency. Global Warming Calculators. “Equivalencies.” Updated June 27, 2005. http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterToolsCalculators.html Accessed August 10, 2007.

4. Earth Tech Inc. RACER (Remedial Action Cost Engineering and Requirements). Version 2006. http://talpart.earthtech.com/RACER.htm

5. McMindes, Daniel. US Army Corps of Engineers. Construction Estimates for Diesel Equipment. Provided July 2007.

Appendix A

List of Assumptions

Diesel Estimates

1. Assumed standard pieces of equipment provided by Army Corps of Engineers. See Appendix B.
2. Assumed 330 horsepower for all pieces of equipment
3. Assumed 1999 EFs for all construction activities using equipment on or before 1999.
4. For all construction after 1999, used EFs that fell closest to the year the EFs were available (1999, 2002, 2005, 2008, and 2010). For example, equipment used in 2001 would use a 2002 emissions factor.
5. For all Heavy Trucks (20 yd, 15 yd, and other hauling trucks), used an Emissions Factor configuration from Sacramento Air Resources Board. EFs were done for 5 year intervals averaging models from 1965 to year of EF. Assumption made to round down to closest 5 year interval from time the truck was used. For example, a truck used in 2002 would have a 2000 EF. These EFs assume 30 mph for all heavy trucks.
6. Assumed water trucks and hydro-seed trucks to be "off-highway". Assumed cement, slurry, 15-yd, and 20-yd trucks to be on-highway trucks.
7. Construction activities not accounted for because of incomplete information: pumping hazardous liquids, helicopter flights, building demolitions, carbon regeneration.

Electricity Estimates

1. RACER assumption for groundwater extraction wells of unconsolidated, sandy-silt soil, 50 ft to top of contamination, and 75 ft to base of contamination.
2. RACER assumptions for contamination levels are 500 ppb influent, 5 ppb effluent.
3. RACER assumptions for GAC treatment systems include dual capacity system for higher flow rate systems (above 200 gpm).
4. Assumed flow rate for each extraction well is equal and adds up to total flow rate of treatment facility.
5. Assumed an average Emissions Factors by state where power production occurred. This factor provided by eGRID.

Appendix B	**Equipment Estimates from Dan McMindes**
CONVERSIONS	
1 acre= 43,560 sf	
1 cy= 27 cubic feet	
1cy=1.35 tons or 1 ton=0.74 cy	
1 US Gallon=0.00495 cy	
Some unit assumptionsunless otherwise specified:**	
Excavation depth to get sf: 2'	
Landfill depth to get sf: 15'	
wells to get lf: 50' depth/well	
Cap: Assume 4 feet fill (2' low perm and 2' veg layer-->add inches that are specified to total volume if under 12" b/c it usually means an additional impermeable layer	
Hauling trucks *nearby import and haul with ~6mi roundtrip for total of 75 mi per day.	

Remediation Activity	**Activity Components**	**Units**	**Units/day**	**Construction Equipment**
Excavation and Backfill	clear and grub	sf	128,000 sf/day	scraper
assumptions	excavation	cy	480cy/day	excavator
no benching	offhaul near site	cy	120cy/day	15 yard truck
easy excavation no rock/boulders	import fill	cy	120cy/day	15 yard truck
small sf to cy ratio	backfill and recompact	cy	480cy/day	roller/sheepsfoot compacter
			with compactor	water truck
	rough grade site	sf	40000 sf/day	scraper/grader
	fine grade site	sf	40000 sf/day	scraper/grader
4 15cy trucks one day 15 minutes per round at approx 30 miles per hour would generate approx 75 miles per day per vehicle	*12 rounds/day holding 10 cy per load assuming 6.25 mi round trip=75 mi/day*			
soil aeration	rip soil 6 inches	sf	10000sf/day	dozer with rippers
8'wide x 1000' long 6 to 12" deep				

Landfill Capping				
use clear and grub above for grading operations	clear and grub	sf	128,000 sf/day	grader/scraper
fill with 2 feet of low perm	rough grade	sf	40000 sf/day	grader/scraper
fill with 2 feet of veg layer	import fill	cy	160cyd/day	20 cyd end dumps
	backfill and recompact	sf	480cy/day	roller/sheepsfoot compacter
			with compactor	water truck
	import fill	cy	160cyd/day	20 cyd end dumps
	backfill and recompact	sf	480cy/day	roller/sheepsfoot compacter
			with compactor	water truck
	fine grade	sf	40000 sf/day	grader/scraper
revegetation	water truck	sf	42000sf/day	
	hydroseed equipment/truck	sf	42000sf/day	
clay capping same as landfill capping				
dewatering same as aeration				
well installation	push type rig	lf	100lf/day	sampling rig
	drill type rig	lf	400 lf/day	hollow stem auger
hauling is the same as import or export				
ust removal is like excavation, but add cy for backfill and add a crane for 4 hours per tank as well as a truck for 4 hours to haul the tank away				
slurry walls under 12 feet deep	excavate and stockpile	lf	100lf per day	backhoe
	add slurry		80cy/dy	slurry truck
	offhaul excess soils	100*12*2/ 27=88.88	120cyd/dy	15 cyd truck
J.H. Baxter--example from Travis Cain	*Construction of a slurry wall (4377'x 2' width, slurry wall depth 50 ft); and 2 bioventing blowers at 500 cf/min;*	*slurry=16211 cy; drilling: 218850 lf;*	*hollow stem auger: 547.1 days; sample rig: 2188.5 days; slurry truck: 202.6 days; 15 cy truck: 135.1 days*	
slurry walls over 12 feet use same effort as drill rigs plus effort for slurry and offhaul above, * *leave out the excavate and stockpile*				

fencing			500lf per day	pickup (ignore this)
assume all bushes and brush and trees gone				backhoe with auger attachment
Pipeline		36" diam-->	300 lf/day	Excavator to dig
		60" diam--> 150 lf/day		Backhoe with sheepsfoot attachment to backfill
				Water truck for same time as backhoe
Dams treat as fill		concrete dam	10 cy/day	concrete truck
		earthen dam	fill (cy to place and compact)	15 yd trucks, sheepsfoot roller, (see excavation)
Sediment ponds are same as excavation				
Removal of drums of Haz Waste		similar to excavation, but double the time it takes to remove.	240 cy/day	excavator 330 hp
			10 barrels per truck	Hauling truck (assume 200 hp)
			20 barrels/day	forklift to put on truck 330 hp
		backfill and recompact	480 cy/day	roller/sheepsfoot compactor 330 hp
			same time	water truck
15cy truck will hold between 8 and 10 cyds depending on density and weight of material. Assumed 10.				
All equipment is assumed to be 330 hp				

Appendix C

Emissions Estimates for Diesel Barges

Puget Sound Maritime Emissions Inventory: Used to estimate emissions from diesel barges when capping sediments.

Horsepower ranges from 40-350 hp, with the average barge engine having 188 hp.
*Assumed 1 engine (propulsion)—some have more than one, auxiliary and propulsion
*Assumed a median use life, since unavailable, to be 7 years (2001 model year).
*Assumed this was a non-road model, not an ocean going vessel (OGV)
*Assumed 130 kW Tier 1 (2001) engine
- Emissions from this engine are 9.8 g/kW-hr NO_x, 1.5 g/kW-hr CO, and 0.4 g/kW-hr for PM.

*Formula is <XX g/kWh x Hours x kW engine>
*Assumed barges hold ½ ton of material for capping per load. Estimated area of cap and volume needed to cover area to determine approximate miles vessel would travel. Then assumed 5 mph to estimate total hours in the water

See Table 4.7, page 273
http://www.maritimeairforum.org/emissions.shtml

Wayne Elson
EPA, Region 10, AWT-107
Office of Air, Waste, and Toxics
1200 6th Avenue
Seattle, WA 98101
206-553-1463 (voice)
206-553-0110 (fax)
elson.wayne@epa.gov
www.westcoastdiesel.org

Appendix D

Median Use Life Provided by Road Construction Modeler

Backhoe: ½ use life= 8 yrs

Bore/Drill Rigs: ½ use life= 2 yrs

Crane: ½ use life= 5 yrs

Dozer: ½ use life= 8 yrs

Dredgers: Not available. Assume 5 yrs

Excavator: ½ use life= 4 yrs

Forklift: ½ use life= 4 yrs

Grader: ½ use life= 5 yrs

Generator: not available. Assume 8 yrs

Loaders: ½ use life= 3 yrs

Off Highway Trucks (Water Truck and Hydro-seed Trucks): ½ use life= 5 yrs

Pumps: ½ use life= assume 5 yrs

Roller: ½ use life= 4 yrs

Appendix E

Site Survey

Site Name:
ID #:
Location (county & state):
RPM:

As part of the Cleanup-Clean Air initiative, the Superfund Program is trying to reduce our emissions footprint at cleanup and redevelopment sites. In order to implement greener cleanup practices, we are first trying to gain insight into our energy use trends (past, present, and future), and corresponding emissions produced. The information you provide is invaluable in ascertaining knowledge we can put forth into further greening our operations in Region 9, so please be as specific as possible. If any information is already filled in for your site, please confirm its accuracy. If any projects are missing on the tabs, please contact Ashley DeBoard (7-4109) immediately so that she can help reformat your workbook. Furthermore, if more OUs are listed for your site than you are responsible for, please answer only for YOUR OUs. For those RPMs who may still be in “Pre RA” phase (see below), feel free to add any info you have available in the “Present RA” questions, regardless if they are rough estimates. Thank you for your time and effort; it is deeply appreciated.

