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Department of Defense Energy Handbook

Spiral 2





Alternative and Renewable Energy Options for DoD Facilities and Bases

AMMTIAC

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This handbook serves as a foundational guide on energy for facility energy managers and base commanders. It provides guidance on usage patterns, reduction of energy consumption, assessment of common renewable energy alternatives, emerging technologies, successes, and lessons learned. The energy handbook is intended to arm facility energy managers with knowledge and information needed to make the best decisions related to energy usage and renewable energy options.

This handbook covers traditional and renewable energy options for DoD facilities and bases. It provides information to help delineate energy options and to identify key factors that may offer insight when making decisions. The handbook is for use as a supplemental resource when performing critical assessments of energy options for their facilities and bases.

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Renewable energy; alternative energy; solar; photovoltaic; solar thermal; concentrated solar; small wind; large wind; wind turbine; biomass; biofuel; biopower; geothermal; power; electricity; fossil fuel; coal; petroleum; natural gas; nuclear power; hydropower; wave power; tidal energy; smart grid; microgrid; lessons learned.

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Preface

This handbook was written by the Advanced Materials, Manufacturing and Technology Information Analysis Center (AMMTIAC), and presents information related to energy and power for Department of Defense facilities and bases.

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AMMTIAC is a Full-Service DoD Information Analysis Center and is well oriented to the needs of its user community. It searches, identifies, collects, reviews, analyzes, appraises, summarizes, computerizes, stores, and provides timely information and data; and advisory, analysis, and other services concerning the available worldwide scientific and technical information and engineering data on advanced materials, manufacturing, and testing technologies that are important to the DoD. AMMTIAC serves as the DoD's central source of engineering and technical data and research and development information on all forms of destructive and nondestructive testing methods and technologies.

Subject areas covered include renewable energy; alternative energy; solar; photovoltaic; solar thermal; concentrated solar; small wind; large wind; wind turbine; biomass; biofuel; biopower; geothermal; power; electricity; fossil fuel; coal; petroleum; natural gas; nuclear power; hydropower; wave power; tidal energy; smart grids; and microgrids.

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1 EXECUTIVE SUMMARY

Over the past several decades, and more particularly the last few years, the Department of Defense (DoD) has been presented with the challenge of reducing energy consumption while continuing to perform its mission at the customarily high level mandated by the Federal Government and expected by the American people. Through legislation, executive orders, DoD directives and policies, and Service-specific guidance, DoD facilities and bases are charged with reducing overall energy use and increasing their reliance on renewable energy sources. This challenge is complicated by the requirement that each unit and facility must maintain the same level of readiness in order to carry out their mission. Thus, operational efficiency must be maintained or improved, and viable alternative and renewable energy options must be implemented.

Much information on renewable and alternative energy options exists. However, such information tends to be scattered among disparate sources, and even then individual sources are insufficient to give facility managers and base commanders the confidence needed to recommend and implement changes. Moreover, not all energy options will have a positive impact; suitable energy alternatives must be assessed for each individual circumstance. This is doubly important, as choosing the wrong energy approach may lead to a number of negative consequences. The need, therefore, is for a reference that provides guidance and pertinent technical information when assessing and formulating power and energy strategies for DoD facilities and bases.

The Department of Defense manages 1.96 billion square feet of facilities and spent $3.6 billion on energy for facilities in the fiscal year of 2009. The Energy Policy Act of 2005 set into law several substantial energy requirements for federal agencies, including renewable energy generation and energy usage reduction requirements. Soon after, in 2007, the Energy Independence and Security Act strengthened the energy usage reduction requirement and added energy auditing and reporting requirements. Through these laws, combined with several executive orders and DoD policies, the DoD has been charged with (1) reducing facility energy consumption 30 percent by 2015, and (2) producing or procuring 25 percent of its facility energy from renewable sources by 2025. Furthermore, they are required to install advanced energy meters; institute energy efficiency, training, and awareness programs; and require energy efficient product procurement, among many other goals and requirements.

The DoD consumes nearly 900 trillion British thermal units of energy each year, and of this total approximately 32 percent is energy for facilities. The DoD uses approximately 30 terawatt-hours of electricity each year, and approximately 3.6 percent of this is from renewable sources. Despite recent success, the Department must make greater strides in the reduction of energy consumption and the increase in use of renewable energy resources in order to provide reliable and cost effective utility services to the warfighter.

Conventional, nonrenewable energy sources are reliable in terms of their ability to provide consistent power levels. However, the DoD is dependent on many of these sources, some of which are from derived from foreign sources, particularly petroleum. While other fossil fuels, such as coal and natural gas are domestically available, they are still nonrenewable and have many environmental issues surrounding them. Nuclear energy and hydropower are also relatively stable power sources, but have their own drawbacks, safety and capital cost being the foremost issues, respectively.

Renewable energy technology has been advancing rapidly in recent years, and with it the implementation of renewable energy projects has progressed, including within the DoD. There have been several successes with both large scale and small scale renewable energy projects. Solar, wind, biomass, and geothermal have all been implemented, while offshore wind, tidal, and wave energy projects are on the horizon and may be implemented with sufficient technical advancements and achievements.

If there is one breakthrough that could make renewable energy much more versatile in its usefulness, it is in the area of energy storage. Currently, energy storage is too expensive, too weight or space restrictive, or too technically immature to be a realistic option for many applications. With sufficient advancement, however, energy storage systems, such as fuel cells paired with electrolyzers, could change the way renewable energy technologies are used.

As a whole, this handbook serves as a foundational guide and information resource on energy for facility energy managers and base commanders. It provides guidance on usage patterns, reduction of energy consumption, assessment of common renewable energy alternatives, emerging technologies, successes, and lessons learned. The energy handbook is intended to arm facility energy managers with knowledge and information needed to make the best decisions related to energy usage and renewable energy options.

This handbook covers traditional and renewable energy options for DoD facilities and bases, and it is intended as a resource for energy managers and base commanders. It provides information to help delineate their energy options and to identify key factors that may offer insight when making decisions. The handbook is for use as a supplemental resource when performing critical assessments of energy options for their facilities and bases. It further provides an expansive bibliography, which is intended to serve as an auxiliary resource to locate additional detail on all topics included herein.

2 CONTENTS OF THIS HANDBOOK

This energy handbook covers many of the technical aspects of energy for DoD facilities and bases, but also has information on relevant policies, organizations, programmatic issues, and resources. The book is separated into five primary sections.

2.1 Part One: Energy Policies, Regulations, Legislation, and Organizations

Part one covers energy policies, regulations, legislation, and organizations. It includes some of the key aspects of the Energy Policy Act, the Energy Independence and Security Act, several executive orders, as well as the DoD Instruction pertaining to energy. In addition, many of the federal organizations that have a role in energy are described and the resources, services and products are referenced.

2.2 Part Two: Traditional Energy Supply and Consumption

Part two provides important background information on traditional energy resources and consumption patterns. This section establishes the baseline for how the energy landscape has appeared in decades past. It details information on fossil fuels, including petroleum, coal, and natural gas, and it also covers other important traditional energy sources such as nuclear power and hydropower. Energy conversion technologies are covered in this section, including fluidized bed combustion, cogeneration, internal combustion engines, gas turbines, microturbines, Stirling engines, and fuel cells.

Consumption patterns for the federal government and, in particular, the DoD are detailed in this section as well. Energy demand patterns such as peak and off peak are covered, while important energy load characteristics such as peak, intermittent, and base loads are described. Plant parameters including, capacity, capacity factor, heat rate, efficiency, and costs are also defined in this section.

2.3 Part Three: Renewable and Alternative Energy Options

Following the traditional energy resources of part two, part three is the focus of this handbook, which is on renewable energy resources. This includes photovoltaics; solar thermal technologies; concentrating solar power; small and large wind conversion technologies; the thermochemical conversion of various biomass resources, such as agricultural-, forestry-, algae-, and waste-based feedstocks; and geothermal energy.

2.4 Part Four: Energy Storage, Transmission, Distribution, and Metering

Part four of this handbook briefly covers the emerging technologies of energy storage. Electrochemical, mechanical, and electromagnetic energy storage options are described. With sufficient technical advancement, energy storage can render some renewable energy technologies economically and practically competitive with traditional energy sources.

Part four also introduces concepts related to power transmission, distribution, and metering. These are important topics, especially when considering renewable energy generation options. Microgrids and smart grids are briefly introduced in this section.

2.5 Part Five: Making Smart Decisions

Part five covers some important aspects related to the evaluation of energy projects and focuses on life cycle cost analysis. Case studies and some lessons learned are also presented. It also provides a summary of the various financing and contracting options available to DoD agencies, as well as a brief description of renewable energy credits.

2.6 Appendices

Finally, the appendices provide a compendium of various useful energy related resources, tools, data compilations, and other valuable information. A complete list of acronyms and symbols that are used throughout the handbook is listed. Many of the terms related to energy and power are defined in a glossary. A comprehensive bibliography is included to provide a thorough list of references and useful sources for further information on all topics covered in this handbook.

2.7 List of Main Chapters, Document Map, and Cross-References

Although the handbook is divided into five main sections as described above, it is further divided into chapters to facilitate an arrangement of topics. The digital version (i.e., PDF) of this handbook has a document map associated with it. This document map is essentially a table of contents that allows the reader to quickly access any specific chapter or subsection in the handbook. To view this document map using Adobe Acrobat or Adobe Reader simply select the "Bookmarks" icon near the top left corner. In addition, many chapters and subsections are referred to from other subsections. The specific section that is referenced can be accessed by clicking on the cross-reference. Similarly, references and footnotes can be clicked on to access the bibliography or note, respectively.

Chapter	Title
Chapter 1	Executive Summary
Chapter 2	Contents of This Handbook
Chapter 3	Introduction
Chapter 4	Federal Energy Legislation, Requirements, and Goals
Chapter 5	Federal Energy Management Organizations, Programs, and Resources
Chapter 6	Energy Supply
Chapter 7	Facility Energy Usage
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Chapter 17	Energy Project Challenges and Lessons Learned

3 INTRODUCTION

The military's reliance on fossil fuels and the existing power grid results in significant risks on a tactical and strategic level. Health and environmental concerns with fossil fuel energy also adds to the incentive of implementing cleaner energy alternatives. Commercial renewable energy technologies are currently available, although their higher costs require research and development to decrease material and manufacturing costs, as well as funding incentives to implement renewable projects which should also lower their costs in the future. The Department of Defense owns, operates and maintains hundreds of thousands of buildings and facilities, requiring several billion dollars per year on energy costs. The DoD has recently introduced goals to implement renewable energy resources on its facilities and bases, considering both on-installation renewable energy projects and commercial renewable energy purchases. Strategies to purchase renewable energy are based on lifecycle cost analyses, benefits, and reliability. The DoD to needs to transition installation energy management strategy to one directed on cost avoidance, security, new technology implementation, while also being stewards of the environment.

In 2009, DoD spent more than $3.5 billion to power its facilities, which is almost a third of the DoD's total energy costs. Facilities energy accounts for approximately 40% of emissions due to their dependence on commercially operated fossil fuel power plants. The percentage of facility energy consumption and emissions are higher during periods of lower operational tempo as lower operational energy expenses are incurred along with reduced operational emissions. Many commercial power generating installations lack the ability to manage their demand for and supply of electricity, are vulnerable to cyber attacks and natural disasters, and overload of the grid. The US also has a high dependence on foreign energy resources resulting in less security for our country, while the money spent on foreign resources is hence not used for jobs and income for US citizens. Increasing renewable power and energy will provide green energy to the DoD, while increasing the safety, security, and overall well-being of US citizens.

DoD goals in renewable energy are to produce or procure 25% by 2025. The plan is to procure renewable energy projects where resources are abundant, and current energy prices are high to obtain the fastest return-on-investment (ROI). This in turn may reduce future renewable energy costs and increase fossil fuel costs, making renewable energy more attractive for additional locations.

There is no doubt fossil fuels currently have lower costs than renewable energy resources. Fossil fuel electricity generation is a very mature technology with established distribution of the fuels to the generating facilities (e.g., trucks, roadways, pipelines, trains, ships, etc.). However, as renewable energy resources mature, their costs are expected to decrease while fossil fuel costs increase. The average electricity cost in December, 2009 in the US, by state, is shown in Figure 1.

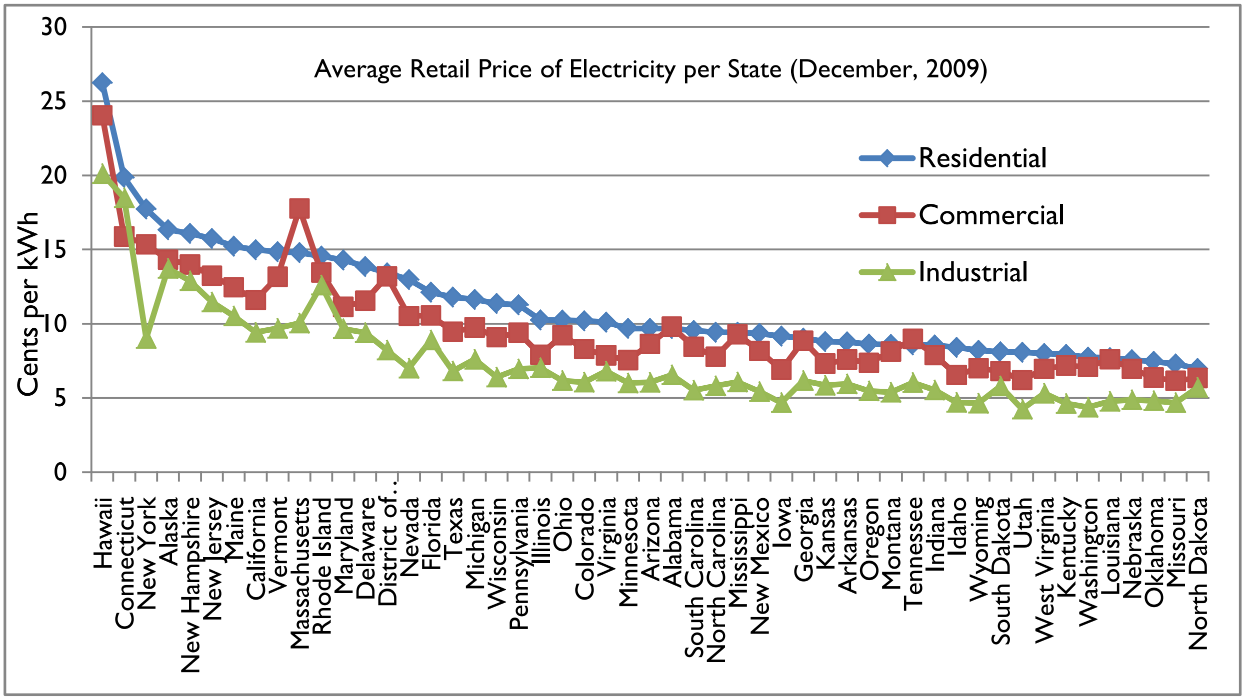


Figure 1. Average electricity costs in the US.

Along with changing costs, there are a number of additional factors to consider in selecting energy sources. Climate, geography, and access to natural resources add to the effectiveness of each of the energy resources. In addition, the health and safety aspects should be considered. Some energy resources require ample amounts of water for cooling and thus may not be feasible in water-restricted locations. Coal and nuclear plants perform best when run for long periods, whereas natural gas plants are designed to be brought on and off-line quickly. Renewable energy sources have the advantage of providing cleaner energy with improved safety in many cases. Some renewable resources, primarily wind and solar, cannot provide continuous power, and thus must be used with energy storage or other resources to meet electrical demands. The best strategy for cost effective, reliable, secure electricity generation is to implement a portfolio of plants of various energy resources to provide uninterrupted power and protect against price spikes in any one particular energy source. Using a smart grid to manage the distribution of electricity can also improve efficiency and security.

PART I: ENERGY POLICIES, REGULATIONS, LEGISLATION, AND ORGANIZATIONS

4 FEDERAL ENERGY LEGISLATION, REQUIREMENTS, AND GOALS

As the DoD adapts to the battlefield of the 21st century, the department must also adapt to the changing energy and environmental landscape. Implementing and complying with energy policies, requirements and goals instituted by the other branches of government is a complex challenge that requires substantial organization, strategy, planning, and execution. Not only is it a challenge because the department is the largest single consumer of energy in the US, but also because its ability to carry out its primary mission cannot be interrupted or compromised in any way.