1. What is the Lead type for your site? (Fund, PRP, Federal) If more than one Lead applies to your site, please list who is directing the current phase by OU or area.

2. How many operable units are at this site?

3. What phase is each of the operable units in? Please specify if the stage is planned or complete.
   a. Pre Remedial Action? Circle One (RI/FS, ROD, RD)
   b. Present Remedial Action? (RA, LTRA, O&M)

4. (Pre RA only)
   a. If no ROD, what are the contaminated media, and an approximate size of contamination? *(i.e. yd^3 of soil, volume/dimensions of groundwater plume)* Can you predict a method, or range of methods of remediation?
   b. If plan is in place, what are the estimated energy needs and an approximate length of time the OU will be active? Please give answers concerning energy needs in units of kW hrs/year and gallons of diesel fuel/ appropriate time frame (years, months, weeks).

5. (Present RA) How long will each operable unit be actively remediated?
   a. Diesel: (If applicable) How long will use of a diesel fleet be required to remediate contamination?
   b. Electricity: (If applicable) How long will use of grid power be necessary to maintain remediation operations at site?

6. (Present RA) DIESEL: **(For each OU)**

a. What are the *types* of diesel equipment being used in your fleet?
b. How many of each type are being used?
c. What is the time frame of their use?
d. What was the previous fuel consumption in the life of the RA unit? How has it changed, and over what time periods?
e. What is the amount of current fuel use? (Please specify units) *ex: 1000 gal/month/vehicle or OU*
f. Will the fuel use on the site decrease or increase in the future and when? Please specify how rate of fuel consumption will change over different time periods. *(ex: fuel use will drop from 1000 gal/mo to 500 gal/mo after 10 months, and to 250 gal/mo after 24 months. The project for OU-02 will be complete in 4 years.)*

7. (Present RA) ELECTRICITY: **(For each OU)** ***This info can be obtained from a utility bill.*

a. What is the type of facility/equipment requiring grid power?
b. What is the time frame of its electricity use?
c. What was the previous level of electricity consumption in the life of the RA unit? How has it changed, and over what time periods?
d. What is the amount of current electricity use (kW hrs/year)?
e. Will the energy use on the site be decreased in the future and when? To what level? *(ex: OU-04 will pump and treat groundwater at 400 gal/min for the first 3 yrs, and will decrease then to 150 gal/min for the remaining 10 years, after which the project will be complete. Corresponding kW hrs drop from 1200 to 600/mo during this time)*

8. For previous “specs” questions regarding fuel and electricity use, if questions cannot be answered completely by RPM, may we have permission to discuss such energy needs with your contractor for the site? If so, please list contact information.

9. Are there currently “Green Practices” taking place at your site such as: cleaner equipment (DPFs, DOCs), cleaner fuels (ULSD), alternative fuels (biodiesel), “renewables” (solar, wind), or participation with utility companies to use their green energy options? Please specify.

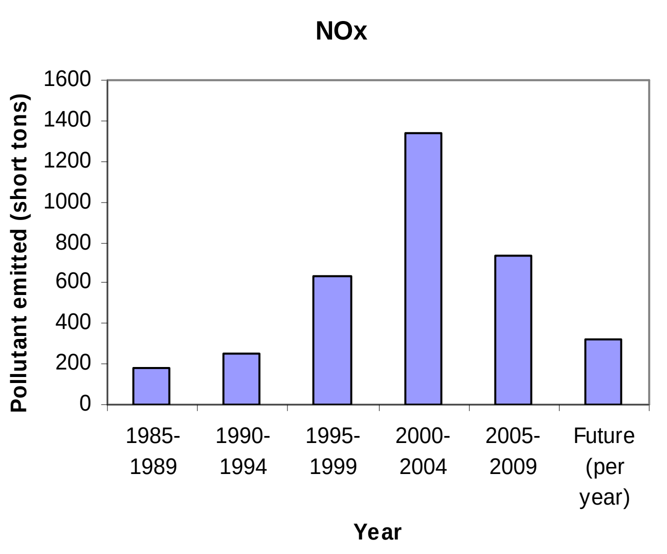
10. Can you list the utility being used at your site for electricity?

Appendix F

Charts and Tables

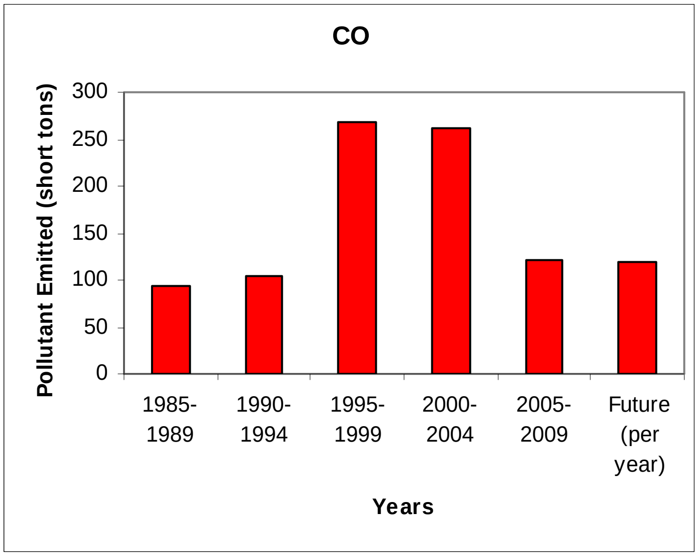
Diesel

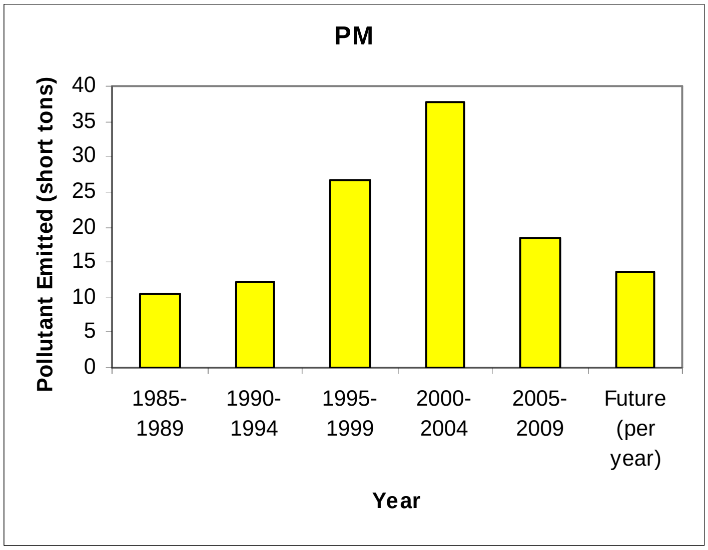
Diesel	Nox(tons)	CO (tons)	PM (tons)
1985-1989	186	93	11
1990-1994	247	104	12
1995-1999	630	268	27
2000-2004	1339	262	38
2005-2009	740	120	18
Future (per year)	325	119	14



Appendix F, (cont.)

Diesel





Appendix F, (cont.)

Electricity

	Total kWH	Total CO2 (tons)	Cars	Homes
1990-1994	73,890,266	36,633	7,193	4,266
1995-2009	176,433,435	83,097	16,317	9,677
2000-2004	262,114,529	115,162	22,613	13,504
2005-2009	481,351,734	193,282	37,953	22,509
Future (per year)	113,177,235	44,611	8,670	5,195

APPENDIX X: UTILITY RATE SCHEDULES

This section provides web addresses to rate schedules for various utilities in Region 9 states and territories. Examine different rate schedules offered by your utility to determine which is optimal for the electricity demands of your site. Also consider demand response rate schedules for remedial activities that do not require a continuous source of power to reduce energy bills. Customers subscribing to this schedule take the risk of utilities shutting off their power during times of peak demand in return for less expensive electricity.

Arizona

Arizona Public Service (APS)

Business: www.aps.com/main/services/business/rates/BusRatePlans_9.html

Residential: www.aps.com/aps_services/residential/rateplans/ResRatePlans_11.html

Salt River Project (SRP)

Business: www.srpnet.com/prices/business/default.aspx

Residential: www.srpnet.com/prices/home/basic.aspx

Tucson Electric Power (TEP)

www.tucsonelectric.com/Business/Programs/pricingplans/tariffs.asp

UniSource Energy Services

http://uesaz.com/Customersvc/PaymentOptions/PricingPlans/tariffs.asp

California

Pacific Gas and Electric Company (PG&E)

http://pge.com/tariffs/ERS.SHTML#ERS

Southern California Edison (SCE)

General Service:

www.sce.com/AboutSCE/Regulatory/tariffbooks/ratespricing/businessrates.htm

Agricultural Pumping:

www.sce.com/AboutSCE/Regulatory/tariffbooks/ratespricing/agriculturerates.htm

San Diego Gas and Electric (SDG&E)

www.sdge.com/regulatory/tariff/current_tariffs.shtml

Commercial and Industrial: www.sdge.com/regulatory/tariff/elec_commercial.shtml

Guam

Guam Power Authority

www.guampowerauthority.com/rates/schedules.html

Nevada

Sierra Pacific Power Company

www.sierrapacific.com/rates/ca/schedules/

Nevada Power Company

www.nevadapower.com/rates/tariffs/schedules/

APPENDIX XI: GREEN PRICING PROGRAMS

Table 13 Utility Green Pricing Programs[367]

State	Utility	Green Pricing Program	Renewable Resource	Price Premiums
AZ	Arizona Public Service	Green Choice Program http://www.aps.com/main/green/choice/choice_7.html	Wind, Geothermal	$1.00 (plus tax) per 100-kWh block in addition to regular bill. Minimum one year commitment.
AZ	Salt River Project	EarthWise www.srpnet.com/environment/earthwise/business.aspx	Solar	$3.00 per 100-kWh block in addition to regular bill.
AZ	Tucson Electric Power Company	GreenWatts www.greenwatts.com/	Solar	$2.00 for 20-kWh, $3.50 for 40-kWh, $5.00 for 60-kWh, $6.50 for 80-kWh, $8.00 for 100-kWh block in addition to regular bill.
AZ	UniSource Energy Services	GreenWatts www.greenwatts.com/	Solar	$2.00 for 20-kWh, $3.50 for 40-kWh, $5.00 for 60-kWh, $6.50 for 80-kWh, $8.00 for 100-kWh block in addition to regular bill.
CA	Anaheim Public Utilities	Green Power www.anaheim.net/utilities/adv_svc_prog/green_power/about_gpower.htm	Various	$1.50 per 100-kWh; $15.00 for 1,000-kWh, $30.00 per 2,000-kWh, or $45.00 per 3,000-kWh block per month. Minimum six month commitment .
CA	Los Angeles Department of Water and Power	Green Power for Green LA www.ladwp.com/ladwp/cms/ladwp000851.jsp	Wind, Landfill Gas	$0.03 per kWh. Minimum 12 month commitment.
CA	PacifiCorp: Pacific Power	Blue Sky www.pacificpower.net/Article/Article35885.html	Wind, Solar, Landfill Gas	$1.95 per 100-kWh increments.
CA	Pacific Gas and Electric (PG&E)	Climate Smart www.pge.com/myhome/environment/whatyoucando/climatesmart/	Forest Conservation, Biomass Projects	$0.0025 per kWh used each month.

CA	Palo Alto Utilities	Palo Alto Green www.cityofpaloalto.org/forms/pagreenenrollment/	Wind, Solar	$0.015 per kWh.
CA	Pasadena Water and Power	Green Power Program www.ci.pasadena.ca.us/waterandpower/greenpower/default.asp	Wind	$25.00 per 1,000-kWh block or All Green Program of $0.025 per kWh used each month.
CA	Roseville Electric	Green Roseville www.roseville.ca.us/electric/green_roseville	Wind, Solar	$0.015 extra per kWh used each month or $15.00 per 1,000-kWh block.
CA	Sacramento Municipal Utility District	Greenergy www.smud.org/community-environment/greenergy/index.html	Wind, Biomass	$0.01 per kWh used each month or $10.00 per 1,000-kWh block (one year commitment for later option).
CA	Silicon Valley Power partnering with 3 Phases	Santa Clara Green Power www.siliconvalleypower.com/green	Solar, Sind	$0.015 per kWh used each month or $15.00 per 1,000-kWh block.
HI	Hawaiian Electric Company, Inc.	Sun Power for Schools www.heco.com/portal/site/heco/menuitem.508576f78baa14340b4c0610c510b1ca/?vgnextoid=b9a85e658e0fc010VgnVCM1000008119fea9RCRD&vgnextchannel=529bf2b154da9010VgnVCM10000053011bacRCRD&vgnextfmt=default&vgnextrefresh=1&level=0&ct=article	Solar	Monthly donation to support PV on Hawaii school buildings.
NV	Nevada Power	Green Power Program www.nevadapower.com/comenv/env/greenpower/	Solar	Monthly tax-deductible donations will be invested in solar education and the construction of solar electric generation facilities at schools in Nevada.

APPENDIX XII: NET METERING PROGRAMS

Net metering programs allow grid-tied utility customers who generate electricity in excess of their consumption at a certain time to “bank” their energy and use it at another time. This is also called net excess generation (NEG). Net metering programs help reduce the payback time for a renewable energy project. Not all utilities offer net metering. The following data on net metering programs were adapted from the Database of State Incentives for Renewables and Efficiency (www.dsireusa.org) and Interstate Renewable Energy Council (http://www.irecusa.org/fileadmin/user_upload/ConnectDocs/NM_table.pdf). Contact the local utility for more information on your local net metering program. For more information, see www.eere.energy.gov/greenpower/markets/netmetering.shtml.

Arizona

Arizona Public Service (APS)

Applicable Sectors: All customers
Applicable Technologies: Solar, Wind, Biomass
Maximum Customer System Size: 100 kW
Maximum enrollment: 15 MW

Any customer NEG will be carried over to the customer's next bill at the utility's retail rate, as a kWh credit. For customers taking service under a time-of-use rate, off-peak generation will be credited against off-peak consumption, and on-peak generation will be credited against on-peak consumption. The customer’s monthly bill is based on the net on-peak kWh and net off-peak kWh amounts. Any monthly customer NEG will be carried over to the customer's next bill as an off-peak or on-peak kWh credit. Any NEG remaining at the customer’s last monthly bill in a calendar year or at the time of a customer shut-off will be granted to the utility.

Though different from net metering, a July 1981 decision by the Arizona Corporation Commission allows net billing at the utility's avoided-cost rate. APS allows net billing.

APS
428 E. Thunderbird Road #749
Phoenix, AZ 85022
Phone: (602) 216-0318
www.aps.com

Salt River Project

Applicable Sectors: Residential
Applicable Technologies: PV
Maximum Customer System Size: 10 kW
Maximum enrollment: none

For each billing cycle, the kWh delivered to SRP are subtracted from the kWh delivered from SRP for each billing cycle. If the kWh calculation is net positive for the billing cycle, SRP will bill the net kWh to the customer under the applicable price plan, Standard Price Plan E-23 or E-26. If the kWh calculation is net negative for the billing cycle, SRP will credit the net kWh from the customer at an average market price. Net negative kWh will not be transferred to subsequent months.

Katie Herring
SRP
1521 N. Project Drive
Tempe, AZ 85281-2025
Phone: (602) 236-5816
http://www.srpnet.com

Tucson Electric Power Company (TEP)

Applicable Sectors: Commercial, Residential
Applicable Technologies: PV, Wind
Maximum Customer System Size: 10 kW
Maximum enrollment: 500 kW

TEP credits NEG to the following month's bill. After each January billing cycle, any remaining credit is granted to the utility. Installations must meet the IEEE-929 standard, local requirements and National Electrical Code requirements. Installations must be completed within six months of pre-installation approval. Time-of-use net metering is not permitted.

Though different from net metering, a July 1981 decision by the Arizona Corporation Commission allows net billing at the utility's avoided-cost rate. TEP allows net billing.

Steve Metzger
Tucson Electric Power
3950 E Irvington Road
Mailstop RC 116
Tucson, AZ 85702
Phone: (520) 745-3316
E-mail: smetzger@tep.com
www.tucsonelectric.com/

California

All Utilities

Applicable Sectors: All customers of all utilities
Applicable Technologies: PV, Wind; Investor owned utilities: PV, Wind, Biogas and Fuel Cells
Maximum Customer System Size: 1 MW
Maximum enrollment: 2.5 percent of each utility’s peak demand

NEG is carried forward to a customer's next bill for up to 12 months. Any NEG remaining at the end of each 12-month period is granted to the customer's utility. Customers subject to time-of-use rates are entitled to deliver electricity back to the system for the same time-of-use price that they pay for power purchases. However, time-of-use customers who choose to net meter must pay for the metering equipment capable of making such measurements. Customer-generators retain ownership of all renewable-energy credits associated with the generation of electricity.

Les Nelson
Western Renewables Group
30012 Aventura, Suite A
Rancho Santa Margarita, CA 92688
Phone: (949) 713-3500
Fax: (949) 709-8044
E-mail: lnelson@westernrenewables.com
www.westernrenewables.com

Hawaii

All Utilities

Applicable Sectors: Residential, Small Commercial (including government)
Applicable Technologies: Solar, Wind, Biomass, Hydroelectric
Maximum Customer System Size: 50 kW
Maximum enrollment: 0.5 percent of each utility's peak demand

A customer whose system produces more electricity than the customer consumes during the month may carry forward NEG in the form of a kWh credit that is applied to the next month's bill. Excess credits can be carried over for a maximum of 12 months. At the end of the 12-month reconciliation period, NEG credits will be granted to the utility without customer compensation unless the customer enters into a purchase agreement with the utility.