The intent of recent federal energy policies and goals is to initiate the shift from nonrenewable energy sources to alternative and renewable energy options while further promoting environmental stewardship. This of course is a challenging and long-term process and is a task that requires a complexity of policies, requirements and goals. For the myriad government agencies, these can be cumbersome to navigate, institute, and ultimately ensure compliance.

Recent federal legislation has established goals and policies to improve energy efficiency and renewable energy use throughout the DoD. This legislation also established cross-agency programs and funding sources for the federal agencies to meets the goals. Since 2000, several executive orders have been signed into law, further increasing the energy efficiency and renewable energy usage goals established in federal legislation. From these executive orders and federal legislation, the DoD has established its own directives for achieving (and in some cases exceeding) the goals and policies set forth by the federal government.

As energy costs increase and environmental concerns about current energy sources rise, the DoD must broaden its focus to include providing power from alternative and renewable sources while promoting more efficient use of energy. This section details laws, policies, instructions, and guidance that pertain to facility energy consumption for the DoD. While many of these policies cover fuels and vehicle energy consumption, this handbook is focused on only the aspects that pertain to DoD facilities within the US. Additionally, the information contained in the following sections is not comprehensive, and in particular does not include short-term requirements of policies in which the deadline passed at the time of writing.

4.1 Energy Security

There is general acceptance that the US must diversify its energy portfolio in order to increase its independence from foreign sources of oil. However, the definition, description, and full scope of energy security are less agreed upon. While energy security could simply be considered as synonymous with energy independence, as stated above, the definition generally requires that access to energy is ensured. A couple of definitions are provided below.

From one perspective, energy security is simply surety, survivability, supply, sufficiency, and sustainability.[1] For instance, surety is access to power and fuel, survivability is the robustness of energy systems, supply is access to alternative and renewable energy sources, sufficiency is the adequateness of power, and sustainability is the impact to mission, community and the environment. Energy security has similarly been summarized as:

> "DoD facilities energy security encompasses sufficiency, surety, and sustainability. Above all, energy security means having adequate power to conduct critical missions for the duration of that mission (sufficiency). Secondarily, and leading to sufficiency, is ensuring resilient energy supplies that are accessible when needed (surety). Finally, the energy supplies must present the lowest life cycle cost, while considering all statutory and executive order requirements, as well as the impact to mission, community, and environment (sustainability)."[2]

Energy security and environmental stewardship are the primary driving forces behind the nation's movement toward alternative and renewable energy sources. The following sections describe public policies that institute goals and requirements to drive the implementation and execution of this movement.

4.2 Federal Legislation

Federal policy pertaining to energy has a very long history and there have been many legislative acts in the past century. One of the first federal acts pertaining to energy was the Federal Power Act of 1920, which established the Federal Power Commission, a predecessor of the Federal Energy Regulatory Commission. More than half of a century later, the Department of Energy Organization Act of 1977 merged several energy-related government agencies into a single department – the Department of Energy (DOE). While these two legislative acts are notable and while there were many enacted before and since, the following sections summarize important federal legislation as it pertains to DoD energy efforts.

In 1978 the National Energy Conservation Policy Act (NECPA) was signed into law by President Gerald Ford. This policy has served as the basis for federal energy policy, goals, and requirements since that time. Numerous subsequent policies; such as the Energy Policy Act (EPAct) of 2005, the Energy Independence and Security Act (EISA), Executive Order (EO) 13514; have amended the original act. Some of these policies are listed in Table 1.

Table 1. Federal policies pertinent to energy.

Year Enacted	Title	Reference Number
1978	National Energy Conservation Policy Act	42 U.S.C. 8253
1988	Federal Energy Management Improvement Act	P.L. 100-615
1992	Energy Policy Act of 1992	H.R. 776
2005	Energy Policy Act of 2005	P.L. 109-58
2007	Strengthening Federal Environmental, Energy, and Transportation Management	E.O. 13423
2007	National Defense Authorization Act FY 2007	P.L. 109-364
2007	Energy Independence and Security Act	P.L. 110-140
2009	Federal Leadership in Environmental, Energy, and Economic Performance	E.O. 13514

4.2.1 Energy Policy Act of 2005

The Energy Policy Act of 2005 was written in response to rising concerns about the security of domestic energy supplies. The EPAct of 2005 built on goals set forth in the EPAct of 1992 and other existing executive orders and legislation. Several of the policies enacted in the EPAct 2005 have had a significant impact on the management and use of energy at DoD facilities. For instance, the EPAct 2005 set new goals for energy-efficient and renewable power usage in addition to defining the sources from which renewable energy is obtained.

4.2.1.1 Energy Usage Reduction

In an effort to improve energy efficiency, the EPAct of 2005 established a new goal for the reduction of energy usage in federal facilities. This goal required that energy usage at federal facilities be reduced by a minimum of two percent annually. Beginning in fiscal year (FY) 2006 federal facilities were required to meet the annual energy usage reduction goals through FY 2015, cumulating to 20 percent total reduction by the end of the goal period (see Table 2). The baseline for measuring energy reduction was established as the energy consumption per gross square foot in FY 2003.

Table 2. Percent reduction in energy usage.[i]

Fiscal Year	Cumulative Percent Reduction
2006	2
2007	4
2008	6
2009	8
2010	10
2011	12
2012	14
2013	16
2014	18
2015	20

4.2.1.2 Facility Exemptions from Established Goals

Some federal facilities may receive exemption from the energy reduction goals set forth in Section 102 of the EPAct of 2005 if:

- The agency has achieved the energy efficient requirements of the 1992 and 2005 EPActs, and any relevant federal laws or executive orders.
- The agency has implemented every practical energy-efficiency improvement project at the facility(ies) that are requesting exemption.
- Compliance with these requirements would be impractical because operations at the facility are of importance to national security.
- Compliance with these requirements would be impractical because of the intensity of the energy that the activities require.

4.2.1.3 Energy Metering

To facilitate the more efficient use of energy and reduce the cost of electricity used in federal facilities the EPAct of 2005 Section 103 established energy metering requirements. It established a requirement that all federal buildings be metered by October 1, 2012, and as often as practical, advanced meters or metering devices are to be used. The advanced meters provide data on a daily basis at least and measure electricity consumption hourly at minimum. Guidance on the implementation of electric metering has been published by the Department of Energy.[3]

In addition, each federal agency was directed to submit a plan describing the implementation of advanced metering. Alternatively, if metering was determined to not be practicable, this was to be demonstrated and documented in the plan.

4.2.1.4 Requirement for Procuring Energy Efficient Products

To further help reach the energy reduction goals set forth in Section 102, the EPAct of 2005 requires that federal agencies must procure only Energy Star or Federal Energy Management Program (FEMP)-approved products for use in facilities (Section 104). However, this requirement does not apply to energy consuming products and systems that are acquired for the purpose of combat or to be used in combat-related missions. Additional exceptions to this requirement include:

- The Energy Star or FEMP-designated product is not cost effective over its life-cycle accounting for energy cost savings.

[i] EPAct 2005, Section 102, pp. 119 Statute 106

- A product that meets the functional requirements of the procuring agency is reasonably unavailable.

4.2.1.5 Energy Efficiency Standards for New Federal Buildings

The EPAct of 2005 sets forth higher energy efficiency standards for new federal buildings. Previously, the design of federal buildings had to meet American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and International Energy Conservation Code (IECC) standards. Section 109 requires that new federal building designs must be able to meet energy consumption levels that are 30 percent less than ASHRAE and/or IECC standards. In addition, the EPAct of 2005 requires that sustainable design principles are applied to the "siting, design, and construction of all new and replacement buildings."

Agencies may receive exemption from the 30 percent requirement, if the building design achieved a rate that was 30 percent lower than ASHRAE/IECC standards before the EPAct of 2005 was written. Agencies may also be exempt if achieving the 30 percent level is not life-cycle cost-effective.

4.2.1.6 Requirement for Renewable Energy

The EPAct of 2005 added a requirement to the federal government that mandates the use of renewable energy sources. Section 203 of the EPAct of 2005 establishes a minimum requirement for the amount of electric energy consumed by the federal government that must be produced by renewable means (see Table 3).

Table 3. Renewable energy requirements for the federal government.[ii]

Fiscal Year	Percent Consumed
2007 - 2009	≥ 3
2010 - 2012	≥ 5
2013+	≥ 7.5

Renewable energy sources, as specified in Section 203, are "electric energy generated from solar, wind, biomass, landfill gas, ocean (including tidal, wave, current, and thermal), geothermal, municipal solid waste, or new hydroelectric generation capacity achieved from increased efficiency or additions of new capacity at an existing hydroelectric project".[ii] To further encourage the use of renewable energy, the credit toward goals outlined in Table 3 are doubled if any of the following occur:

- The energy is produced and used on-site (i.e., at a federal facility).
- The energy is produced on federal lands and consumed at a federal facility.
- The renewable energy is produced on Native American land as defined in Title XXVI of the 1992 EPA.

In addition, the EPAct of 2005 supported the goal of the 1997 Federal Government's Million Solar Roofs (MSR) Initiative that set out to achieve the installation of solar energy systems in 20,000 federal buildings by 2010. The intent was to further help federal agencies meet the goals set forth in Section 203. The MSR Initiative was concluded in 2006.[4]

4.2.2 National Defense Authorization Act

The National Defense Authorization Act (NDAA) for FY 2007 became Public Law 109-364 on October 17, 2006. This legislation is particularly relevant to defense energy since it set a higher standard for

[ii] EPAct 2005, Section 203, 119 Statute 652

implementing renewable energy in the DoD. The NDAA for FY2010 amended the terms of the FY07 NDAA renewable energy goal to make it more clear and defined.

4.2.2.1 Renewable Energy

Section 2852 of the FY07 NDAA set forth a new renewable energy goal to meet the DoD's electricity needs. The new goal is 25 percent of the electric energy consumed by the DoD shall be produced or procured from renewable resources by 2025. This goal became part of the US Federal Code in Section 2911(e). This terms used to set this goal are different than those used for the EPAct 2005 requirement, and therefore the DoD has reported two different renewable energy metrics.

Section 2842 of the FY10 NDAA amended 2911(e) by removing "electric energy" and replacing it with "facility energy". This essentially allows thermal energy to be counted toward the renewable energy goal.

4.2.3 Energy Independence and Security Act

Signed into law in December 19, 2007, by George W. Bush, the Energy Independence and Security Act established energy policy to improve overall energy efficiency and increase the availability and use of renewable energy sources.[5] The energy efficiency policies developed in EISA have a significant impact on the operation of existing federal facilities and the design of future federal buildings.

4.2.3.1 Energy Intensity Reduction

Most significantly, EISA superseded the energy requirements that were set forth in the EPAct of 2005 by increasing the overall energy reduction goals for all federal facilities. Instead of 20 percent energy usage reduction by 2015, as stated in the EPAct of 2005, all federal facilities (with some exception) are required to achieve 30 percent energy usage reduction by 2015. The minimum percentage of reduced energy usage escalates annually from 2006 until 2015 as listed in Table 4. The rate of reduction is nearly identical to the requirement found in Executive Order 13423 (see Section 4.3.1), which preceded the EISA. Similar to the EPAct of 2005, this energy reduction requirement is established for comparison with the energy consumed per gross square foot in FY 2003.

Table 4. Percent reduction in energy usage.[iii]

Fiscal Year	Percent Reduction
2006	2
2007	4
2008	9[iv]
2009	12
2010	15
2011	18
2012	21
2013	24
2014	27
2015	30

4.2.3.2 Building Leasing Restriction

To help achieve these energy requirements, Section 435 of the EISA prohibits federal agencies from leasing a facility that has not earned the Environmental Protection Agency (EPA) Energy Star label within the previous year. This restriction begins in December 2010 (i.e., three years after the EISA was signed into law).

Facilities can be exempted from this policy if there is no space in an Energy Star-labeled building that meets the operational needs of a federal agency. In addition, a building can receive an exemption if the agency is leasing space in a building it has occupied previously; if the building is of historical, architectural or cultural significance; or if the lease is for less than 10,000 square feet.

4.2.3.3 Reduction in Consumption of Fossil Fuel Energy in New and Renovated Buildings

Section 433 of the EISA requires the gradual step-down and eventual elimination of fossil fuel-generated energy sources consumed at any new federal building or major renovations. Table 5 lists the required percent reductions in fossil fuel-derived energy at new and renovated federal buildings, as compared to the energy consumption by a similar building in FY 2003. Sustainable design principles are required for siting, design, and construction. For new facilities proposed or major renovations planned prior to the EISA, the Office of the Federal Procurement Policy was required to provide guidance to direct the renegotiation of the designs such that they would comply with the new policy.

Table 5. Percent reduction in usage of energy derived from fossil fuels.[v]

Fiscal Year	Percent Reduction
2010	55
2015	65
2020	80
2025	90
2030	100

These percentage reduction requirements can be lessened for a specific building if it can be demonstrated that meeting such requirements would be technically impractical considering the functional needs of the building.[v] For privatized military housing the DoD may be permitted to develop

[iii] EISA, Section 431, p. H.R. 6-116
[iv] EISA accounted for the requirements that existed during the two previous fiscal years (FY 2006 and 2007) and then required a 9 percent reduction from the FY 2003 baseline in FY 2008 and 3 percent annual reductions thereafter.
[v] EISA, Section 433, p. H.R. 6-121

alternative criteria to the required percentage reduction in energy derived from fossil fuels so long as equivalent energy savings, sustainable design, and green building performance can be achieved. The EISA also directed the DOE with assistance from the DoD and General Services Administration (GSA) to develop a green building certification system and level.

Section 523 of the EISA requires each new federal building or a facility undergoing a major renovation to utilize solar hot water heaters to provide a minimum of 30 percent of the hot water demand.

4.2.3.4 Energy Efficient Replacement of Equipment and Renovation of Existing Facilities

Section 434 of the EISA pertains to the replacement of heating and cooling equipment and the renovation of facilities that are not considered major renovations (covered under section 433). The policy requires that such efforts employ the most energy efficient and life cycle cost effective designs, systems, equipment, and controls.

Each federal agency is required to develop a process that enables a review of each major equipment upgrade to ensure that it meets the requirements. The federal agency is then required to report this process to the Director of the Office of Management and Budget (OMB).

4.2.3.5 Energy Metering

Section 434 of the EISA requires that all federal agencies establish metering for natural gas and steam by October 1, 2016.

4.2.3.6 Energy Management

Each federal agency, according to section 432, is required to identify all covered facilities that constitute 75 percent or more of an agency's facility energy use.[6] A covered facility is a group of facilities at one or more locations that are managed as an integrated operation. The agency must designate an energy manager for each covered facility.

The EISA further requires that energy managers perform annual comprehensive energy and water evaluations for 25 percent of each agency's facilities. (For DoD instruction regarding this requirement, refer to *Section 4.4.2.7.3*.) This will hence require that each facility is evaluated every four years. Consequent to these evaluations, if the energy manager implements any energy or water-saving measure, they are required to ensure that the equipment and controls, once fully commissioned, operate according to design specifications. The energy manager is further required to implement an operations, maintenance, and repair plan upon commissioning and to ensure that the plan is followed. Moreover, the energy manager is required to measure equipment and system performance during the entire life of the system to ensure it operates, is maintained, and is repaired properly. Finally, the energy manager is required to measure and verify energy and water savings.

The DOE was directed by the EISA to develop a web-based tracking system. This purpose of this system is to certify compliance with the aforementioned facility energy management requirements. It is also intended to track the "estimated cost and savings for measures required to be implemented in a facility," as well as the "measured savings and persistence of savings for implemented measures."[vi] Facility energy managers are required to enter benchmarking information into the system and update it yearly. DoD Instruction (DODI) 4170.11 (see *Section 4.4.2*) directs DoD components to use spreadsheets provided by the Deputy Under Secretary of Defense (Installations and Environment) (DUSD(I&E)) to report energy usage until the DoD issues guidance on the use of a DOE web based system.[7]

[vi] EISA, Section 432, p. H.R. 6-119.

Through the Energy Star program, the DOE has released a web-based tool called "Portfolio Manager" that enables energy managers to track and improve energy efficiency at their facilities. The tool is available at https://www.energystar.gov/istar/pmpam/.