Maria Tome
Hawaii Department of Business, Economic Development, and Tourism
Strategic Industries Division
P.O. Box 2359
Honolulu, HI 96804
Phone: (808) 587-3809
Fax: (808) 587-3820
E-mail: mtome@dbedt.hawaii.gov
http://hawaii.gov/dbedt/info/energy/

Nevada

Investor-Owned Utilities

Applicable Sectors: Commercial, Industrial, Residential
Applicable Technologies: Solar, Wind, Biomass, Hydroelectric, Geothermal
Maximum Customer System Size: 1 MW (utilities may impose fees on systems greater than 100 kW)
Maximum enrollment: 1 percent of each utility's peak capacity

For all net-metered systems, customer NEG is carried over to the following month as a kWh credit, without expiration. If a customer is billed for electricity under a time-of-use schedule, any customer NEG during a given month will be carried forward to the same time-of-use period as the time-of-use period in which it was generated, unless the subsequent billing period lacks a corresponding time-of-use period. If there is no corresponding time-of-use period, then the NEG carried forward must be apportioned evenly among the available time-of-use periods. Excess generation fed to the grid is considered electricity generated or acquired by the utility to comply with Nevada's energy portfolio standard.

Peter Konesky
Office of the Governor
Nevada State Office of Energy
727 Fairview Drive, Suite F
Carson City, NV 89701
Phone: (775) 687-9704
Fax: (775) 687-9714
E-mail: pkonesky@dbi.state.nv.us
http://energy.state.nv.us

Citations

---

[1] DOE. http://eia.doe.gov/oiaf/1605/ggrpt/carbon.html.

[2] Dellens, Amanda, EPA National Network for Environmental Management Studies Fellow. "Green Remediation and the Use of Renewable Energy Sources for Remediation Projects." http://cluin.org/s.focus/c/pub/i/1474/.

[3] Olsen, Ken. Solar On-Line: Learning Center. PV 201 course materials. sol@solenergy.org. www.solenergy.org and Nondestructive Testing Resource Center. www.ndt-ed.org/EducationResources/HighSchool/Electricity/voltage.htm.

[4] DOE, Energy Information Administration. http://www.eia.doe.gov/kids/classactivities/MeasuringElectricityIntermediateSecondaryJuly2003.pdf.

[5] Ibid

[6] Ibid

[7] Olsen, Ken. Solar On-Line: Learning Center. PV 201 course materials. sol@solenergy.org. www.solenergy.org.

[8] DOE, Energy Information Administration. http://www.eia.doe.gov/kids/glossary/index.html#Btu.

[9] EPA, CHP Partnership. *Catalogue of CHP Technologies.* Page 1. http://www.epa.gov/chp/documents/catalog_of_%20chp_tech_entire.pdf.

[10] EPA. http://www.epa.gov/CHP/definitions.html#three.

[11] EPA, Office of Solid Waste and Emergency Response, Gill, Michael and Mahutova, K. May 2004. *Introduction to Energy Conservation and Production at Waste Cleanup Sites*. EPA Engineering Forum Issue Paper. EPA 542-S-04-001. Page 10. www.epa.gov/swertio1/tsp/download/epa542s04001.pdf

[12] EERE. http://www.eere.energy.gov/greenpower/markets/netmetering.shtml.

[13] Dellens, Amanda, EPA National Network for Environmental Management Studies Fellow. "Green Remediation and the Use of Renewable Energy Sources for Remediation Projects." Page 3. http://cluin.org/s.focus/c/pub/i/1474/.

[14] EPA. http://www.epa.gov/climatechange/emissions/co2_human.html#carbonsequestration.

[15] Ibid

[16] NETL. http://www.netl.doe.gov/technologies/carbon_seq/FAQs/project-status.html#Terrestrial_Field.

[17] EPA. http://www.epa.gov/sequestration/local_scale.html.

[18] EPA. http://www.epa.gov/sequestration/faq.html.

[19] EPA. http://www.epa.gov/sequestration/rates.html.

[20] EPA. http://www.epa.gov/sequestration/faq.html.

[21] EERE. http://www1.eere.energy.gov/solar/pv_physics.html.

[22] Lawton Ltd. http://www.lawton-bes.co.uk/sun21/solar_electricity.html.

[23] EERE. http://www1.eere.energy.gov/solar/solar_glossary.html.

[24] Ibid

[25] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 4.

[26] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 53 and EERE www1.eere.energy.gov/solar/solar_glossary.html.

[27] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 49.

[28] Olsen, Ken. Solar On-Line: Learning Center. PV 201 course materials. sol@solenergy.org. www.solenergy.org.

[29] Ibid

[30] EERE. http://www1.eere.energy.gov/solar/solar_glossary.html.

[31] Ibid

[32] EERE. http://www.eere.energy.gov/greenpower/markets/netmetering.shtml.

[33] EERE. http://www1.eere.energy.gov/solar/pv_systems.html.

[34] EERE. http://www1.eere.energy.gov/solar/solar_cell_materials.html.

[35] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 3.

[36] Olsen, Ken. Solar On-Line: Learning Center. PV 101 course materials. sol@solenergy.org. www.solenergy.org.

[37] Nano Solar. www.nanosolar.com

[38] Kyocera International Inc. http://global.kyocera.com/news/2005/0201.html.

[39] California Public Utilities Commission, CA Solar Initiative. http://www.gosolarcalifornia.ca.gov/solar101/orientation.html.

[40] Northern Arizona Wind and Sun. http://store.solar-electric.com/zomuttracmou4.html.

[41] NREL. http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/Table.html (select "Flat Plate Tilted South at Latitude.")

[42] Ibid

[43] Olsen, Ken. Solar On-Line: Learning Center. PV 201 course materials. sol@solenergy.org. www.solenergy.org.

[44] Ibid

[45] EERE. December 2003. *A Consumer's Guide: Get Your Power from the Sun*. Page 5. www.nrel.gov/docs/fy04osti/35297.pdf.

[46] Olsen, Ken. Solar On-Line: Learning Center. sol@solenergy.org. PV 201 course materials. www.solenergy.org.

[47] Ibid

[48] Ibid

[49] Ibid

[50] Olsen, Ken. Solar On-Line: Learning Center. sol@solenergy.org. PV 101 course materials. www.solenergy.org.

[51] Ibid

[52] Ibid

[53] Ibid

[54] Ibid

[55] Olsen, Ken. Solar On-Line: Learning Center. sol@solenergy.org. PV 201 course materials. www.solenergy.org.

[56] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 17.

[57] Olsen, Ken. Solar On-Line: Learning Center. sol@solenergy.org. PV 201 course materials. www.solenergy.org.

[58] Olsen, Ken. Solar On-Line: Learning Center. sol@solenergy.org. PV 201 course materials. www.solenergy.org.

[59] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 17.

[60] Gipe, Paul. "Rate of Return Calculator of Solar PV Using @IRATE Function." www.wind-works.org/Solar/RateofReturnCalculationofSolarPVUsingIRATEFunction.html.

[61] The Solar Guide. www.thesolarguide.com/solar-energy-systems/choosing-a-solar-provider.aspx. and Sustainable Development Fund Solar Photovoltaics Grant Program. "Solar PV Grant Program Tips on Choosing a PV Installer." http://www.trfund.com/sdf/solarpv_documents/PV_Con_Tips.pdf.

[62] The Solar Guide. http://www.thesolarguide.com/solar-energy-systems/warrantees.aspx.

[63] EERE. December 2003. *A Consumer's Guide: Get Your Power from the Sun*. Page 14. www.nrel.gov/docs/fy04osti/35297.pdf.

[64] San Francisco Sierra Club. Sept-Oct 2006. "Volunteers make solar power easier and more affordable for homeowners." *Sierra Club Yodeler*. http://sanfranciscobay.sierraclub.org/yodeler/html/2006/09/feature3.htm

[65] EERE. January 2004. "PV FAQs." www.nrel.gov/docs/fy04osti/35489.pdf.

[66] Zweibel, Ken, NREL. Presentation "PV Module Recycling in the US." March 2004. Page 3. www.nrel.gov/pv/thin_film/docs/**pv**_module_recycling_in_the_us.ppt

[67] EERE. www1.eere.energy.gov/solar/panel_disposal.html.

[68] Caraway, Rosemarie, EPA Region 9, Remedial Project Manager. Caraway.RoseMarie@epa.gov.

[69] EERE. www1.eere.energy.gov/windandhydro/wind_how.html.

[70] Ibid

[71] Institut für Solare Energieversorgungstechni. http://www.iset.uni-kassel.de/pls/w3isetdad/www_iset_page.show_menu?p_name=7261007&p_lang=eng.

[72] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 7. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[73] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 5. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf

[74] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 5. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[75] EERE. www1.eere.energy.gov/windandhydro/wind_how.html.