4.2.3.7 Product Procurement

The EISA in section 525 requires the procurement of Energy Star or Federal Energy Management Program-designated products. Section 524 of the EISA requires that federal agencies purchasing commercial-off-the-shelf (COTS) products that employ a standby mode mush choose a product with a draw of 1 watt or less (if practical) in standby mode. If such a product is not available, the product with the lowest available standby power wattage will suffice. This requirement only applies if the product is life-cycle cost effective, practicable, and does not negatively affect the utility and performance of the product.

4.2.3.8 Energy Savings Performance Contracts

The EISA includes several sections that were intended to facilitate the use of energy savings performance contracts (ESPCs). Section 514 permanently authorizes ESPCs. Section 511 eliminates the requirement for reporting on ESPCs that have a cancellation ceiling of more than $10 million. Section 512 permits a federal agency to use any combination of appropriated funds and private financing under an ESPC. This improves the flexibility of ESPCs.

Section 513 restricts federal agencies from limiting the maximum contract term to less than 25 years. This section of the EISA further restricts federal agencies from limiting the total amount of obligations under ESPCs or other private financing when used for energy savings measures. In addition, federal agencies are permitted to use the measurement and savings verification to satisfy the requirements for energy audits, calculation of energy savings, and any other evaluation of costs and savings.

Section 515 redefines *energy savings reduction* to include the following:[vii]

- The increased use of an existing energy source by cogeneration or heat recovery
- The sale or transfer of electrical or thermal energy generated onsite from renewable sources or cogeneration, but in excess of federal needs, to utilities or non-federal energy users

Section 516 removes a restriction and thus allows federal agencies to retain the full cost savings from energy and water utility incentive programs.

Section 517 essentially facilitated the establishment of an ESPC training program available to contract officers.

4.2.3.9 Reporting Requirements

Section 527 requires each federal agency, which is bound by any requirement of the EISA, to annually compile and submit an efficiency status report to the Director of the Office of Management and Budget. The report is to include the following:

- Compliance with each of the pertinent requirements of the EISA
- Status of the implementation of initiatives to:
    - Improve energy efficiency
    - Reduce energy costs
    - Reduce emissions of greenhouse gases (GHGs)
- Savings to the taxpayers

[vii] EISA, Section 515, p. H.R. 6-168

4.3 Executive Orders

4.3.1 Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation Management

Executive Order (EO) 13423, was signed in January 2007 and established goals and policies to improve overall energy efficiency and security. The EO preceded the EISA of 2007 but the policies and goals set forth in EO 13423 supersede those in EO 13101 (September 1998), EO 13123 (June 1999), EO 13134 (August 1999), EO 13148 (April 2000), and EO 13149 (April 2000).

Some of the goals set forth in EO 13423 are more ambitious than those set forth in the EPAct of 2005. Instructions for implementing the policies established in EO 13423 were published by the Council on Environmental Quality, which is an organization in the Executive Office of the President.[8] The instructions define agency requirements for implementing the EO and also define the general strategies for achieving them.

4.3.1.1 Energy Intensity Reduction

Section 2 (a) of EO 13423 sets forth the requirement to reduce energy intensity. By the end of fiscal year 2015, each federal agency must reduce their energy intensity by 3% annually or 30% overall relative to 2003 agency baseline energy usage. This goal was transformed into law with the signing of the EISA of 2007 (see *Section 4.2.3.1*).

4.3.1.2 Renewable Energy

Section 2 (b) of EO 13423 requires an increased usage of new renewable energy. The EPAct of 2005 set forth specific requirements for the minimum amount of electricity consumed that must be derived from renewable sources (see *Section 4.2.1.6*). The EO further requires that at least half of the renewable energy consumed by an agency each fiscal year must be obtained from *new* renewable sources. In this case, "new" means that the renewable energy generation source must have been in service after January 1, 1999.[9] In addition, the EO encourages that each federal agency implement renewable energy generation projects on agency property for agency use to the extent feasible.

4.3.1.3 Acquisition of Goods and Services

Section 2 (d) cites the requirement of the head of each federal agency to ensure that when goods and services are acquired they are among other things, energy-efficient.

4.3.1.4 Sustainability Guidance for New and Existing Buildings

Section 2 (f) requires that new construction and major renovation projects for agency buildings comply with the guiding principles established in the *Federal Sustainable Buildings Memorandum of Understanding*.[10] The EO further requires 15 percent of each agency's existing federal buildings to incorporate the sustainable practices given in the guiding principles by the end of FY 2015.

4.3.1.5 General Guidance on Energy Efficiency and Sustainability

The responsibility for achieving these goals falls primarily to the heads of the federal agencies. The agency heads are required to implement practices to improve energy efficiency, reduce or eliminate greenhouse gas emissions, reduce the use of petroleum products, and employ renewable energy technologies. These practices must also be sustainable, so that they don't become time and cost prohibitive.

4.3.1.6 Exemptions

There are however, some instances in which an activity may obtain an exemption from the policies set forth in EO 13423. The Director of National Intelligence can exempt an intelligence activity (including people, resources, and facilities) to protect intelligence sources and processes from disclosure.[viii] Agency heads can obtain an exemption from EO 13423 for facilities and resources used in agency law enforcement activities. Additional exemptions for agency activities can be applied for through the requisite Council on Environmental Quality (CEQ) Chair. These exemptions are submitted to the President for approval.

4.3.2 Executive Order 13514 – Federal Leadership in Environmental, Energy, and Economic Performance

Executive Order (EO) 13514, signed in October 2009 by President Obama, followed and expanded upon EO 13423. It set forth numerous additional federal energy requirements and established policy directed toward the goal of reducing greenhouse emissions for all Federal Agencies.[ix] Many of the goals of EO 13514 focus on improving emissions standards for new buildings and establishing new standards to improve emissions in existing structures.

4.3.2.1 Reducing Greenhouse Gas Emissions through Energy Reduction and Renewable Energy

The EO enforces the establishment of a target by which greenhouse gas emissions are to be reduced compared to a 2008 baseline. The reductions are to be achieved, among other methods, by:

- Reducing the energy intensity in agency buildings
- Increasing use of renewable energy and implementing onsite renewable energy generation projects
- Reducing use of fossil fuels

Section 9 of the EO required the Department of Energy, through its Federal Energy Management Program, to establish procedures for accounting and reporting on GHG emissions, which are to be updated every three years. Additionally, the EO requires the FEMP to provide an electronic accounting and reporting capability.

4.3.2.2 Advanced Planning through Integrating Federal and Local Efforts

The EO encourages federal agency cooperation with regional and local planning by setting forth various requirements. For instance, federal agencies are required to align federal policies to increase the effectiveness of local planning, such as locally generated renewable energy. Furthermore, for new or expanded federal facilities the EO requires federal agencies to identify and analyze the impacts from energy usage and alternative energy sources in all environmental impact statements (EIS) and environmental assessments. Moreover, federal agencies are required to coordinate with regional programs for environmental management.

4.3.2.3 Sustainable Buildings

Executive Order 13514 requires federal agencies to implement not only the design of high performance sustainable buildings, but additionally, sustainable construction, operation and management, maintenance, and deconstruction. The following are directives further detailing this requirement:

[viii] EO 13423, p. 3922
[ix] EO 13514, p. 52117

- Beginning in 2020, all new federal buildings that enter the planning process must be to achieve net-zero energy by 2030.
- All new construction and major renovations to federal buildings must comply with the guiding principles established in the *Federal Sustainable Buildings Memorandum of Understanding*.[10]
- A minimum of 15% of existing facilities and leased facilities (larger than 5,000 gross square feet) must meet the guiding principles established in the *Federal Sustainable Buildings Memorandum of Understanding*.[10]
    - Federal agencies must also make annual progress toward 100 percent conformance with the guiding principles for existing federal buildings.
- Minimize energy consumption through cost-effective, innovative strategies, such as highly reflective and vegetated roofs.
- Manage existing building systems to reduce the consumption of energy.
    - Identify alternatives to renovation that reduce existing assets' deferred maintenance costs.
- When adding assets to the agency's real property inventory, identify opportunities to:
    - Consolidate and dispose of existing assets
    - Optimize the performance of the agency's real property portfolio
    - Reduce associated environmental impacts
- Utilize best practices and technologies when rehabilitating federal historic buildings to promote long-term viability of the buildings.

Additionally, the EO required the Department of Transportation to provide recommendations to location strategies for sustainability plans. In particular, the recommendations are intended to promote sustainable development of new federal facilities.

4.3.2.4 Energy Efficient Products and Services

Executive Order 13514 requires that 95 percent of new contract actions (that include task and delivery orders) for products and services are energy-efficient (i.e., Energy Star or FEMP designated) with the exception of the acquisition of weapon systems or in instances where the product or service will not meet performance requirements. In particular, the EO requires the promotion of electronics stewardship and preference toward EPEAT-registered electronic products, Energy Star and FEMP designated electronic equipment.

4.3.2.5 Limitations and Exemptions

Executive Order 13514 is applicable to the components of a federal agency that are within the US. Applicability to components outside the US can be determined by the head of the respective agency.

There are some instances in which an activity may obtain an exemption from the policies set forth in EO 13514. The Director of National Intelligence can exempt an intelligence activity (including people, resources, and facilities) to protect intelligence sources and processes from disclosure.[x] Agency heads have the authority to exempt law enforcement activities from EO 13514 when it is necessary to protect undercover operations. The head of an agency is also permitted to exempt particular agency activities and facilities if they are vital to the interests of national security. Additional exemptions for agency

[x] EO 13514, p. 52125

activities can be applied for through the requisite CEQ Chair. These exemptions are submitted to the President for approval.

4.4 DoD Policies, Strategies, and Plans

The Department of Defense has issued policies, strategies, and plans to integrate the facility energy efforts of the services and other defense agencies. While these may be updated periodically and new plans and strategies may be implemented, the key elements as of the writing of this handbook are captured in the following sections.

4.4.1 DOD Directive 4140.25 – DoD Management Policy for Energy Commodities and Related Services

DOD Directive (DODD) 4140.25 was reissued April 12, 2004 to supersede the directive issued August 25, 2003. The directive was reissued in order to update policy and responsibilities pertaining to energy management, fuel usage, and publication authorization.

4.4.1.1 Facility Energy Management

DOD Directive 4140.25 denotes that the Deputy Under Secretary of Defense (Installations and Environment) is responsible for serving as the department's central manager for facility energy policy on installations, electricity, coal, natural gas, propane, heating fuels, and steam.

4.4.1.2 Energy Commodity and Storage and Distribution Infrastructure Management

The directive further denotes that it is the responsibility of the Defense Logistics Agency (DLA) for the materiel management of petroleum, including infrastructure for the storage and distribution of the energy commodity. It is further the responsibility of the DLA to manage agreements pertaining to energy commodities and facilities. The directive also denotes that the DLA is responsible for support in procuring coal and natural gas.

4.4.1.3 Army Responsibilities

The directive requires the Army to provide wartime planning and management of overland petroleum distribution. In addition, the Army must provide support for installing and maintaining tactical storage and distribution systems.

4.4.2 DoD Instruction 4170.11 – Installation Energy Management

DOD Instruction 4170.11 addresses energy management for Department of Defense installations. DODI 4170.11 was reissued on December 11, 2009 to incorporate changes in public laws, namely EPAct of 2005 and the 2007 EISA, and the policy requirements from EO 13423. It thereby superseded the DODI 4170.11 issued on November 22, 2005. The instruction implements policy established in DODD 4140.25. It further establishes guidance, responsibilities and procedures for installation energy management.

4.4.2.1 General Purpose of the Policy

The policies developed in DODI 4170.11 are intended to ensure that the DoD utility infrastructure is secure, safe, reliable and efficient, and that utility commodities are procured in an effective and efficient manner. In addition, this instruction sets forth policy to ensure that the DoD invests in cost-effective renewable energy sources and energy efficient facility designs.[xi] Further, the instruction establishes the

[xi] DODI 4170.11, p. 2

policy that the DoD regionally consolidate requirements for the purpose of leveraging bargaining power when negotiating energy deals. DODI 4170.11 is applicable to all US-funded facilities.

4.4.2.2 Policy Development

The DODI 4170.11 requires that DoD policy initiatives regarding energy efficiency and consumption reduction to be coordinated through an interservice working group forum led by DUSD(I&E).

4.4.2.3 Goals

The DODI 4170.11 sets forth several goals for the DoD, in addition to goals from the EISA. The following are some of the goals that the department as a whole is set to achieve:

- Modernize the infrastructure
- Increase utility and energy conservation
- Enhance demand reduction
- Improve energy flexibility

The instruction further establishes that specific program goals are to be published through DUSD(I&E) memorandums as required.

4.4.2.4 Defense Organizational Responsibilities

The DODI 4170.11 prescribes various responsibilities regarding facility energy management to specific organizations in the DoD. These responsibilities are detailed in *Chapter 5*. The instruction generally directs various tasks to the heads of DoD components. Some of these are as follows:

- Designate government personnel to represent the DoD component in organizations (national, international, government, or industry) that deliberate installation energy policy matters
    - Coordinate any contact with international organizations with the Under Secretary of Defense for Policy
- Designate energy managers for covered facilities as required by the EISA (see *Section 4.2.3.6*)
    - These energy managers are responsible for implementing the requirements of all applicable laws, policies and DoD issuances at their facilities
- Provide program and budget funds to meet energy goals
- Implement DoD policies and procedures to measure progress in meeting energy goals
- Report energy use and progress in meeting conservation goals, program costs, and Energy Conservation Investment Program (ECIP) program (see *Section 5.5.2*) execution
- Develop programs that result in facilities that achieve optimum performance and maximize energy efficiency
- Provide trained energy program managers, operators, and maintenance personnel for facilities
    - Conduct training programs to ensure energy efficient operation and maintenance of sustainable facilities (see *Section 4.4.2.6*)
- Require the following for leases of contractor-operated, government-owned facilities:
    - Implement energy conservation procedures
    - Permit contract modification to accommodate energy efficiency improvements

    - Measure and report energy use and resulting savings
- Develop internal energy awareness programs with the following objectives
    - Create awareness of energy conservation goals
    - Disseminate information on energy matters and conservation techniques
    - Emphasize energy conservation at all levels
    - Relate energy conservation to operational readiness
    - Promote energy efficiency awards and recognition
    - Promote energy awareness at the workplace
    - Observe October as energy awareness month
- Assign representatives to participate in interagency working groups in support of the Interagency Energy Management Task Force (IATF, see *Section 5.1*) as required

4.4.2.5 Reporting Mechanisms

The DODI requires several reporting mechanisms to be used for the purposes of tracking energy conservation, investments, and performance. The following sections provide more detail on these reporting mechanisms.

4.4.2.5.1 Annual Energy Management Report

The EISA requires the DoD, among other federal agencies, to submit an annual report (see Section 4.2.3.9). The Annual Energy Management Report (AEMR) is the primary mechanism used by the DoD to track and measure its energy performance. The format is determined by the DOE on an annual basis. The DODI instructs DoD components to maintain a utility energy reporting system to prepare the data for the AEMR.

In addition to the AEMR, DODI 4170.11 requires DoD components to submit a long-term plan and strategy for achieving the requirements of EPAct of 2005, EISA, and EO 13423. This should be submitted along with the AEMR. The plan and strategy can be updated annually with the AEMR. The DUSD(I&E) is responsible for compiling inputs from DoD components and submits the report.

4.4.2.5.2 Energy Conservation Investment Program

The ECIP (see *Section 5.5.2*) requires DoD components to notify Congress prior to execution of a project under the program. In addition, DoD components are required to submit quarterly project status updates for active projects to DUSD(I&E) within 30 days of the end of each fiscal quarter.

4.4.2.6 Training and Awareness

According to DODI 4170.11, the DoD components are responsible for their own energy programs including awareness campaigns, training, and education. The training and education can be administered through commercially-available or internal programs including technical courses, seminars, conferences, software, videos, and certifications.

Awareness programs are required for the DoD component to promote goals, tools, and progress at various organizational levels. This can be accomplished through web sites, conferences, emails, displays, reports, newsletters, handbooks, or other methods.

DoD components are required to have award programs that recognize individuals, organizations, and installations for their energy conservation efforts. On-the-spot and incentive awards are required to acknowledge exceptional performance. The instruction further recommends participation in the DOE's Federal Energy and Water Management Awards Program.

The DoD is required to emphasize the benefit of showcase facilities; preferably one per service per year. Such facilities offer demonstration of best practices and innovative techniques for improved energy efficiency.

4.4.2.7 Energy Efficiency

The DODI requires DoD components comply with the EISA, specifically to ensure all large capital energy investments in facilities use energy efficient designs, systems, equipment, and controls so long as they are life cycle cost effective. There are further requirements for life cycle cost analysis (LCCA).

4.4.2.7.1 Life Cycle Cost Analysis

Life cycle cost analysis is required when making investment decisions about products, services, construction, and other projects related to energy consumption. The instruction further requires that DoD components implement all projects that have a 10 year or less simple payback as long as it is financially feasible. The instruction recommends combining projects and aggregating energy efficiency projects with renewable energy projects when considering life cycle costs.

4.4.2.7.2 Passive Solar Designs

The instruction requires DoD components to use passive solar designs when they are cost effective over the life of the project.

4.4.2.7.3 Facility Energy Audits

The EISA requires a complete energy evaluation for 25% of federal facilities every four years (see *Section 4.2.3.6*). DODI 4170.11 reiterates this requirement and directs it to energy managers for each DoD component. Results of the audit must be entered into the DOE database as required by the EISA. However, the DoD instruction states that performing these energy audits may be cost prohibitive for the department to accomplish. As an alternative approach in order to comply with the legislation, the DoD advises the use of utility energy services contracts (UESCs) and ESPCs for executing the energy audits. Planning software and decision screening systems are suggested for assisting in the process of determining the investment required to meet energy reduction goals.

4.4.2.7.4 Sustainability Initiatives

According to the DODI, life cycle cost analysis is required for sustainable development projects, which are additionally required to adhere to the Whole Building Design Guide.[xii] Military construction (MILCON), facility repair, and sustainment projects are required to include an energy analysis to comply with EISA, EOs, and the Code of Federal Regulations, Section 434 of Title 10.

New construction and major renovations are required to perform 30 percent better than ASHRAE Standard 90.1-2004. Additionally, they are required to incorporate the five guiding principles established in the *Federal Sustainable Buildings Memorandum of Understanding*.[10] Renewable energy systems are required to be considered, but only if they are cost effective based on a LCCA. A Leadership in Energy and Environmental Design (LEED) rating of silver or equivalent is further required. Costs associated with sustainable development are required to be reported on DD Form 1391.[11]

4.4.2.7.5 Repair and Minor Construction

The DODI requires that energy efficiency is considered when executing minor construction or repair. Such efforts are to be incorporated using operations and maintenance (O&M) funding.

[xii] Whole Building Design Guide, www.wbdg.org

4.4.2.7.6 Energy Conservation Investment Program Requirements

Energy Conservation Investment Program funds are required to be allocated evenly based on the previous year's facility energy use and obligation rate for the past five years. When submitting a proposed project, the method used for savings verification must be identified on DD Form 1391. Project title, installation, savings to investment ratio (SIR), payback, estimated project cost, and annual energy savings (in BTUs) must be included. A minimum SIR of 1.25:1 is required. Up to 25 percent of annual ECIP budget is permitted for use on renewable energy applications that do not meet the SIR and payback period criteria.

4.4.2.7.7 Alternative Financing

The DODI requires that any payments made on an alternative financing agreement must be from energy or water related cost savings. The contract file must contain the basis for all cost savings that will be used to pay for the project.

4.4.2.7.8 Data Management

DoD components are required to track all costs (estimated and actual), savings (estimated and verified), interest rates, measurement and verification information, mark-ups, and changes to project scope that may affect costs and savings. The DODI directs DoD components to use spreadsheets provided by DUSD(I&E) to report energy usage until the DoD issues guidance on the use of a DOE web based system.

Financed project agreements are required to have a project facilitator. Furthermore, the component is required to ensure that annual costs do not exceed savings and contracts are awarded to and executed by trained and experienced teams.

4.4.2.7.9 Audits

A DoD contracting center that awards or administers an ESPC or task order is required to conduct internal audits at least every five years. The audits are intended to ensure project performance and guaranteed savings.

4.4.2.7.10 Procurement of Energy Efficient Products

When life cycle cost effective, DoD components are required to select energy efficient products, such as those designated by the FEMP or have the Energy Star label. The DODI designates the DLA distribution centers as the focal point for the procurement of energy efficient products. Procuring agents are required to procure products that are in the top 25 percent for energy efficiency.

4.4.2.7.11 Solar Hot Water

As required in the EISA (see *Section 4.2.3.3*), the DODI requires that a minimum of 30 percent of facility hot water is generated through solar hot water heaters in new construction or facilities undergoing major renovation.

4.4.2.8 Energy Security and Flexibility

The DODI requires that DoD components enact steps to ensure the security of energy resources. This includes vulnerability assessments, assurance of critical assets, use of renewable energy and distributed energy, and a procurement strategy.

4.4.2.8.1 Vulnerability Assessments

The instruction requires installations to perform periodic evaluations of basic mission requirement vulnerability to disruptions in energy supply. The risk of any disruption also must be evaluated and actions to eliminate unacceptable energy security risks must be implemented. Additionally, off-base utility distribution and energy supply systems must be investigated periodically. The critical nodes of any systems that are found to have unacceptable risk implications must be nominated for the Defense Critical Infrastructure Program, which falls under DODD 3020.40.

4.4.2.8.2 Renewable Energy

The instruction requires the implementation of passive solar designs in new facility construction. Furthermore, when cost effective, DoD components are required to purchase renewable energy at a fair market price. Additionally, when cost effective, energy efficiency opportunities in renewable energy technologies must be pursued.

4.4.2.8.3 Distributed Energy Generation

For the purposes of providing flexibility and energy security to mitigate unacceptable risk, the DODI requires the use of distributed energy resources, such as microturbines, fuel cells, combined heat and power (CHP) and renewable technologies. For mission critical and remote sites that require off-grid generation systems that are owned and operated by the DoD component, innovative energy generation technology must be used. These include solar lighting, photovoltaic arrays, wind turbines, microturbines and fuel cell demonstration projects.

4.4.2.8.4 Procurement Partnerships and Strategy

The DODI requires that components competitively acquire direct supply natural gas (DSNG) under the Defense Energy Support Center (DESC) program (DSNGP), when cost effective and as reliable as other practical alternative energy sources. All capable DoD installations are required to participate in DSNGP. There are some additional exceptions for installations.

4.4.2.9 Conservation Metrics

When energy management control systems (EMCSs) are installed, the DODI requires that these systems are provided with the sufficient O&M support in order to maintain efficiency and the subsequent savings. The DODI requires energy managers to ensure compliance with building energy usage benchmarking and reporting requirements specified in the EISA.

4.4.2.9.1 Energy Metering

The EISA and EPAct of 2005 requires meters and submeters for all appropriate facilities. The DODI specifies that the appropriate facilities are those where metering is cost effective and practical. Electricity, natural gas, and water metering at all appropriate facilities are required to be implemented by 2012. Meters are also required in all MILCON and ESPC projects, as well as major renovations. For facilities that are not appropriate for metering, the determination of exemption is required to be documented. Advanced digital meters are required when utility costs exceed guidelines specified in the *DoD Energy Manager's Handbook*.[12] These meters are also required on all new construction and utility system renovations that are greater than $200,000. In individual cases where advanced meters are not practical, more conventional meters can be used. Safety switches are required for all new electrical metering systems.

4.4.2.9.2 Electrical Load Reduction

DoD components are required by the DODI to reduce electricity consumption during power emergencies by identifying load shedding techniques. Examples of the techniques are listed in the DODI.

4.4.2.10 Utilities Privatization

The DODI requires with some exception that DoD components privatize electric and natural gas utilities. Some systems can be excepted by the Secretary of Defense due to security or economic viability issues, or due to pending base closure. The services are required to provide funding to support privatization contracts.

When considering privatization, a margin of error analysis must be incorporated in utilities privatization efforts and feasible alternatives must also be evaluated. Analyses are required to encompass both quantifiable and non-quantifiable aspects. The analysis must include estimates of O&M, recapitalization, discount rate, and inflation rate. A contractor cost estimate is also required and must include taxes paid to the federal government and inflation rate. Cost realism and risk assessment are also required in the analysis.

When systems are privatized, DoD components are required to conduct a post-conveyance (i.e., transfer of ownership) review of each system. The review is required two to three years after award of privatization or one year after the price is re-determined, whichever is later. The review must include the following:

- Joint detailed inventory
- Updated lists of:
    - Requirements reflecting changes
    - Transition requirements
    - Deficiencies
- Contract cost changes due to updated:
    - Updated inventory
    - Connections
    - Disconnects
- Description of inventory changes due to connections and disconnects

The costs are to be accounted for the period starting with award and compared to projections. The original estimate and contract cost must be retained until the analysis is performed. The contract cost must be normalized to inflation factors from the estimate and changes in mission or regulations. Results from analyses must be retained until all conveyances are complete. Upon privatization the government must negotiate with the sole source on changes in inventory and future price.

4.4.3 Unified Facilities Criteria – Energy Conservation

Prescribed by Mil-STD-3007, the Unified Facilities Criteria (UFC) provides the Air Force, Army, Navy, DoD agencies, and DoD field activities with procedures for planning designing, constructing, operating, maintaining, restoring, and modernizing their facilities.[13, 14] UFC 3-400-01, which focuses on energy conservation, establishes standards and policies for energy conservation in the construction of new facilities or renovation of existing facilities. This document applies to every new or existing facility that is owned or leased by the DoD inside and outside of the continental United States. Similar to DODI 4170.11, UFC 3-400-01 implements the policies and standards detailed in the following laws and industry standards for all new and existing facilities.

- ASHRAE Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings
- United States Code Title 10, Part 433, Energy Efficient Standards for the Design and Construction of New Federal and Commercial and Multi-Family High Rise Residential Buildings
- United States Code Title 10, Part 435, Energy Efficient Standards for New Federal Low Rise Residential Buildings

- United States Code Title 10, Code of Federal Regulations, Part 436 – Federal Energy Management and Planning Programs, Subpart A – Methodology and Procedures for Life Cycle Cost Analysis
- 2006 International Energy Conservation Code
- Executive Order 13221
- Executive Order 13423
- Energy Independence and Security Act (EISA) of 2007

In addition to adhering to the standards and laws listed above, UFC 3-400-01 provides a list of energy conservation measures that must be included in any conservation project. These measures are:

- Optimize building position and orientation to minimize the amount of energy required to provide heating and cooling to the facility
- Properly insulate and seal the facility
- Employ highly reflective and emissive roofing materials to reflect the sun's heat back into the sky[xiii, 15]
- Use motion detectors and programmable temperature devices to regulate the use of lighting and heating/cooling in unoccupied rooms
- Use centralized air flow streams with zero cross-contamination heat exchangers to reduce the amount of energy required to heat of cool a facility
- Employ natural lighting where possible

4.4.4 Army Regulations, Strategy, and Campaign Plan

In addition to several regulations, the US Army developed an energy strategy and a separate campaign plan to ensure that Army installations receive secure and cost-effective energy. *The US Army Energy Strategy for Installations* was signed in July 2005 and *The U.S. Army Energy and Water Campaign Plan for Installations* was implemented toward the end of 2005 and updated in December 2007.

4.4.4.1 Army Regulations

The Army has published a series of regulations that have components related to facility energy. Army Regulation 420-1 (AR420-1) was published in February 2008 and includes a section on utilities and energy management.[16] The section covers the following topics:

- Procurement and energy supply
- Energy and water management
- Energy and water management reporting
- Implementation plans and reporting requirements
- Army energy public affairs program
- Energy organizations
- Energy and water conservation programs and awards
- Resourcing

[xiii] Also known as a "Cool Roofing"

- Utility services
- Energy source selection
- Energy program
- Electric systems

AR420-41 contains Army policy information on the acquisition and sale of utility services.[17]

4.4.4.2 Army Energy Strategy for Installations

The Army's energy strategy projects energy, cost, and environmental impacts through the year 2030. The strategy for installations is focused on the following five initiatives:

1. Eliminate energy waste in existing facilities
2. Increase energy efficiency in renovation and new construction
3. Reduce dependence on fossil fuels
4. Conserve water resources[xiv]
5. Improve energy security

4.4.4.2.1 Eliminating Energy Inefficiencies

All installations with utility costs in excess of $10 million should have an energy manager that has been certified to Army standards in energy management. The role of the energy manager is to serve the Garrison Commander and plan and execute energy programs. Furthermore, the energy manager is responsible for conducting evaluations of energy consumption based on building type, area, and environment. Energy training, metering and management systems are also important to eliminate energy inefficiencies.

4.4.4.2.2 Increasing Energy Efficiency

The Army energy strategy recommends the use of emerging technologies and efficient electrical systems for new construction and repair projects to offset the increasing demand for electricity and ideally reduce the consumption of electricity generated from nonrenewable fuels. Furthermore, the Army's strategy is to pursue bundled and long-term utility contracts, shave peak loads, and ultimately reduce utility costs.

An additional strategy is to incorporate sustainable design and development standards into construction and renovation projects. The strategy sets forth the goal to achieve platinum ratings through Military Construction Army (MCA), Operations and Maintenance Army (OMA), and Residential Communities Initiative (RCI) projects. It is also recommended that the Army pursue transitioning to using full life cycle costs and benefits rather than simple first cost methods.

4.4.4.2.3 Reducing Dependence on Fossil Fuels

The Army energy strategy calls for an increased reliance on renewable energy, including geothermal, solar, biomass, and wind. Improved maintenance practices with heating systems are also important for sustaining system efficiencies and thereby keeping fossil fuel consumption at a minimum.

[xiv] Water conservation is outside the scope of this handbook, and therefore is not detailed in subsequent sections.

4.4.4.2.4 Improving Energy Security

The Army energy strategy sets forth the imperative to make utility distribution systems safe, secure, and reliable. Vulnerability assessments and response plans are important elements of securing energy for mission critical facilities.

4.4.4.3 Army Energy and Water Campaign Plan for Installations

To implement the energy strategy, the Army developed a campaign plan for installations.[18] *The Army Energy and Water Campaign Plan for Installations* was initially developed to ensure that the energy efficiency and security goals of the Army are met through 2030. Updated every two years, the document provides a detailed plan for accomplishing the major initiatives noted in the strategy for installations (see *Section 4.4.4.2*).

To achieve these initiatives, this plan sets up actions, milestones, and funding strategies to ensure that the Army can meet the specific energy and water conservation goals set forth in the Energy Policy Act of 2005, Executive Order 13423, and any other relevant federal energy regulations.[18] In developing energy performance requirements for new construction and renovations, the Army employs energy and sustainable design standards developed in the Energy Policy Act of 2005 and Executive Order 13423. The Army also uses the renewable energy goals set forth in the EPAct of 2005 as the basis for the renewable energy usage standards detailed in the plan. In addition, the plan has set forth milestones for achieving LEED silver (FY 2009), gold (FY 2015), and platinum (FY 2020) design standards for new building construction.

4.4.5 Air Force Energy Policies and Plan

The US Air Force has developed several policy and planning documents in order to strategically implement approaches to meeting federal and DoD energy goals. The Air Force has published an energy management policy directive, an energy management instruction, and most recently, an energy plan. These are described in the following sections.

4.4.5.1 Air Force Policy Directive – Energy Management

Air Force Policy Directive (AFPD) 90-17, Energy Management, was published in July 2009 to implement several DOD instructions and a memorandum, including DODI 4170.10, DODI 4170.11, DODI 5126.47, and the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) Memorandum titled "Implementing Executive Order 13423".[19] This directive was published to establish the overall Air Force energy policy, and with it the directive establishes energy goals, objectives and metrics. These have since been updated in the Air Force Energy Plan (see *Section 4.4.5.3*). Moreover, the directive established an Energy Senior Focus Group (SFG) and energy management steering groups at several levels to aid in the execution of energy policy. This organizational structure has since been changed. The new Air Force energy governance structure is provided in *Section 5.5.8*.