[76] Aermotor Windmill. http://www.aermotorwindmill.com/Links/Education/Index.asp.

[77] EERE. http://www1.eere.energy.gov/windandhydro/wind_how.html.

[78] American Wind Energy Association. http://www.awea.org/smallwind/toolbox2/factsheet_what_is_smallwind.html.

[79] NREL. http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html.

[80] Solcomhouse. www.solcomhouse.com/Darrieus-windmill.jpg.

[81] American Wind Energy Association. Sept 2003. *Permitting Small Turbines: A Handbook*. Page 14. http://www.awea.org/smallwind/documents/permitting.pdf.

[82] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 4. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[83] Iowa Energy Center. 2006. *Wind Energy Manual*. www.energy.iastate.edu/Renewable/wind/wem-index.htm.

[84] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 7. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[85] Iowa Energy Center. 2006. *Wind Energy Manual*. www.energy.iastate.edu/Renewable/wind/wem-index.htm.

[86] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 3. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[87] Iowa Energy Center. 2006. *Wind Energy Manual*. http://www.energy.iastate.edu/Renewable/wind/wem/systems.htm#seven.

[88] De Montfort University. www.dmu.ac.uk/.

[89] Iowa Energy Center. 2006. *Wind Energy Manual*. http://www.energy.iastate.edu/Renewable/wind/wem/systems.htm#seven.

[90] California Energy Commission. www.energy.ca.gov/distgen/equipment/wind/cost.html.

[91] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 12-13. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[92] American Wind Energy Association. http://www.awea.org/faq/basicen.html.

[93] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 10. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[94] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 4. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[95] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 16. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[96] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 19. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[97] EERE. http://www.eere.energy.gov/greenpower/markets/netmetering.shtml.

---

[98] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 3. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[99] American Wind Energy Association. www.awea.org/smallwind/toolbox/INSTALL/financing.asp.

[100] Windustry's Wind Farmers Network. windfarmersnetwork.org/eve/forums/a/tpc/f/3840095483/m/9190067093.

[101] American Wind Energy Association. www.awea.org/smallwind/toolbox/INSTALL/financing.asp.

[102] Ibid

[103] American Wind Energy Association. http://www.awea.org/faq/sagrillo/ms_used_0211.html.

[104] Argonne National Laboratory, Wind Energy Development Programmatic EIS. http://windeis.anl.gov/guide/photos/photo2.html.

[105] Ibid

[106] American Wind Energy Association. www.awea.org/faq/sagrillo/ms_OandM_0212.html.

[107] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 3. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[108] American Wind Energy Association. Sept 2003. *Permitting Small Turbines: A Handbook*. Page 20. www.awea.org/smallwind/documents/permitting.pdf and American Wind Energy Association. www.awea.org/faq/sagrillo/ms_codesnov04.html.

[109] American Wind Energy Association. http://www.awea.org/faq/sagrillo/ms_zoning3.html.

[110] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 15. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[111] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 17. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[112] American Wind Energy Association. Sept 2003. *Permitting Small Turbines: A Handbook*. Page 16. http://www.awea.org/smallwind/documents/permitting.pdf.

[113] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 8. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.

[114] EPA, Technology Innovation Program. Sept 2004. "Technology News and Trends." http://www.clu-in.org/products/newsltrs/tnandt/view.cfm?issue=0904.cfm.

[115] EPA, LMOP. September 1996. *A Landfill Gas to Energy Project Development Handbook*. Page 3-12, http://epa.gov/lmop/res/pdf/handbook.pdf.

[116] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 9. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF

[117] Ibid

[118] EPA, LMOP. http://epa.gov/lmop/overview.htm#converting.

[119] EPA, LMOP. October 2002. *Powering Microturbines with Landfill Gas*. EPA430-F-02-012. Page 1. http://www.epa.gov/lmop/res/pdf/pwrng_mcrtrbns.pdf.

[120] Oregon Department of Energy. www.oregon.gov/ENERGY/RENEW/Biomass/docs/landfill.PDF.

[121] EPA, LMOP. October 2002. *Powering Microturbines with Landfill Gas*. EPA430-F-02-012. Page 3. http://www.epa.gov/lmop/res/pdf/pwrng_mcrtrbns.pdf.

[122] CA Energy Commission. http://www.energy.ca.gov/distgen/equipment/microturbines/cost.html.

[123] Ibid

[124] EPA. http://www.epa.gov/methane/sources.html.

[125] DOE, Energy Information Administration. http://www.eia.doe.gov/oiaf/1605/gwp.html.

[126] EPA, LMOP. http://epa.gov/lmop/overview.htm#methane.

[127] EPA, LMOP. http://epa.gov/lmop/over-photos.htm#3.

[128] EPA. http://www.epa.gov/landfill/benefits.htm.

[129] Ibid

[130] EPA, LMOP. September 1996. *A Landfill Gas to Energy Project Development Handbook*. Page 3-2 to 3-6, http://epa.gov/lmop/res/pdf/handbook.pdf.

[131] EPA, LMOP. May 2007. "An Overview of Landfill Gas Energy in the United States." Page 5. http://www.epa.gov/landfill/docs/overview.pdf.

[132] EPA, LMOP. May 2007. "An Overview of Landfill Gas Energy in the United States." Page 7. http://www.epa.gov/landfill/docs/overview.pdf.

[133] EPA, LMOP. September 1996. *A Landfill Gas to Energy Project Development Handbook*. Page 2-2, http://epa.gov/lmop/res/pdf/handbook.pdf.

[134] EPA, LMOP. http://epa.gov/lmop/over-photos.htm#5.

[135] EPA Combined Heat and Power Partnership. *Catalogue of CHP Technology*. Page 1. http://www.epa.gov/CHP/basic/catalog.html.

[136] EPA, LMOP. September 2006. *A Landfill Gas to Energy Project Development Handbook*. Page 9-13. http://epa.gov/lmop/res/pdf/handbook.pdf.

[137] EPA, LMOP. September 2006. *A Landfill Gas to Energy Project Development Handbook*. Page 3-16. http://epa.gov/lmop/res/pdf/handbook.pdf.

[138] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California*. Pages 26-28. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.

[139] California Climate Action Team. December 2005. *Draft State Agency Work Plans*. Page 80. http://www.climatechange.ca.gov/climate_action_team/reports/2006-02-06_AGENCY_WORKPLANS.PDF.

---

[140] EPA, LMOP. www.epa.gov/lmop/faq-3.htm.

[141] EPA, Office of Solid Waste and Emergency Response, Gill, Michael and Mahutova, K. May 2004. "Introduction to Energy Conservation and Production at Waste Cleanup Sites." EPA Engineering Forum Issue Paper. EPA 542-S-04-001. Pages 5-6.

[142] Chern, Shiann-Jang, RPM, EPA Region 9. Chern.Shiann-Jang@epa.gov

[143] National Aeronautics and Space Administration. http://www.nasa.gov/centers/goddard/news/topstory/2003/0508landfill.html and EPA, LMOP. http://www.epa.gov/lmop/res/nasa.htm.

[144] BMW. http://www.bmwusfactory.com//community/environment/gastoenergy.asp.

[145] California Energy Commission. http://www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/index.html.

[146] EERE. http://www.eere.energy.gov/consumer/your_workplace/farms_ranches/index.cfm/mytopic=30004.

[147] Penn State University. www.biogas.psu.edu/terminology.html.

[148] Penn State University. www.biogas.psu.edu/plugflow.html.

[149] EPA, AgStar Program. 1997. *AgStar Handbook*. Page i. www.epa.gov/agstar/pdf/handbook/intro.pdf.

[150] California Energy Commission. http://www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/index.html.

[151] EERE. http://www.eere.energy.gov/consumer/your_workplace/farms_ranches/index.cfm/mytopic=30004.

[152] California Energy Commission. http://www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/index.html and Penn State University. www.biogas.psu.edu/terminology.html.

[153] California Energy Commission. http://www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/index.html.

[154] Penn State University, www.biogas.psu.edu/basics.html.

[155] EPA, AgStar Program. 1997. *AgStar Handbook*. Chapter 1. http://epa.gov/agstar/pdf/handbook/chapter1.pdf.

[156] EPA, AgStar Program. 2002. *Managing Manure with Biogas Recovery Systems Improved Performance at Competitive Costs*. Page 4. http://www.epa.gov/agstar/pdf/manage.pdf.

[157] Schanbacher, Floyd, Ohio State University, Dept. of Animal Sciences Ohio Agriculture R & D Center. January 31, 2007. "Digester Basics." Powerpoint presented at Waste-to-Energy Workshop for the Ohio Livestock & Food Processing Industries. http://www.chpcentermw.org/pdfs/070131-Wooster-OH/2007_Jan31_WoosterOH_Schanbacher.pdf.

[158] EPA, AgStar Program. 2002. *Managing Manure with Biogas Recovery Systems Improved Performance at Competitive Costs*. Page 8. http://www.epa.gov/agstar/pdf/manage.pdf.

[159] Schanbacher, Floyd, Ohio State University, Dept. of Animal Sciences Ohio Agriculture R & D Center. January 31, 2007. "Digester Basics." Powerpoint presented at Waste-to-Energy Workshop for the Ohio Livestock & Food Processing Industries. http://www.chpcentermw.org/pdfs/070131-Wooster-OH/2007_Jan31_WoosterOH_Schanbacher.pdf.

[160] EPA, AgStar Program. 2002. *Managing Manure with Biogas Recovery Systems Improved Performance at Competitive Costs*. Page 8. http://www.epa.gov/agstar/pdf/manage.pdf.

[161] Schanbacher, Floyd, Ohio State University, Dept. of Animal Sciences Ohio Agriculture R & D Center. January 31, 2007. "Digester Basics." Powerpoint presented at Waste-to-Energy Workshop for the Ohio Livestock & Food Processing Industries. http://www.chpcentermw.org/pdfs/070131-Wooster-OH/2007_Jan31_WoosterOH_Schanbacher.pdf.

[162] EPA, AgStar Program. 2002. *Managing Manure with Biogas Recovery Systems Improved Performance at Competitive Costs*. Page 8. http://www.epa.gov/agstar/pdf/manage.pdf.

[163] California Energy Commission. http://www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/index.html; The Minnesota Project. Aug 2002. *Final Report: Haubenschild Farms Anaerobic Digester*. Pages 5-8. www.mnproject.org/pdf/Haubyrptupdated.pdf and Penn State University. www.biogas.psu.edu.

[164] Wilkie, Ann, University of Florida, Soil and Water Science Department. 2003. "Anaerobic Digestion of Flushed Dairy Manure." http://dairy.ifas.ufl.edu/files/WEF-June2003.pdf.

[165] Ohio Biomass Energy Program. *Turning Manure into Gold*. Page 9. www.manuremanagement.cornell.edu/Docs/TurningManuretoGold.pdf.

[166] EPA, AgStar Program. 1997. *AgStar Handbook*. Page 3-2. www.epa.gov/agstar/pdf/handbook/chapter3.pdf.

[167] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California*. Page 6. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.

[168] EPA, LMOP. Sept 1996. *A Landfill Gas to Energy Project Development Handbook*. Page 3-12. http://epa.gov/lmop/res/pdf/handbook.pdf.

[169] California Energy Commission. http://www.energy.ca.gov/distgen/equipment/microturbines/cost.html.

[170] Schanbacher, Floyd, The Ohio State University, Dept. of Animal Sciences Ohio Agriculture R & D Center. January 31, 2007. "Digester Basics." Powerpoint presented at Waste-to-Energy Workshop for the Ohio Livestock & Food Processing Industries. http://www.chpcentermw.org/pdfs/070131-Wooster-OH/2007_Jan31_WoosterOH_Schanbacher.pdf.

[171] California Energy Commission. www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/index.html.

[172] EPA, AgStar. 2002. *Managing Manure with Biogas Recovery Systems Improved Performance at Competitive Costs*. Page 8. http://www.epa.gov/agstar/pdf/manage.pdf.

[173] Ibid

[174] EPA, AgStar Program. 1997. *AgStar Handbook*. Pages 8-4—8.5. www.epa.gov/agstar/pdf/handbook/chapter8.pdf.

[175] EPA, AgStar, ASERTTI, USDA. Jan 2007. *A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures*. Pages 15-16. http://epa.gov/agstar/pdf/protocol.pdf.

[176] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Page 10.7. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

[177] Eastern Research Group, Inc. July 2005. *An Evaluation of a Mesophilic, Modified Plug Flow Anaerobic Digester for Dairy Cattle Manure*. http://www.epa.gov/agstar/pdf/gordondale_report_final.pdf.

[178] California Energy Commission. http://www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/projects.html.

[179] Zhang, Zhiqin, California Energy Commission. Presentation at the Organic Residuals Symposium. July 12-14, 2006, Sacramento, California. “Recycling of Non-Hazardous Organic Residuals to Products and Energy.” Page 17. www.energy.ca.gov/2006publications/CEC-999-2006-013/CEC-999-2006-013.PDF.

[180] Zhang, Zhiqin, California Energy Commission. Presentation at the Organic Residuals Symposium. July 12-14, 2006, Sacramento, California. “Recycling of Non-Hazardous Organic Residuals to Products and Energy.” Page 18. www.energy.ca.gov/2006publications/CEC-999-2006-013/CEC-999-2006-013.PDF. and Emigh, Michael, Valley Fig Growers. Presentation at the Clean Fuels for California and the West Conference. January 18, 2006. http://www.energetics.com/napavalleyCHPworkshop/pdfs/emigh.pdf. and Emigh, Michael, Valley Fig Growers. Presentation at the 6th Annual Microturbine Applications Workshop. January 19, 2006. http://www.ms.ornl.gov/maw06/pdfs/presentations/Day3/Emigh.pdf.

[181] Emigh, Mike, Valley Fig Growers. Presentation at the Clean Fuels for California and the West Conference. January 18, 2006. Page 14, 16, 34-35. http://www.energetics.com/napavalleyCHPworkshop/pdfs/emigh.pdf; Emigh, Mike, Valley Fig Growers. Presentation at the 6th Annual Microturbine Applications Workshop. January 19, 2006. Page 21, 23-28. http://www.ms.ornl.gov/maw06/pdfs/presentations/Day3/Emigh.pdf;

[182] Emigh, Mike, Valley Fig Growers Association. Presentation at the Clean Fuels for California and the West Conference. January 18, 2006. Page 16. http://www.energetics.com/napavalleyCHPworkshop/pdfs/emigh.pdf.

[183] Emigh, Mike, Valley Fig Growers Association. Presentation at the Clean Fuels for California and the West Conference. January 18, 2006. Page 35-45. http://www.energetics.com/napavalleyCHPworkshop/pdfs/emigh.pdf and Emigh, Mike, Valley Fig Growers. Presentation at the 6th Annual Microturbine Applications Workshop. January 19, 2006. Pages 23-28. http://www.ms.ornl.gov/maw06/pdfs/presentations/Day3/Emigh.pdf.

[184] Southern Illinois University at Carbondale. http://www.siu.edu/~perspect/05_sp/coalsidebar2.html.

[185] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/glossary.html.

[186] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/1.html.

[187] Coaltec Energy USA. http://www.coaltecenergy.com/poultrylitterproject.html.

[188] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/1.html.

[189] EERE. http://www1.eere.energy.gov/biomass/gasification.html.

[190] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/index.html.

[191] International Energy Agency, Task 33. May 2005. *Observations on the Current Status of Biomass Gasification*. Page 1. http://media.godashboard.com/gti/IEA/58_BiomassGasification.pdf.

[192] Gasification Guide. http://www.gasification-guide.eu/index.php?id=10&r=6.

[193] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/7.html.

[194] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/6.html.

[195] EERE. http://www1.eere.energy.gov/biomass/small_modular_gasification.html.

[196] Ibid

[197] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/2.html.

[198] Bioenergy Feedstock Information Network. http://bioenergy.ornl.gov/faqs/index.html#eco3.

[199] NREL. February 2000. *Small Modular Biopower Initiative Phase I Feasibility Studies Executive Summaries*. NREL/TP-570-27592. http://www.nrel.gov/docs/fy00osti/27592.pdf.

[200] Rizzo, Rob, Mt. Wachusett Community College. Presentation June 2007. http://www.delaware-energy.com/Download/BIO-MASS-CONF/Rob%20Rizzo.pdf.

[201] EPA. www.epa.gov/oar/particlepollution/health.html and EPA. www.epa.gov/air/urbanair/nox/hlth.html.

[202] EPA. May 2002. *Health Assessment Document for Diesel Engine Exhaust*. EPA/600/8-90/057F. Page 603. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060 and EPA Region 1. http://www.epa.gov/ne/eco/diesel/.

[203] California Air Resources Board. “Facts about California’s Accomplishments in Reducing Diesel Particulate Matter Emissions.” Page 1. http://www.arb.ca.gov/diesel/factsheets/dieselpmfs.pdf.

[204] EPA. 2005. *National Emissions Inventory*. www.epa.gov/ttn/chief/trends.

[205] EPA, West Coast Collaborative. June 2005. “Public Health and Environmental Impacts of Diesel Emissions.” Page 1. http://westcoastcollaborative.org/files/outreach/Health-Enviro-Factsheet.pdf.

[206] EPA. www.epa.gov/nonroad-diesel/2004fr/420f04032.htm.

[207] Ibid

[208] EPA. 2005. *National Emissions Inventory*. www.epa.gov/ttn/chief/trends.

[209] EPA, West Coast Collaborative. “West Coast Collaborative PowerPoint.” Page 22. http://westcoastcollaborative.org/files/outreach/WCCppt.pdf.

[210] EPA, West Coast Collaborative. “West Coast Collaborative PowerPoint.” Page 4. http://westcoastcollaborative.org/files/outreach/WCCppt.pdf.

[211] California Air Resources Board. “Facts about California’s Accomplishments in Reducing Diesel Particulate Matter Emissions.” Page 1. http://www.arb.ca.gov/diesel/factsheets/dieselpmfs.pdf.