4.4.5.2 Air Force Instruction – Energy Management

Air Force Instruction (AFI) 90-1701, Energy Management, implements the Air Force policy directive with the same title, AFPD 90-17.[20] The instruction was published to provide guidance on the Air Force energy program, as well as to detail the energy-related responsibilities (e.g., various tasks, goals, requirements, etc.) for various Air Force offices. The instruction details energy program focus areas including the following:

- Encouraging compliance
- Alternative fuel use
- Aviation fuel strategy/optimization

- Blending aircraft fuel
- Energy audit program
- Utility energy consumption and greenhouse gas emission reduction
- New building standards
- Metering program
- Leased building standards
- Appliance standards
- Renewable power generation technology
- Renewable fuel pumps at fueling station
- Energy efficient vehicle fleets
- Enhanced use lease (EUL) program

The Air Force energy management instruction further details the Energy Senior Focus Group and related working and advisory groups. The SFG working groups include:

- Acquisition and Technology WG
- Aviation Operations WG
- Provide Infrastructure WG
- International WG
- Culture Change WG
- Strategic Communication Integration Advisory WG
- Critical Infrastructure Program Advisory WG
- Innovative Financing Advisory WG

The scope, goals, and objectives are detailed for each WG in the instruction. The Air Force energy program management structure is also detailed (see Figure 2).

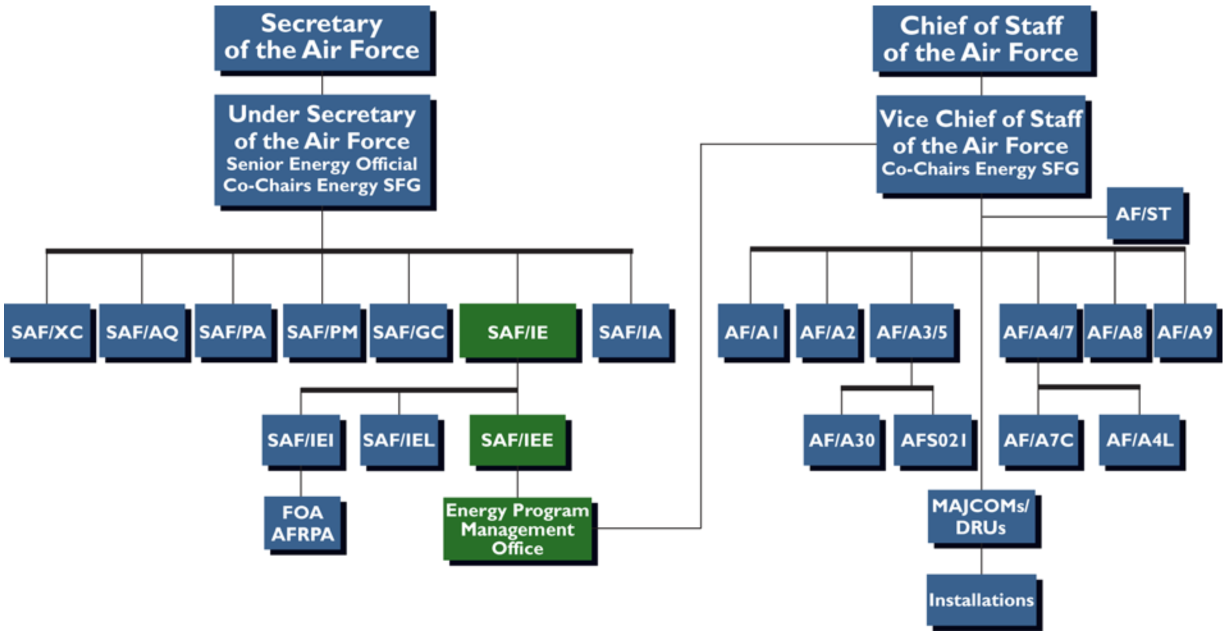


Figure 2. Air Force energy management program office organization.[20]

4.4.5.3 Air Force Energy Plan

Developed in 2010, the *Air Force Energy Plan* provides the framework for implementing energy-reduction efforts and communicating energy goals throughout the Air Force.[21] The *Air Force Energy Plan* also outlines all the goals, objectives, and performance metrics of Air Force energy policy. In addition, the plan outlines task governance and establishes a multi-level management structure to meet Air Force energy objectives.

The plan is founded on three essential concepts: reduce demand, increase supply, culture change. These principles are intended to guide energy management within the Air Force. The plan provides a background on how energy is critical to Air Force operations. It also establishes eight end state goals that are designed to represent the holistic, achievable outcomes of the Air Force's energy management efforts. These end state goals are:

- Sustainability strategies are incorporated to aid in greenhouse gas mitigation
- Bases meet Air Force energy security criteria, while optimizing the mix of on-base and off-base generation
- Aircraft are flying on alternative fuel blends if cost competitive, domestically produced, and have a lifecycle greenhouse gas footprint equal to or less than petroleum
- Forward operating bases are capable of operating on renewable energy
- Energy utilization is optimized as a tactical advantage across disciplines
- Research, development, test, and evaluation (RDT&E) has delivered the new cost-effective energy technologies necessary to substantially reduce demand and increase supply
- Acquisitions prioritize energy as a key consideration
- Make energy a consideration in all that we do

Adhering to Executive Order 13423, the *Air Force Energy Plan* outlines the goal of reducing installation energy usage by three percent annually. When designing new Air Force facilities, they must be designed to exceed ASHRAE standards by 30 percent (set in the 2005 EPAct). The *Air Force Energy Plan* sets a goal for renewable energy usage at facilities at five percent usage by FY 2010, 7.5 percent FY 2013, and 25 percent by FY2025, with 50 percent of the renewable energy increase coming from new renewable sources. This goal is similar to the renewable energy goal established in the 2005 EPAct. For the long term, the *Air Force Energy Plan* sets qualitative installation goals for ensure that forward operating bases can operate on renewable energy, and that all Air Force installations can securely generate power from on and off-base supplies. These and other Air Force goals, objectives, and metrics are outlined in Figure 3.

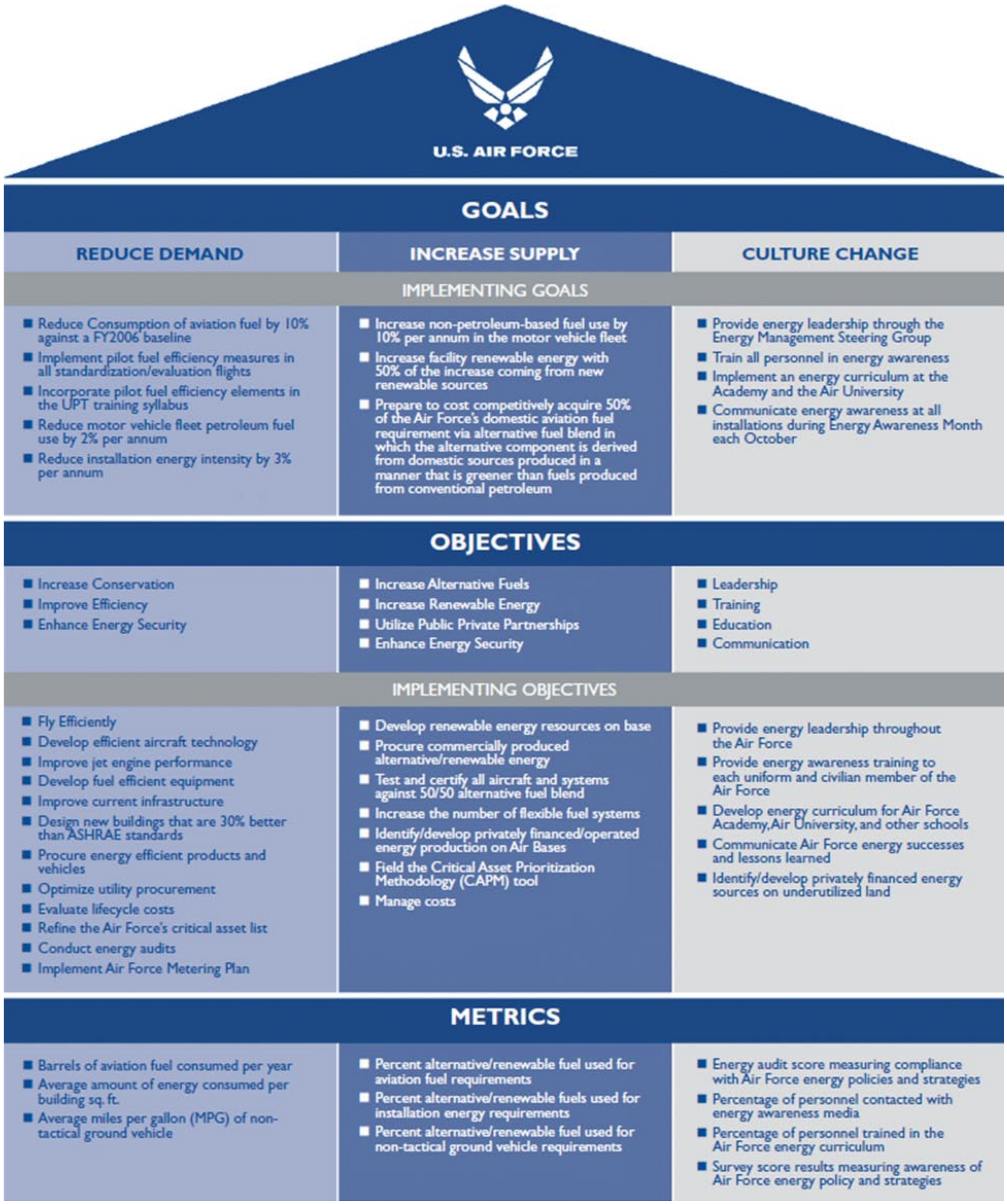


Figure 3. Air Force energy goals, objectives, and metrics.[19]

The *Air Force Energy Plan* describes several constraints that may impede implementation of energy management efforts. These include funding, operations tempo, energy expertise, and manpower resources. The plan also summarizes the roles and responsibilities of the working groups under the Energy Senior Focus Group, which are also described in AFPD 90-17 and AFI 90-1701 (see *Section*

4.4.5.1). The working groups are tasked with implementing the various aspects of the energy plan. Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8 summarize the goals and timelines associated with the energy plan as they pertain to the individual working groups.

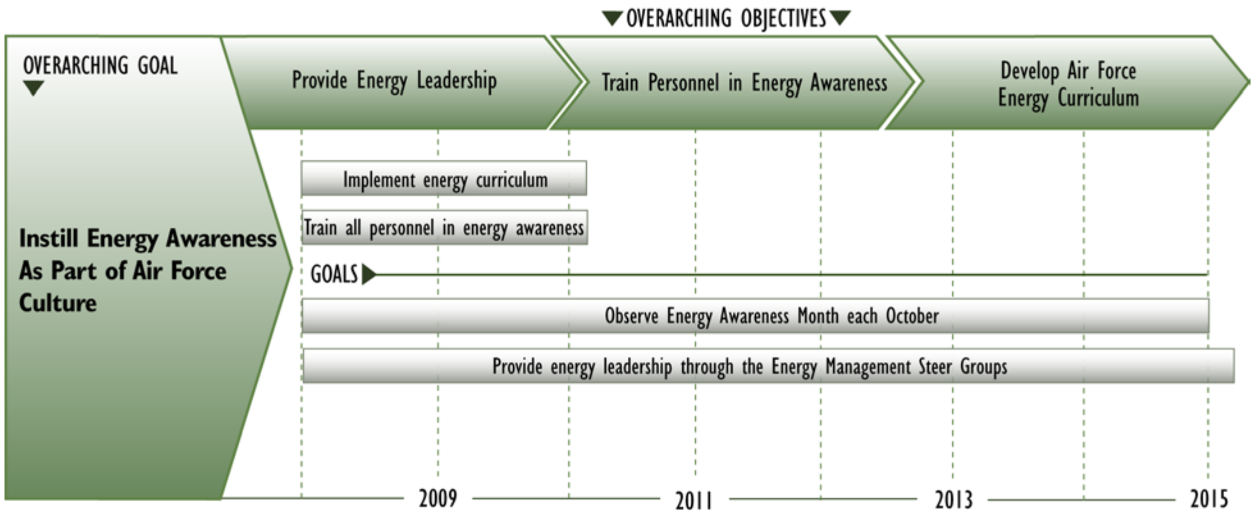


Figure 4. Culture change energy plan.[21]

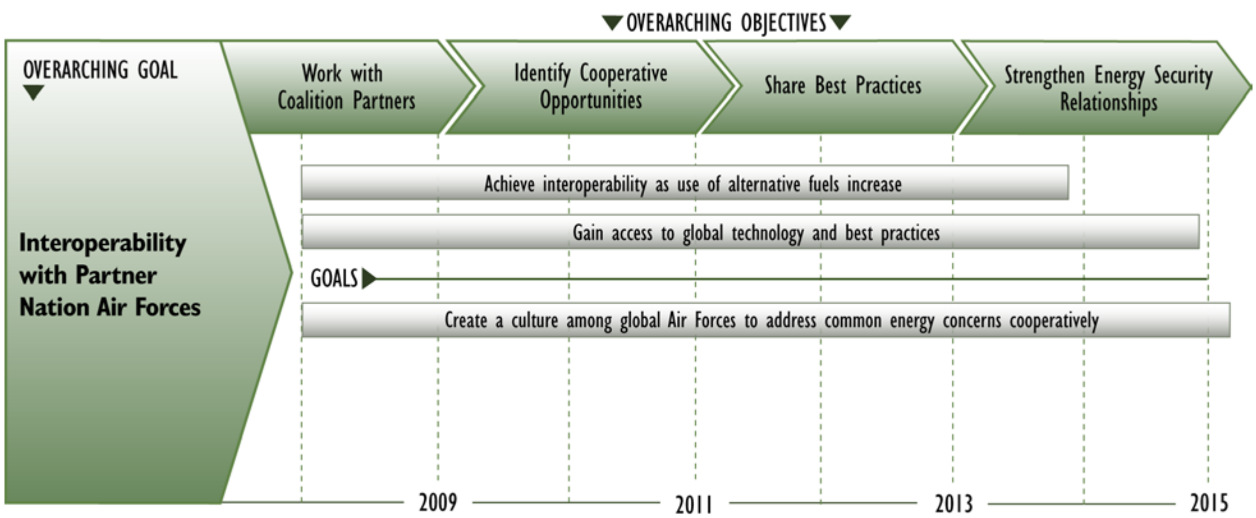


Figure 5. International energy plan.[21]

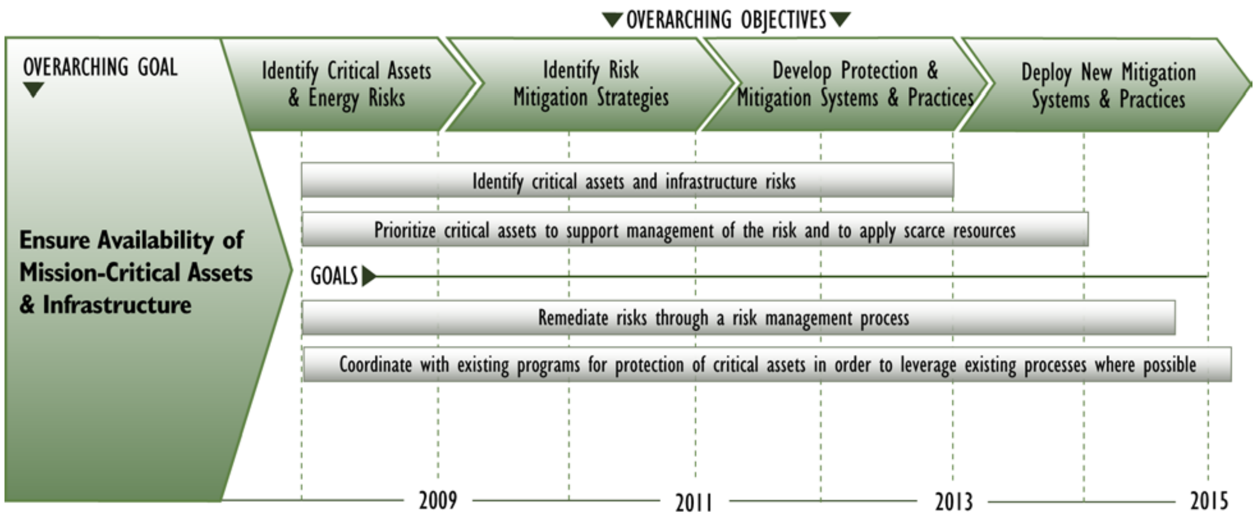


Figure 6. Critical infrastructure program energy plan.[21]

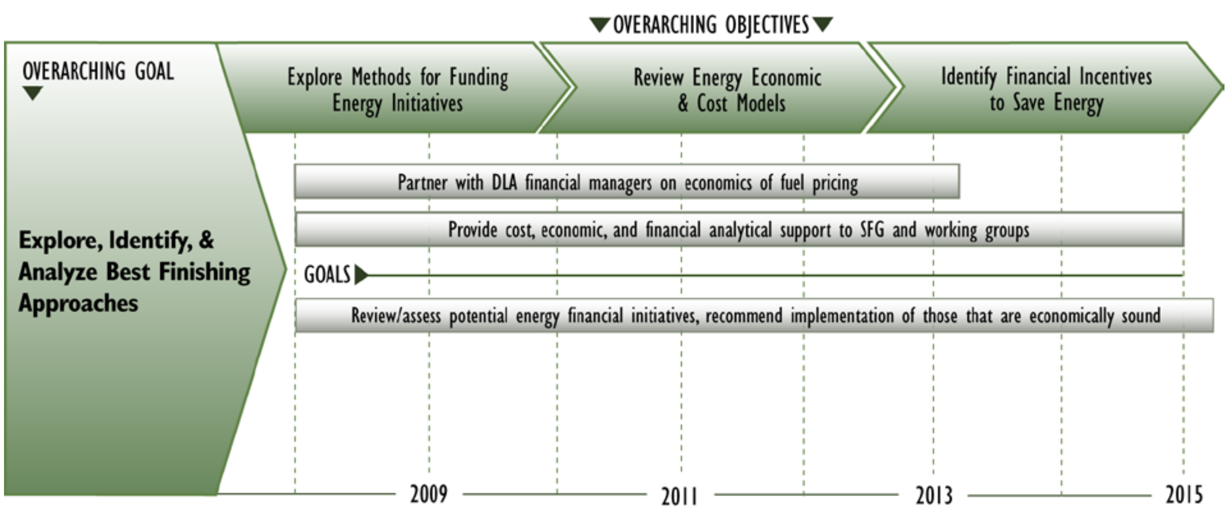


Figure 7. Innovative financing energy plan.[21]

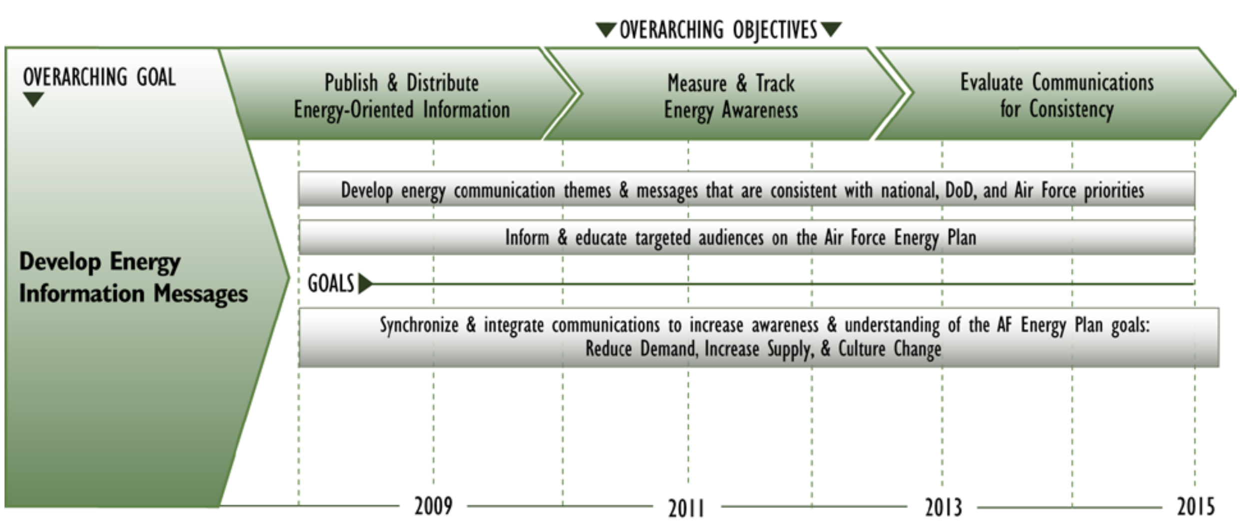


Figure 8. Strategic communications integration energy plan.[21]

Finally, the Air Force Energy Plan describes several areas of focus for the implementation of the energy plan. These include alternative fuels, carbon emissions reduction, communication, energy security, forward operating bases, international energy landscape, model energy base initiative, nuclear energy options, and renewable energy development and deployment.

In addition to the overarching energy plan, the Air Force has also published subsidiary energy plans. These include plans on aviation operations, acquisition and technology, and infrastructure.

4.4.6 Naval Energy Strategy

In 2009 the Navy published a brief document outlining the strategic approach to improving energy security, while increasing energy efficiency and focusing on environmental stewardship.[22] The document describes the Naval energy vision, governance structure, and strategic approach (see Figure 9). It further describes tactical energy security and shore energy security as they pertain to the Navy.

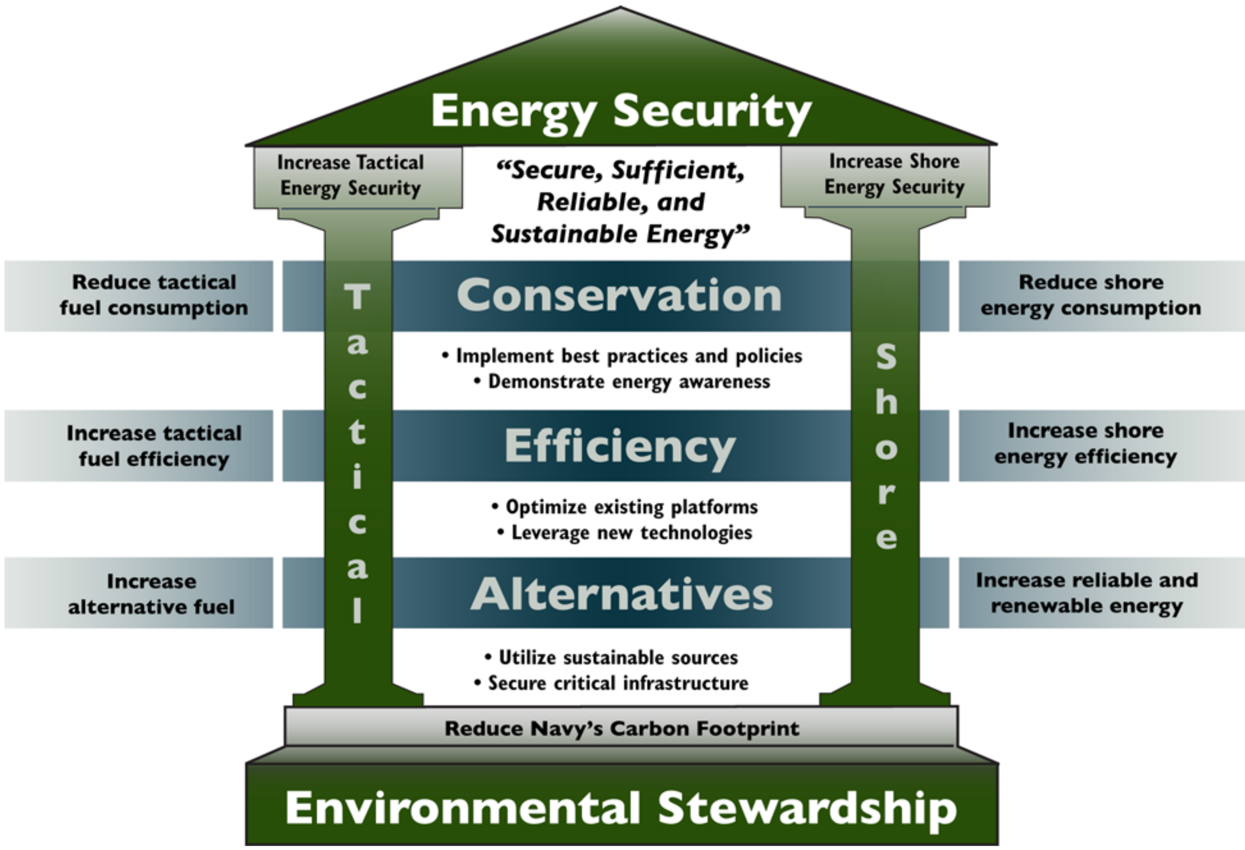


Figure 9. Naval energy strategic approach.

4.5 Summary of Requirements Established Under Various Policies

The policies that govern energy actions are varied and complex. The DoD must adhere to federal policies, but as described in the previous sections, each DoD service has implemented its own policies, goals, and metrics. Table 6 attempts to summarize many of the important aspects of these federal and agency requirements. It must be noted, however, that this summary is not nearly complete, and each individual policy should be consulted as needed.

Table 6. Summary of energy requirements organized by policy and subject.[23]

	EPAct 2005 (except as noted)	EO 13423	EISA 2007	EO 13514	Implementing Instructions	Air Force Policy
Facility Energy Efficiency	Reduce facility energy intensity (2003 baseline) • ($MBTU/ft^2$) 2%/yr (Title I, Subtitle A, Sec. 102)	Reduce facility energy intensity (2003 baseline) • 3% ($MBTU/ft^2$)/yr • Total 30% by 2015. (Sec. 2(a))	Same as EO 13423 (Title IV, Sub. C, Sec. 431)	General charge to increase energy efficiency and reduce GHG emissions (Sec. 2(a)(i))	Reference [7]	Air Force Energy Program Procedural Memorandum (AFEPPM) 04-1
Building Performance, Sustainability, and Fossil Fuel Consumption	Establishes building performance standards – 30% below ASHRAE 90.1 if life-cycle cost effective. (Title I, Sub. A, Sec. 109)	All new MILCON and major renovation comply with *Guiding Principles* in Reference [10] 15% of existing buildings must comply with *Guiding Principles* in Reference [10] by end of FY15 (Sec. 2(f))	Establishment of the Office of Federal High-Performance Green Buildings at the federal level (Sec. 436) Reduce fossil fuel consumption by: ***2010:*** 55% ***2015:*** 65% ***2020:*** 80% ***2025:*** 90% ***2030:*** 100% (Title IV, Sub. C, Sec. 433)	***2020 & after:*** New federal buildings that enter the planning process must be designed to achieve zero-net-energy by 2030 (zero emissions). New federal buildings must comply with *Guiding Principles* in Reference [10] 15% of existing buildings (> 5,000 gross ft^2) comply with the *Guiding Principles* in Reference [10] by 2015 Make annual progress toward 100% conformance with *Guiding Principles* in Reference [10]. (Sec. 2(g))	References [10, 24]	Reference [25] LEED is the AF standard. • 100% capable of achieving LEED Silver certification • Program sustainable design and development (SDD) costs at 2% of primary facility cost • 5%/FY for formal LEED certification • 10% LEED certified in FY10 and after • All sustainment, restoration, and modernization (S/R&M) projects shall consider using LEED principles where financially feasible

	EPAct 2005 (except as noted)	EO 13423	EISA 2007	EO 13514	Implementing Instructions	Air Force Policy
Renewable Energy	Annual goals for electricity generated with renewables • ***FY07 – FY09:*** 3% • ***FY10 – FY12:*** 5% • ***FY13 & after:*** 7.5% • ***By 2025:*** 25% Double count renewable energy produced and used on federal land ((10 USC 2911) Title II, Subtitle A, Sec. 203)	50% of statutorily required renewable energy must be from sources placed into service after 1 Jan 1999. Implement new renewable energy generation on agency property for agency use (Sec. 2(b))	New/renovated facility with a hot water requirement must be 30% solar generated (Title V, Sub. C, Sec. 523)	Increase agency use of renewable energy and implement renewable energy generation projects on agency property (Sec. 2(a)(ii))	Reference [26]	
Advanced Utility Meters	Meter all facilities for electrical where economically feasible by October 1, 2012. (Title I, Sub. A, Sec. 103)	N/A	Steam and natural gas meters by October 16, 2016 (Title IV, Sub. C, Sec. 434)		References [27, 28]	Meter steam at plant Electric, gas, and water meters on renovations > $200k Meter all buildings >35k ft^2 for electrical and >50k ft^2 for natural gas
Utility Meter Measurement and Reporting	Electric meter reports (annually) (Title I, Sub. A, Sec. 103)		Identify covered facilities and perform energy evaluation every 4 yrs, establish plans for reporting energy savings (Title IV, Sub. C, Sec. 432)		Web-based certification and benchmarking system OMB issues energy scorecards semi-annually Reference [12]	

	EPAct 2005 (except as noted)	EO 13423	EISA 2007	EO 13514	Implementing Instructions	Air Force Policy
Product Procurement	Must purchase Energy Star or FEMP-designated products when feasible (Title I, Sub. A, Sec. 104)	Procure energy efficient products (Sec. 2(d))	Same as EPAct 2005 Minimize standby energy use in purchases of energy consuming products (Sections 524 & 525)	95% of new contract actions including task and delivery orders, are energy-efficient (Energy Star or FEMP) (Sec. 2(h))	Reference [29]	Can be waived if the agency head determines in writing that no Energy Star or FEMP-designated product (a) meets the functional requirement of the agency; (b) is not cost-effective over the life of the product taking energy cost savings into account; or (c) the product requirement is combat-related
Commissioning, Re-commissioning, and Retro-Commissioning			Verification and documentation, during the period beginning on the initial day of the design phase of the facility and ending not earlier than 1 year after the date of completion of construction. (Title IV, Sub. C, Sec. 432)			
Greenhouse Gases		Reduce greenhouse gas emissions through reduction of energy intensity (Section 2)		Reduce GHG emissions in absolute terms by FY20, relative to 2008 baseline (Section 2(a))		

5 FEDERAL ENERGY MANAGEMENT ORGANIZATIONS, PROGRAMS, AND RESOURCES

There are several organizations, programs, activities, and resources at the federal, DoD, and service levels that support DoD energy efficiency and renewable energy efforts. This section summarizes the organizations and other resources that are dedicated to helping the DoD to reduce overall energy consumption and improve renewable energy use. For instance, some of these organizations provide training, flow requirements from the federal level down to the individual activity, evaluate energy-efficiency related projects, and identify funding sources that will maximize the return on investment (ROI) for the DoD activity. Furthermore, some of these organizations can assess a facility's energy performance according to requirements and if necessary, establish a plan to improve facility performance.

The energy efficiency and renewable energy projects that are developed and implemented by these energy organizations will significantly improve the ability of the DoD meet its operational requirements both domestically and abroad, while meeting the performance requirements established in the previous section. Intra-agency collaboration on technology development and project funding for energy efficiency and renewable energy efforts through these energy organizations will result in a much greater return on investment. Spreading the initial investment costs over several energy organizations will make more advanced energy technologies easier to develop. These cost savings are in addition to the reduced impact that the DoD's energy usage will have on the environmental as it employs renewable resources and net-zero building designs.

5.1 Federal Interagency Energy Management Task Force

Created as part of the Federal Energy Management Improvement Act (1988), the Federal Interagency Energy Management Task Force (IATF) is a group of federal energy managers who address energy issues affecting all federal facilities. Comprised of principals from each of the 15 US executive departments and several other federal agencies, the IATF assists in the implementation of energy-related legislation into federal energy management activities. In addition, the IATF creates working groups to develop energy initiatives and resolve technical issues. These working groups foster collaboration between agencies in order to improve the efficiency of solving technical issues related to energy management, since many issues are similar government-wide.

5.1.1 Federal Utility Partnership Working Group

The Federal Utility Partnership Working Group (FUPWG) holds biannual meetings to collaborate and share information on programs and projects relevant to federal agencies, utility providers and energy service companies (ESCOs). The mission of the FUPWG is to establish working relationships with the utility providers in order to implement energy efficiency and renewable energy projects, meet energy management goals, and expand energy management communication.

5.1.2 Interagency Sustainability Working Group

The Interagency Sustainability Working Group (ISWG) is the federal level working group charged with developing policy and reporting guidance for the adoption of sustainable building design and operations in the federal sector. The ISWG develops guidance and tools that are designed to help federal agencies implement sustainability policies for federal facilities.

5.1.3 Renewable Energy Working Group

The Renewable Energy Working Group (REWG) brings together federal agencies and industry members involved in renewable energy to collaborate and share information on projects, lessons learned, funding, and technology related to renewable energy. This working group provides guidance on policies and requirements related to renewable energy.