[212] EPA. www.epa.gov/oar/particlepollution/health.html.

[213] EPA. March 2007. *Cleaner Diesels: Low Cost Ways to Reduce Emissions from Construction Equipment*. Page 5. http://www.epa.gov/sectors/pdf/emission_0307.pdf.

[214] EPA. March 2007. *Cleaner Diesels: Low Cost Ways to Reduce Emissions from Construction Equipment*. Page 5-6. http://www.epa.gov/sectors/pdf/emission_0307.pdf

[215] Manufacturers of Emission Controls Association. http://www.meca.org/cs/root/diesel_retrofit_subsite/what_is_retrofit/what_is_retrofit.

---

[216] EPA, West Coast Collaborative. www.westcoastcollaborative.org.

[217] Manufacturers of Emission Controls Association. http://www.meca.org/cs/root/diesel_retrofit_subsite/what_is_retrofit/what_is_retrofit.

[218] ICF Consulting for EPA. May 2005. *Emission Reduction Incentives for Off-Road Diesel Equipment Used in the Port and Construction Sectors*. Page 17. http://www.epa.gov/sectors/pdf/emission_20050519.pdf.

[219] Manufacturers of Emission Controls Association. http://www.meca.org/cs/root/diesel_retrofit_subsite/what_is_retrofit/what_is_retrofit.

[220] Schattanek, Guido. November 2004. "The Greening of Construction: Implementing Clean Diesel Control Programs on Transportation Projects." *Sustainable Development*, Issue 59. http://www.pbworld.com/news_events/publications/network/issue_59/images/schattanek_fig1_250.jpg.

[221] Manufacturers of Emission Controls Association. http://www.meca.org/cs/root/diesel_retrofit_subsite/what_is_retrofit/what_is_retrofit.

[222] Virginia Department of Environmental Quality. http://www.deq.virginia.gov/mobile/mobcomp.html

[223] Lenox, Katey, Oak Ridge National Laboratory. June 18-22 2000. "Extending Exhaust Gas Recirculation Limits in Diesel Engines." Air and Waste Management Association 93rd Annual Conference presentation. Salt Lake City, UT. Page 15. http://www-chaos.engr.utk.edu/pap/crg-awma2000-slides.pdf; CA Air Resources Board. http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm; and EPA. http://www.epa.gov/otaq/retrofit/verif-list.htm.

[224] Manufacturers of Emissions Controls Association. April 2006. *Retrofitting Emission Controls On Diesel-Powered Vehicles*. Page 14. https://vault.swri.edu/Retrofit/Documents/TechPaper.pdf.

[225] Manufacturers of Emissions Controls Association. April 2006. *Retrofitting Emission Controls On Diesel-Powered Vehicles*. Page 9. https://vault.swri.edu/Retrofit/Documents/TechPaper.pdf.

[226] Manufacturers of Emissions Controls Association. April 2006. *Retrofitting Emission Controls On Diesel-Powered Vehicles*. Page 18. https://vault.swri.edu/Retrofit/Documents/TechPaper.pdf.

[227] EPA, West Coast Collaborative. "Diesel Emissions Mitigation Opportunities." Page 2. http://westcoastcollaborative.org/files/outreach/Diesel%20Emission%20Mitigation.pdf.

[228] Ibid

[229] Ibid

[230] EPA, West Coast Collaborative. "Diesel Emissions Mitigation Opportunities." Page 1. http://westcoastcollaborative.org/files/outreach/Diesel%20Emission%20Mitigation.pdf.

[231] EPA, West Coast Collaborative. "Diesel Emissions Mitigation Opportunities." Page 2. http://westcoastcollaborative.org/files/outreach/Diesel%20Emission%20Mitigation.pdf.

[232] Manufacturers of Emission Controls Association. April 2006. *Retrofitting Emission Controls On Diesel-Powered Vehicles*. Page 16. https://vault.swri.edu/Retrofit/Documents/TechPaper.pdf.

[233] California Air Resources Board. October 2000. "Appendix XI, Diesel PM Control Technologies." Page 40. http://www.arb.ca.gov/diesel/documents/rrpapp9.pdf.

[234] Washington State University Extension Energy Program. "Diesel Oxidation Catalyst." Page 3. www.energy.wsu.edu/ftp-ep/pubs/renewables/DieselOxidation.pdf.

[235] Washington State University. "Diesel Oxidation Catalyst." www.energy.wsu.edu/documents/renewables/DieselOxidation.pdf. And Washington State University. "Diesel Particulate Filters." www.energy.wsu.edu/documents/renewables/Retrofitparticualtefilters.pdf.

[236] EPA, Office of Enforcement and Compliance Assurance. December 2006. "Diesel Pump Labeling Requirements." Page 4. http://www.clean-diesel.org/images/DPLabelFacts121406.pdf.

[237] EPA, OTAQ. http://www.epa.gov/otaq/highway-diesel/regs/420f06064.htm and http://www.epa.gov/nonroad-diesel/.

[238] Clean Air Fleets. http://www.cleanairfleets.org/altfuels.html.

[239] EPA, OTAQ. http://www.epa.gov/otaq/highway-diesel/regs/420f06064.htm.

[240] EPA, OTAQ. http://epa.gov/otaq/regs/fuels/diesel/diesel.htm.

[241] EPA. http://www.epa.gov/smartway/growandgo/documents/factsheet-biodiesel.htm.

[242] NREL. Williams, A., R.L. McCormick, R. Hayes, and J. Ireland. March 2006. *Biodiesel Effects on Diesel Particulate Filter Performance*. NREL/TP-540-39606. http://www.nrel.gov/docs/fy06osti/39606.pdf.

[243] EPA. http://www.epa.gov/smartway/growandgo/documents/factsheet-biodiesel.htm.

[244] NREL. April 2005. "Biodiesel Blends: Clean Cities Factsheet." DOE/GO-102005-2029. http://www.nrel.gov/vehiclesandfuels/npbf/pdfs/37136.pdf.

[245] Clean Air Initiative. http://www.cleanairnet.org/infopool/1411/article-33906.html.

[246] EERE. http://www.eere.energy.gov/afdc/fuels/natural_gas_cng_lng.html.

[247] EERE. http://www.eere.energy.gov/afdc/fuels/natural_gas_benefits.html.

[248] EPA. http://www.epa.gov/cleandiesel/construction/strategies.htm#fuels

[249] EPA. http://www.epa.gov/cleanschoolbus/retrofit.htm,

[250] Clean Air Fleets. http://www.cleanairfleets.org/altfuels.html.

[251] Ibid

[252] Ibid

[253] Ibid

[254] EPA, Region 9. http://www.epa.gov/region09/waste/biodiesel/questions.html.

[255] EPA, OTAQ. http://www.epa.gov/otaq/retrofit/documents/biodiesel_calc.xls.

[256] EPA, Region 9. http://www.epa.gov/region09/waste/biodiesel/questions.html.

---

[257] EPA, OTAQ. http://www.epa.gov/otaq/retrofit/documents/biodiesel_calc.xls.

[258] EPA, Region 9. http://www.epa.gov/region09/waste/biodiesel/questions.html.

[259] EERE. http://www.epa.gov/region09/waste/biodiesel/benefits.html.

[260] EERE. http://www.eere.energy.gov/afdc/fuels/natural_gas_benefits.html.

[261] EERE. http://www.eere.energy.gov/afdc/fuels/natural_gas_benefits.html.

[262] Ibid

[263] EPA, OTAQ. "Clean Alternative Fuels: Compressed Natural Gas Fact Sheet." http://eerc.ra.utk.edu/etcfc/docs/EPAFactSheet-cng.pdf.

[264] Ibid

[265] EPA. http://www.epa.gov/otaq/diesel/construction/strategies.htm.

[266] Ibid

[267] EPA. http://epa.gov/otaq/retrofit/techlist-lubrizol.htm.

[268] Ibid

[269] EPA. http://www.epa.gov/otaq/highway-diesel/regs/420f06064.htm.

[270] EERE. July 2007. "Clean Cities Alternative Fuel Price Report." Page 3. www.eere.energy.gov/afdc/pdfs/afpr_jul_07.pdf.

[271] EPA, OTAQ. "Clean Alternative Fuels: Compressed Natural Gas Fact Sheet." http://eerc.ra.utk.edu/etcfc/docs/EPAFactSheet-cng.pdf.

[272] EPA, OTAQ. June 2003. Clean Fuel Options for Heavy-Duty Trucks and Buses. EPA420-F-03-015. Page 4. http://www.epa.gov/otaq/retrofit/documents/f03015.pdf.

[273] Clean Air Fleets. http://www.cleanairfleets.org/altfuels.html.

[274] EERE. http://www.eere.energy.gov/afdc/progs/all_state_summary.cgi?afdc/0.

[275] California Public Utilities Commission. Sept 2007. *California Solar Initiative Program Handbook*. Page 7. http://www.gosolarcalifornia.ca.gov/documents/CSI_HANDBOOK.PDF.