5.2 Council on Environmental Quality

The Council on Environmental Quality is a White House office that coordinates federal environmental efforts and develops environmental policies and initiatives. The CEQ is involved with the implementation of EO policies, such as collecting agency reports and evaluating exemptions.

5.2.1 Office of the Federal Environmental Executive

The Office of the Federal Environmental Executive is administered under the CEQ in the Executive Office of the President. This executive works with the OMB to provide leadership, guidance, and resources for sustainability efforts. The executive is primarily responsible for implementing EO 13514.

5.3 Office of Management and Budget

The Office of Management and Budget is a White House office that supports the preparation of the federal budget and oversees the administration of the budget in the executive departments. The OMB is involved with the implementation of the EISA, such as collecting agency reports.

5.4 Department of Energy

The Department of Energy was established to improve the energy security of the US while supporting the advancement of science and technology related to energy. There are numerous organizations and programs that are subordinate to the DOE; however, only a few are described here.

5.4.1 Office of Energy Efficiency and Renewable Energy

The Office of Energy Efficiency and Renewable Energy (EERE) provides support for clean energy technologies for the purpose of advancing the economy, protecting the environment, and improving energy independence. The EERE is a relatively large organization that administers ten programs. These include:

- Biomass Program
- Building Technologies Program
- Federal Energy Management Program
- Geothermal Technologies Program
- Hydrogen, Fuel Cells and Infrastructure Technologies Program
- Industrial Technologies Program
- Solar Energy Technologies Program
- Vehicle Technologies Program
- Wind and Hydropower Technologies Program
- Weatherization and Intergovernmental Program

5.4.1.1 Federal Energy Management Program

The Federal Energy Management Program, operated by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), facilitates the implementation of energy management and investment practices for all facets of the federal government. While not centrally focused on the DoD, many of the activities performed as part of the FEMP have a significant impact on energy management at DoD installations. The FEMP assists federal agencies in designing, building, retrofitting, and maintaining federal facilities to be energy-efficient. Part of this assistance entails the analysis of new energy regulations are they are implemented. By analyzing these regulations, the FEMP can help with the identification, evaluation, and implementation of renewable energy sources, energy technologies, and products to ensure that federal agencies like the DoD comply with new regulations.

5.4.2 National Renewable Energy Laboratory

The National Renewable Energy Laboratory (NREL) is the federal government's chief laboratory for renewable energy technology, research and development. The laboratory specializes in several areas of expertise including:

- Renewable electricity
- Renewable fuels
- Integrated energy system engineering and testing
- Strategic energy analysis

The laboratory is also chartered to transfer technologies developed at NREL to relevant energy markets.

5.4.3 Advanced Research Projects Agency – Energy

Modeled after the Defense Advanced Research Projects Agency (DARPA), the DOE established an entity to invest in high risk, high payoff energy related projects. The Advanced Research Projects Agency – Energy (ARPA-E) funds and manages energy projects that are potentially revolutionary. This model accesses and stimulates some of the most innovative experts to develop and evolve promising technical concepts to industrial applications.

5.5 Department of Defense

Although the DoD is largely segmented by the three services, Army, Navy, and Air Force, there are several organizations at the department level that support energy related efforts. In addition, each of the services has its own programs and organizations that are dedicated to supporting energy efficiency, renewable energy, and sustainable buildings projects. Some of these organizations are described in the following sections.

5.5.1 Office of the Deputy Under Secretary of Defense (Installations and Environment)

The role of DUSD(I&E) is to implement policies and guidance that pertain to the management of DoD facility energy resources. Development and implementation of these policies will help ensure that the DoD adheres to EPAct 2005 and EO 13423. The mission of DUSD(I&E) is to support military forces through providing installation cost-effective, safe, sustainable, and environmentally sound assets and services.

5.5.1.1 Facilities Energy Directorate

Within DUSD(I&E) is the Facilities Energy Directorate (FED). As part of the DUSD(I&E), the FED focuses on implementation of the directives detailed in EO 13514, EO 13423, the EPAct of 2005, the EISA, and DODI 4170.11 throughout the DoD. The FED provides technical resources and support to DoD installations and facility energy managers to ensure DoD energy goals are met. In addition, the FED assists the Office of the Secretary of Defense (OSD) with funding allocation for the Energy Conservation Investment Program (ECIP, see *Section 5.5.2*).

5.5.1.2 Responsibilities According to DODI 4170.11

The DODI 4170.11 (see *Section 4.4.2*) delegates responsibilities to various organizations. According to the instruction the following responsibilities are given to the DUSD(I&E):

- Oversee the implementation of the EISA, EPAct of 2005, and EO 13423.
- Represent the DoD on the following committees
  - Interagency Energy Policy Committee
  - Steering Committee on Strengthening Federal Environmental, Energy, and Transportation
- Implement policies and provide guidance to the DoD regarding managing facility energy resources
- Serve as the primary advisor for facility energy policy
- Provide energy conservation and resource management, including goals, annual guidance, investment, and reporting
- Develop procedures to measure energy conservation accomplishments by the DoD

5.5.2 Executive Order 13423 Executive Committee

The DUSD(I&E) established a committee to implement EO 13423. The committee is made up of senior DoD leaders and is designed to eliminate any obstacles that would prevent the DoD from complying with EO 13423. A working group made up of representatives from OSD, Army, Navy, Air Force, and other defense agencies provides programmatic, logistical, and technical support.

5.5.3 Energy Conservation Investment Program

An important facet of the DoD's energy management strategy, the Energy Conservation Investment Program focuses on improving energy efficiency at DoD facilities, while reducing energy-related costs. [30] The program provides funding, which is controlled by the OSD through MILCON, for clean energy, water, and renewable energy projects. Program and project guidance is provided in an OSD memorandum.[31]

5.5.4 Whole Building Design Guide

The DoD, its service components, and sub-organizations, among other government organizations, sponsor the Whole Building Design Guide (WBDG). The WBDG is an internet-based resource that provides guidance, criteria, and technology on buildings-related topics from the perspective of the whole building. The WBDG, which is a program of the National Institute of Building Sciences, provides resources on design guidance, project management, operations and maintenance, as well as documents and references, tools, and continuing education opportunities.

5.5.5 Defense Logistics Agency

The Defense Logistics Agency serves the Army, Navy, Air Force, Marine Corps, other federal agencies, and joint and allied forces by providing various logistics, acquisition, and technical services. The DLA provides these services for fuel and energy support through the Defense Energy Support Center.

5.5.5.1 Defense Energy Support Center

The Defense Energy Support Center is a DLA activity that procures all non-nuclear energy sources for the Department of Defense and federal civilian agencies. These energy sources are procured through the following commodity business units:

- Facilities and Distribution Management
- Bulk Fuels
- Installation Energy
- Direct Delivery Fuels
- Missile Fuels

Under the Installation Energy business unit (DESC-A), the DESC operates programs that focus on the efficient delivery coal, electric, natural gas, and renewable energy to installations in the continental US, Alaska, and Germany. DESC-A also serves as the single utility energy manager for the DoD Direct Supply Natural Gas Program.[32]

5.5.5.2 Responsibilities According to DoD 4170.11

The DODI 4170.11 (see *Section 4.4.2*) delegates various responsibilities to specific organizations. In particular, according to the instruction, DLA is responsible for the following:

- Maintaining a DoD energy database to provide petroleum and alternative fuel data
    - This is required to fulfill the reporting requirements of the EPAct of 2005, the EISA, and EO 13423
    - Fuel supplied by the GSA is not entered into this database
- Monitor energy markets to determine existing or potential adverse conditions and advise DoD components

5.5.6 Army

The US Army has several organizations and programs that support energy related efforts and provide resources pertinent to such efforts. Two of the key programs include the Army Corps of Engineers and the Army Energy Program.

5.5.6.1 US Army Corps of Engineers – Energy Branch

A component of the US Army Corps of Engineers (USACE) Engineering Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL), the Energy Branch focuses on the following objectives:[33]

- Eliminate energy waste in existing facilities
- Increase energy efficiency in renovation and new construction
- Reduce dependence on fossil fuels

- Improve energy security and independence

The Energy Branch is also engaged in several research projects to integrate power delivery and distribution, energy efficiency, and conservation measures. Two major focus areas of the Energy Branch are efficient and sustainable buildings and power and energy systems. To improve energy efficiency at Army Installations, the Energy Branch works with the individual installations to improve the flow of energy systems (e.g., HVAC, electricity, gas) throughout its facilities. The improved energy flow reduces the amount of energy that is required to heat, cool, and light these installations.

5.5.6.2 Army Energy Program

Similar to the FED, the Army Energy Program develops and implements programs related to key energy directives (i.e., federal laws and statutes, executive orders, DoD guidance, and Army guidance). In support of these directives, the Army Energy Program provides descriptions, guidance, and information about funding sources for the individual initiatives established by federal and DoD energy directives. The Army Energy Program also provides training and workshops on federal and DoD energy policies, conservation best practices, and new energy efficient technologies. In addition, the Army Energy Program facilitates multiple renewable energy research and development efforts to meet the DoD's goal of having 25 percent of its power supplied by renewable sources by 2025[xv].

The Army Energy Program has provides several specialized energy programs and plans. These include:

- Utilities Contracting Policy Office
- Utilities Modernization Program
- Sustainable Installation Program
- Western Power Grid Peak Demand and Energy Reduction Program
- Resource Efficiency Manager Program
- Power Reliability Enhancement Program

5.5.7 Navy

The Navy has a centralized energy program as shown in Figure 10. The Naval Energy Office was established to develop and implement program models and investment strategies for energy projects in order to achieve energy goals set forth by the Navy, DoD, and federal government. There are additional organizations that support energy-related efforts.

[xv] Detailed in the 2007 National Defense Appropriations Act.

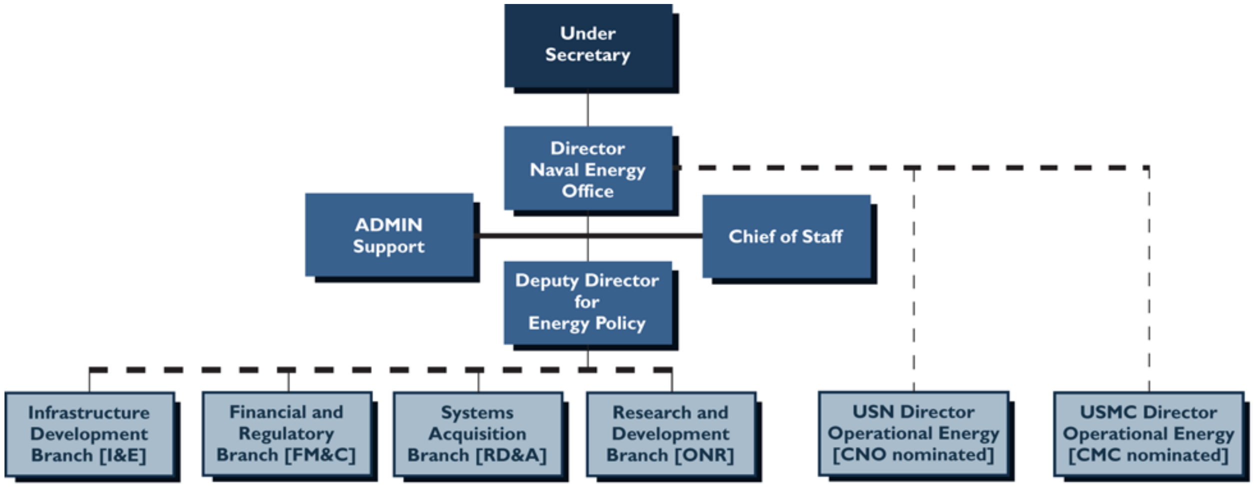


Figure 10. Naval energy organization.[22]

5.5.7.1 Navy Facilities Engineering Command Energy and Utility Department

The Navy Facilities Engineering Command (NAVFAC) provides facility life-cycle support to the Navy, Marine Corps, and other DoD Agencies. Navy facility power management is the responsibility of the Energy and Utility Department (EUD) of the Navy Facilities Engineering Service Center. The EUD works with NAVFAC Headquarters and their component commands to improve the performance of energy systems and reduce life-cycle costs through its Energy Programs and Utilities Engineering Divisions.[34] In addition, the EUD validates new energy technologies for potential use at naval facilities. Evaluating these new technologies greatly reduces the risks associated with implementing these technologies at Navy facilities. The EUD also operates the NAVFAC Energy Projects Team, which develops and implements energy-efficiency projects that reduce energy costs and assist navy facilities in achieving energy related goals set forth in Federal and DoD policies.

5.5.8 Air Force

The Air Force administers its facility energy policy and programs primarily through the Air Force Civil Engineer Support Agency (AFCESA). There are several subordinate organizations, which are also briefly described in the following sections. In general, however, the Air Force governs its energy programs through via the structure depicted in Figure 11.

Figure 11. Air Force energy governance structure.[23, xvi]

5.5.8.1 Air Force Civil Engineer Support Agency

The Air Force Civil Engineer Support Agency is a field unit that reports to the Office of the Civil Engineer at the Air Force Headquarters. AFCESA is tasked with providing resources and support in the area of energy management among other areas.

5.5.8.2 Air Force Facility Energy Center

The Air Force Facility Energy Center (AFFEC) is the division of the AFCESA (AFCESA/CEN) that is responsible for ensuring that the Air Force meets and exceeds federal energy goals. To achieve these tasks, AFFEC identifies, evaluates, and implements energy technologies and funding strategies that improve the overall energy efficiency of the Air Force.[35] AFFEC is organized into four branches (i.e., Conservation, Utility Commodities, Capital Investment, and Utilities Privatization) that manage and implement energy efficiency efforts and funding strategies.

5.5.8.2.1 Conservation Branch

The AFFEC Conservation Branch (AFCESA/CENE) assists in the development of energy implementation policy and guidance for Air Force facilities.[35] In addition, the Conservation Branch provides oversight for the Air Force Resource Efficiency Manager program. The main focus of Resource Efficiency Managers is to reduce energy consumption and utility costs at federal installations.[36] The Conservation Branch also focuses on the promotion of energy awareness through training courses and educational materials.[35]

5.5.8.2.2 Utility Commodities Branch

The main focus of the Utility Commodities Branch (AFCESA/CENC) is to assist Major Commands (MAJCOMs) and installations with the development and implementation of renewable energy efforts and negotiate utility rates at Air Force installations. As part of this focus, the Utility Commodities Branch facilitates the acquisition of renewable energy and renewable energy certificates.[35] The efforts of the Utility Commodities Branch have helped the Air Force become one of the largest buyers of renewable energy in the federal government.

5.5.8.2.3 Capital Investment Branch

The Capital Investment Branch (AFCESA/CENI) of the AFFEC primarily operates as the management office for Air Force energy programs. They are required to develop and implement funding strategies

[xvi] See Appendix for list of acronyms and corresponding full term or phrase.

that will enable to Air Force to meet installation energy requirements set forth in the EPAct of 2005, Executive Order 13423, DoD Instruction 4170.11, and any other relevant federal energy policies.

5.5.8.2.4 Utilities Privatization Branch

The Utilities Privatization Branch (AFCESA/CENU) works with local municipalities to transfer operation of utility systems from the Air Force to municipal utility companies. Transference of responsibility to the municipal utilities enables Air Force installation commanders to shift the focus of installation operations and maintenance activities towards core defense functions.

5.5.8.3 Air Force Real Property Agency

The Air Force Real Property Agency (AFRPA) is an organization that acquires, manages, and disposes of Air Force real property assets. The agency serves to manage the Air Force's real property, and as part of this, support enhanced use lease programs.

PART II:

TRADITIONAL ENERGY SUPPLY AND CONSUMPTION

6 ENERGY SUPPLY

6.1 Introduction to Energy, Fuel, and Power

Basically defined, *energy* is a system's ability to perform work, and *power* is the rate at which energy is transferred to perform work. There are many forms of energy but all forms can be placed into one of two categories: kinetic and potential. Kinetic energy is simply the energy of motion. Potential energy is the energy stored by an object or system due to its position or state. Forms of kinetic energy include radiant, sound, motion, and thermal energy. Forms of potential energy include electrical, chemical, gravitational, nuclear, and stored mechanical energy. A *fuel* is a substance that has stored energy which can be released deliberately to provide useful work or heat.