[276] Pacific Gas and Electric Company, San Diego Gas and Electric, San Diego Regional Energy Office, Southern California Edison, Southern California Gas Company. May 2007. *Self-Generation Incentive Program Handbook*. Page 3. http://www.sce.com/NR/rdonlyres/2FE187D0-3629-4201-A93F-AE7A827F5D03/0/2007_SGIP_Handbookr3070508.pdf.

[277] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 17.

[278] NorCal Solar. 2006-2007. *Solar Energy Resource Guide*. 7th edition. Page 18.

[279] Solar Pathfinder. http://www.solarpathfinder.com/index2.html.

[280] EPA. http://www.epa.gov/adminweb/administrator/actionplan.htm.

[281] EPA Region 9. Machol, Ben. *Energy and Climate Change Strategy*. December 2007. Page 14.

[282] Whitehouse. http://www.whitehouse.gov/news/releases/2007/12/20071219-1.html.

[283] EPA. http://www.epa.gov/greeningepa/energy/fedreq.htm and EERE. http://www1.eere.energy.gov/femp/about/legislation.html.

[284] EPA, Energy Star Program. http://www.energystar.gov/index.cfm?c=pt_reps_purch_procu.pt_reps_exec_orders.

[285] Ibid

[286] EERE. http://www1.eere.energy.gov/femp/about/legislation.html.

[287] EPA. http://www.epa.gov/greeningepa/energy/fedreq.htm.

[288] EPA. http://www.epa.gov/greeningepa/greenpower/buy.htm.

[289] California Solar Initiative. http://www.csi-epbb.com/.

[290] EERE. http://www.eere.energy.gov/solar/cfm/faqs/third_level.cfm/name=Photovoltaics/cat=The%20Basics.

[291] EERE. http://www1.eere.energy.gov/solar/solar_glossary.html.

[292] EERE. http://www.eere.energy.gov/solar/cfm/faqs/third_level.cfm/name=Photovoltaics/cat=The%20Basics.

[293] Olsen, Ken, Solar On-Line: Learning Center, sol@solenergy.org, PV 201 course materials, www.solenergy.org.

[294] EERE. http://www1.eere.energy.gov/solar/photoelectric_effect.html.

[295] EERE. http://www1.eere.energy.gov/solar/printable_versions/doping_silicon.html.

[296] Special Materials and Research Technology. www.specmat.com/Overview%20of%20Solar%20Cells.htm.

[297] Olsen, Ken, Solar On-Line: Learning Center, sol@solenergy.org, PV 201 course materials, www.solenergy.org.

[298] Ibid

[299] Ibid

[300] EERE. www1.eere.energy.gov/solar/solar_glossary.html#battery.

[301] EERE. http://www1.eere.energy.gov/windandhydro/wind_consumer_faqs.html.

[302] Olsen, Ken, Solar On-Line: Learning Center, sol@solenergy.org, PV 201 course materials, www.solenergy.org

[303] Ibid

[304] Ibid

[305] Ibid

[306] Ibid

[307] Ibid

[308] Ibid

[309] Ibid

[310] The Solar Guide. http://www.thesolarguide.com/solar-energy-systems/choosing-a-solar-provider.aspx and Sustainable Development Fund Solar Photovoltaics Grant Program. "Solar PV Grant Program Tips on Choosing a PV Installer." http://www.trfund.com/sdf/solarpv_documents/PV_Con_Tips.pdf.

[311] NREL. http://www.nrel.gov/learning/re_csp.html.

[312] Ibid

[313] British Wind Energy Association. http://www.bwea.com/edu/extract.html.
[314] Ibid
[315] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 6. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.
[316] NREL. Photographic Information Exchange. http://www.nrel.gov/data/pix/Jpegs/14676.jpg.
[317] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 6. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf.
[318] EERE. March 2005. *Small Wind Electric Systems: A U.S. Consumer's Guide*. Page 22. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/small_wind/small_wind_guide.pdf and American Wind Energy Association. http://www.awea.org/faq/windpower.html.
[319] EPA, LMOP. September 1996. *A Landfill Gas to Energy Project Development Handbook*. Page 2-3, http://epa.gov/lmop/res/pdf/handbook.pdf.
[320] EPA, AgStar Program. 1997. *AgStar Handbook*. Page 3-3. www.epa.gov/agstar/pdf/handbook/chapter3.pdf.
[321] EERE. http://www.eere.energy.gov/de/gas_fired/tech_basics.html.
[322] Ibid
[323] EERE. http://www.eere.energy.gov/de/gas_fired_engines.html.
[324] EPA, February 2002. *A Brief Characterization of Reciprocating Engines in Combined Heat and Power Applications*. Page 2. http://www.epa.gov/lmop/res/pdf/chp_recipengines.pdf.
[325] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 6. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[326] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 5. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[327] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 6. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[328] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 5. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[329] Ibid
[330] Ibid
[331] EERE. http://www.eere.energy.gov/de/industrial_turbines/tech_basics.html.
[332] Ibid
[333] Ibid
[334] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 8. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[335] EERE. www.eere.energy.gov/de/microturbines/tech_basics.html.
[336] EPA, LMOP. October 2002. *Powering Microturbines with Landfill Gas*. EPA430-F-02-012. Page 1. http://www.epa.gov/lmop/res/pdf/pwrng_mcrtrbns.pdf.
[337] Ibid
[338] EPA, LMOP. October 2002. *Powering Microturbines with Landfill Gas*. EPA430-F-02-012. Page 2. http://www.epa.gov/lmop/res/pdf/pwrng_mcrtrbns.pdf.
[339] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 11-12. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[340] EPA, LMOP. October 2002. *Powering Microturbines with Landfill Gas*. EPA430-F-02-012. Page 3. http://www.epa.gov/lmop/res/pdf/pwrng_mcrtrbns.pdf.
[341] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 9. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[342] EPA, LMOP. "Adapting Boilers to Utilize Landfill Gas." www.epa.gov/lmop/res/pdf/boilers.pdf.
[343] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 9. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[344] California Energy Commission. April 2002. *Economic and Financial Aspects of Landfill Gas to Energy Project Development in California.* Page 9. http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF.
[345] Adapted from EPA, AgStar Program. 1997. *AgStar Handbook.* Pages 2-2, 2-4,2-5,2-6,2-7. www.epa.gov/agstar/pdf/handbook/intro.pdf.
[346] Dairy Power Production Program. http://www.energy.ca.gov/pier/renewable/biomass/anaerobic_digestion/projects.html.
[347] CA Energy Commission. http://www.energy.ca.gov/development/biomass/anaerobic.html.
[348] Leggett, Jeannie, Graves, Robert, Lanyon, Les, Penn State University, College of Agricultural Sciences G77. "Anaerobic Digestion: Biogas Production and Odor Reduction from Manure." http://www.age.psu.edu/extension/factsheets/g/G77.pdf.
[349] EERE. http://www.eere.energy.gov/consumer/your_workplace/farms_ranches/index.cfm/mytopic=30003.
[350] Ibid
[351] Ibid
[352] Food and Agriculture Organization of the United Nations. http://www.fao.org/sd/EGdirect/EGre0022.htm.
[353] EERE. http://www.eere.energy.gov/consumer/your_workplace/farms_ranches/index.cfm/mytopic=30003.
[354] Food and Agriculture Organization of the United Nations. http://www.fao.org/sd/EGdirect/EGre0022.htm.
[355] Ibid
[356] EERE. http://www.eere.energy.gov/consumer/your_workplace/farms_ranches/index.cfm/mytopic=30003.

---

[357] Ibid
[358] Fondahl, Lauren, EPA Region 9. Personal communication. October 5, 2007 and 40 CFR 503.32(a). http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=fdf2e06805b14dec0ec66ed24d7b7e67&rgn=div8&view=text&node=40:29.0.1.2.40.4.13.3&idno=40.
[359] EERE. http://www.eere.energy.gov/consumer/your_workplace/farms_ranches/index.cfm/mytopic=30003.
[360] NETL. http://www.netl.doe.gov/technologies/coalpower/gasification/basics/5.html and http://www.netl.doe.gov/technologies/coalpower/gasification/basics/4.html.
[361] EPA. September 2006. *Alternative Technologies/Uses for Manure Draft*. www.epa.gov/npdes/pubs/cafo_report.pdf.
[362] Food and Agriculture Organization of the United Nations. http://www.fao.org/DOCREP/T0512E/T0512e0a.htm.
[363] Food and Agriculture Organization of the United Nations. http://www.fao.org/DOCREP/T0512E/T0512e0a.htm and NETL. June 2002. *Benchmarking Biomass Gasification Technologies for Fuels, Chemicals, and Hydrogen Production*. Pages 7-8. www.netl.doe.gov/technologies/coalpower/gasification/pubs/pdf/BMassGasFinal.pdf.
[364] Ibid
[365] Ibid
[366] Modified from image courtesy Dennis Johnson, EPA. Johnson.Dennis@epa.gov.
[367] Adapted from EERE. http://www.eere.energy.gov/greenpower/markets/pricing.shtml?page=1.