Kinetic Energy (Energy of Motion)
- Radiant
- Sound
- Motion
- Thermal

Potential Energy (Stored Energy)
- Electrical
- Chemical
- Mechanical
- Gravitational
- Nuclear

There are many sources of energy which are used to perform work on a system of any scale. For instance, on a molecular scale thermal energy can be used to form or destroy bonds between atoms and molecules. On a macroscopic scale, chemical energy stored in an energetic material, for example, can be used to propel a rocket away from the Earth's gravitational pull.

Energy behaves according to the First Law of Thermodynamics, also known as the law of conservation of energy, which can be formalized as:

> *Although energy assumes many forms, the total quantity of energy is constant, and when energy disappears in one form it appears simultaneously in other forms.*[37]

From this law it is clear that energy cannot be created, but rather converted from one form to another. Thus energy must be harvested from various sources, and then it can be used to power the function of artificial devices and processes.

6.1.1 Nonrenewable and Renewable Energy

Energy sources can be categorized in a variety of ways. Perhaps the most meaningful approach is to separate them into nonrenewable and renewable categories. *Nonrenewable energy* sources cannot be regenerated or replaced within a timescale that is sufficient to sustain their consumption. Thus, these energy sources will eventually become exhausted. Conversely, *renewable energy* sources can be replenished by natural processes at a rate that exceeds their consumption.

6.1.2 Traditional and Alternative Energy

Energy sources can also be categorized as traditional or alternative. Traditional energy sources are those which have been in use for a long period of time to supply a substantial amount of power; these include some renewable energy sources, such as hydroelectric power, and of course nonrenewable sources, such as fossil fuels.

Alternative energy is a largely misused term. In the context of energy, alternative is often used as a synonym for renewable, and in some texts these terms appear interchangeably. However, the word alternative means unconventional or nontraditional. It is the case that many renewable energy sources are alternative, but not all renewable energy sources are alternative. For instance, hydroelectric power is a renewable resource, but is not unconventional and therefore not alternative. An example of a nonrenewable, alternative resource is synthetic fuels.

6.1.3 Scope of this Handbook

For the purposes of this handbook, nonrenewable and traditional energy sources are described briefly to establish a basis for augmenting or replacing these with renewable energy sources. It is beyond the scope of this handbook to describe these nonrenewable energy sources in any significant detail. Thus, the focus of this handbook is on renewable energy sources. The following sections describe nonrenewable energy sources, whereas the more significant renewable energy sources are described in another section of this handbook.

6.2 Nonrenewable, Traditional Energy Sources

The most common energy sources to power and heat facilities are derived from fossil fuels. Nuclear power also generates a significant amount of the electrical power consumed by facilities. These energy sources are described in the subsequent sections. The consumption of energy by source, including fossil and nuclear fuels is described in *Section 6.6*.

6.2.1 Fossil Fuels

Fossil fuels are derived from carbonaceous or hydrocarbon solids, liquids, and gases that have been formed from the decay of organisms contained within the Earth's crust that were exposed to heat and pressure over time. The most common fossil energy sources are coal, petroleum, and natural gas. Their respective energy content is provided in Table 7.

Table 7. Energy content of basic fossil fuels.[38]

Fossil Fuel	Energy Content	
Coal	23.2 – 30.2 MJ/kg	20 – 26 x 10^6 BTU/ton
Petroleum	38.5 MJ/L	5.8 x 10^6 BTU/bbl[xvii]
Natural Gas	38.4 MJ/m^3	1,032 BTU/ft^3

6.2.1.1 Coal

Coal is an abundant, solid, nonrenewable fossil fuel that has been used as an energy resource for thousands of years. Explorers discovered coal in US in 1673, but commercial production (i.e., mining) did not begin until 1748 in Virginia.[39] Coal is commonly used as a fuel source for combustion to convert its stored energy to heat. This can be used as a simple heat source or to generate steam to drive a turbine and generate electricity. There are several different types of coal, including lignite, sub-bituminous, bituminous, anthracite, and graphite.

Lignite, which is also known as brown coal, has the lowest energy content of the various types of coal because it was not subjected to excessive heat and pressure. Sub-bituminous coal has a higher energy content than lignite, and bituminous coal has a higher energy content than sub-bituminous coal. Anthracite is considered the highest quality of coal; it has a relatively high energy content and a moisture content less than 15 percent. The different types of coal are classified according to ranking. Lignite is considered the lowest ranking while anthracite is the highest ranking coal. Bulk densities of several types of coal are provided in Table 8.

[xvii] bbl is an abbreviation for barrel, where 1 bbl = 42 gal = 159 L = m^3

Table 8. Density of several coal types.[38]

Coal Type	Density, kg/m^3 (lb/ft^3)
Anthracite	800-930 (50-58)
Bituminous	670-910 (42-57)
Lignite	640-860 (40-54)

Even though coal is found throughout the world, the US has the largest known coal resource. The coal reserves are spread across large areas of the country and it is mined in 27 states. There are several processes by which coal is converted into a useful form of industrial-scale energy, including combustion, coal gasification and liquefaction.

6.2.1.1.1 Coal-to-Electricity

Coal can be converted to electricity through a relatively simple process. Typically before the coal reaches the conversion plant, it is processed or cleaned to remove undesired contaminants that are present in raw coal, such as sulfur (S), ash, arsenic (As), mercury (Hg), lead (Pb), nickel (Ni), antimony (Sb), selenium (Se), and chromium (Cr). This also improves the heating value of the coal by 10 to 30 percent.[40]

In the most traditional coal-to-electricity process, processed coal is first milled into a powder, then mixed with hot air and sent to a furnace or boiler. The coal is essentially used as a fuel, which is combusted to heat water. The resulting steam is used to drive a turbine and thus produce electricity via a generator.

Coal power plants in the US range in capacity from a half megawatt (MW) up to approximately 1,400 MWs.[41] These plants can operate for many decades. As of 2008, the oldest operating coal power plant, a 6 MW unit, was commissioned in 1924.[42] The average age of the approximately 1,400 coal plants in operation is 42 years. The DOE estimates that 92% of the coal consumed in the US is used to generate electricity. The electricity generated from coal makes up approximately half of the electricity produced in the US.[43]

Due to increased environmental awareness and regulations there has been much more focus on clean coal technologies. These range from pre-combustion to post-combustion and carbon capture technologies, which are described in some detail in the following section.

6.2.1.1.2 Clean Coal Technology

In general, clean coal is the idea of reducing emissions and improving efficiency during the use of coal as an energy source through the implementation of improved processing, combustion, conversion, and post-combustion technologies. Several of these technologies or innovations are described in the following paragraphs.

6.2.1.1.2.1 Processing

Processing coal to remove impurities prior to sending it to combustion plants has become standard practice. Coal is cleaned by mechanical or physical separation processes, which remove most of the impurities. Chemical processing technology exists that enables the complete removal or purification of coal, however these are simply too expensive to be used in the industry.

6.2.1.1.2.2 Combustion

The main products from the combustion of coal are thermal energy, carbon dioxide (CO_2), and water vapor. However, any impurities in the coal that were not removed prior to combustion result in byproducts. Some are released as solids (i.e., ash) and some as gases. The primary gaseous byproducts that are potentially hazardous to the environment, in addition to CO_2, are sulfur and nitrogen oxides. When coal is combusted, air, which is 80% nitrogen (N_2), is used as the oxygen source. Under high thermal energy conditions, the diatomic nitrogen gas breaks down and combines with unconsumed oxygen, thereby forming nitrogen oxides (NO_x). In addition, sulfur present in the coal will combine with the excess oxygen to form sulfur oxides (SO_x). If untreated these pollutants are released to the atmosphere via the plant flue.

Nitrogen oxides can be largely prevented from forming by limiting the amount of excess oxygen during the combustion process. This can be accomplished by introducing a staged combustion process, which utilizes multiple combustion chambers. A fuel-rich combustion mixture is sent through the first combustion chamber and excess fuel is consumed in a subsequent stage. This minimizes the amount of oxides formed. Approximately 75 percent of large coal-fired plants in the US utilize staged combustion.[44]

6.2.1.1.2.3 Fluidized Bed Combustion

An alternative to the traditional combustion chambers used to burn coal, the fluidized bed system injects streams of air from the bottom to suspend pulverized coal particles (see Figure 12). Under high temperature conditions the coal reacts with the oxygen in the air stream to burn. This process is more efficient since the temperature (1400 to 1700°F) required is approximately half that of the traditional coal boilers (3000°F).[45] Furthermore, due to the lower temperature, N_2 is not as likely to breakdown and form NO_x. Another advantage of fluidized bed combustion is that limestone or dolomite can be injected while the coal is being combusted, which enables for the removal of sulfur and thus prevention of the formation of SO_x during combustion rather than in a separate process after combustion. Approximately 95 percent of the sulfur contained in coal particles is removed in the combustion chamber.[46] Fluidized bed combustion chambers have some flexibility in the type of fuel they burn. For instance, in addition to pulverized coal, fluidized beds can burn almost any combustible material such as municipal waste.

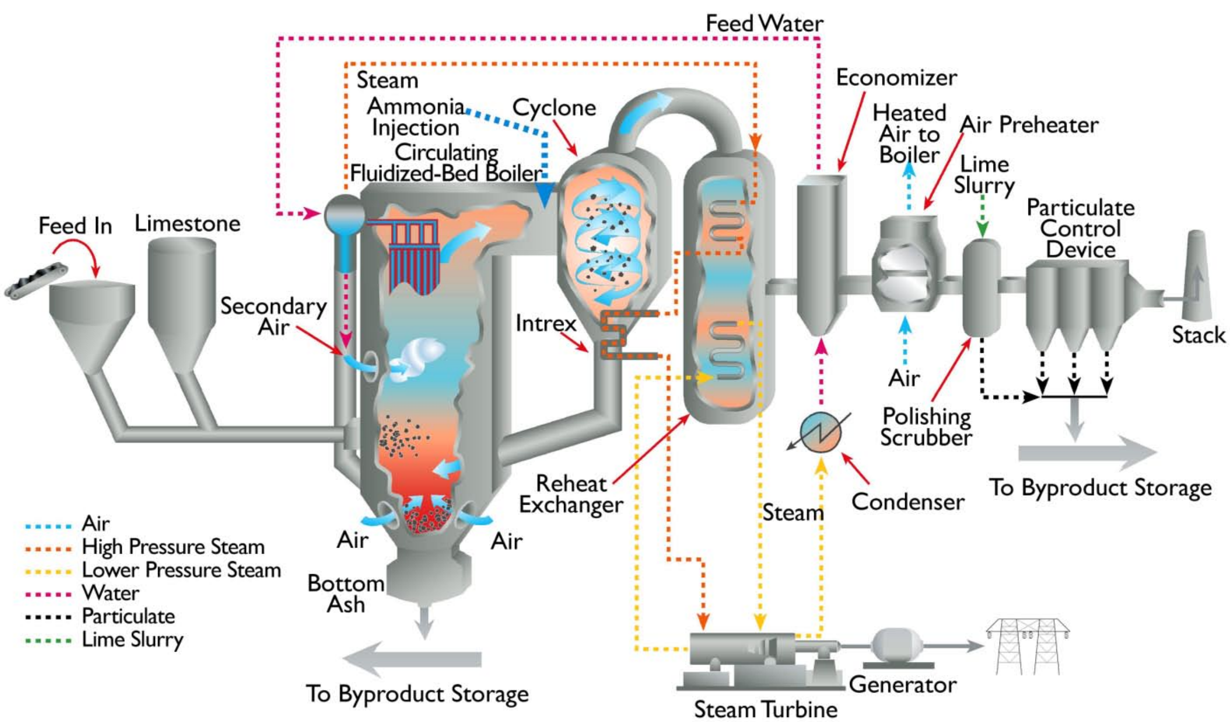


Figure 12. Large-scale fluidized circulating fluidized bed combustion process flow diagram.[47]

A more recent advancement to the fluidized bed combustion chamber adds pressurization to enable dual use of the combustion gases and thereby improve efficiency. The hot, pressurized stream of gases is sent through a gas turbine to generate electricity in addition to utilizing the heat for steam generation. Further improvements to the pressurized fluidized bed combustion (PFBC) have simplified the design, improved durability, increased efficiency, and reduced pollution characteristics.[46]

6.2.1.1.2.4 Post Combustion

The flue gas can be sent through a desulfurization process to remove the sulfur oxides. This flue gas desulfurization utilizes wet scrubbers to spray sulfur dioxide with lime or limestone and water, which ultimately produces gypsum. Flue gas desulfurization units are required on all new coal combustion plants (since 1978).[48] The gypsum can be sold for use in construction or agricultural products.

Catalytic and non-catalytic purification units can also be implemented to remove NO_x from the flue gas. The selective catalytic reduction (SCR) process adds ammonia (NH_3) to the flue gas and the mixture is sent through a catalyst bank where reactions convert the NO_x, oxygen (O_2), and NH_3 to N_2 and water vapor.[40] Catalysts can remove up to 90% of the nitrogen oxides, but it is a more expensive technique than staged-combustion.[44] A lower cost alternative to the SCR process is a selective non-catalytic reduction (SNCR) process. This process utilizes NH_3 or urea reagents to react under heat to convert NO_x to nitrogen. Although less expensive, this process is not as effective. The reduction rate of NO_x to N_2 is less for SNCR than it is for SCR.[40]

6.2.1.1.2.5 Carbon Capture and Sequestration

Aside from concerns involved with various mining techniques, one of the primary environmental issues associated with the use of coal as a fuel to derive electricity or even heat is the inevitable generation of CO_2. Carbon dioxide is released to the atmosphere after combustion via the flue gas. In order to mitigate this environmental concern there has been increasing research on methods to first capture the CO_2. Once captured, however, a secondary problem arises regarding what to do with the CO_2. Carbon sequestration methods involve the long-term storage of CO_2.

Carbon capture and sequestration, also known as carbon capture and storage (CCS), generally involves three steps: 1) isolating and removing CO_2 from the waste stream, 2) compressing it, and 3) finally storing it. There are myriad methods being investigated to accomplish these steps, but none are economically viable or practical. It is estimated that incorporating CCS to a coal power plant can add 75 percent to the cost of the electricity produced.[49] Sample costs with and without CCS are provided in Figure 13.

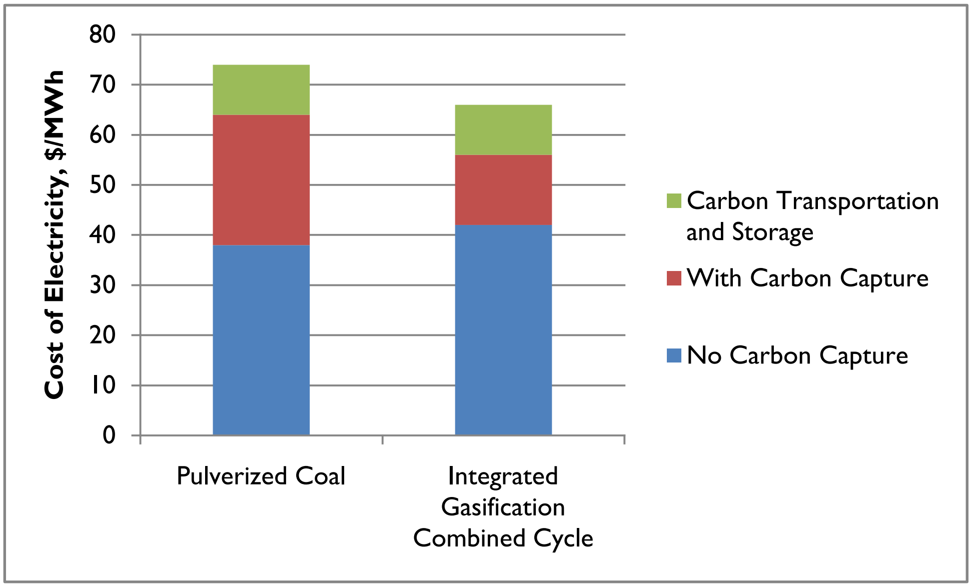


Figure 13. Cost of electricity for coal-to-electricity processes with carbon capture and storage.[40]

6.2.1.1.2.6 Coal Gasification

Coal can be converted into other types of energy sources or fuels, such as synthetic fuel and hydrogen, through a process that decomposes the solid into its base constituents in the presence of steam and oxygen under high temperature and pressure conditions (see Figure 14). The products of this gasification process are carbon monoxide (CO), hydrogen and other gaseous compounds, otherwise known as syngas. During the process contaminants are separated and removed.

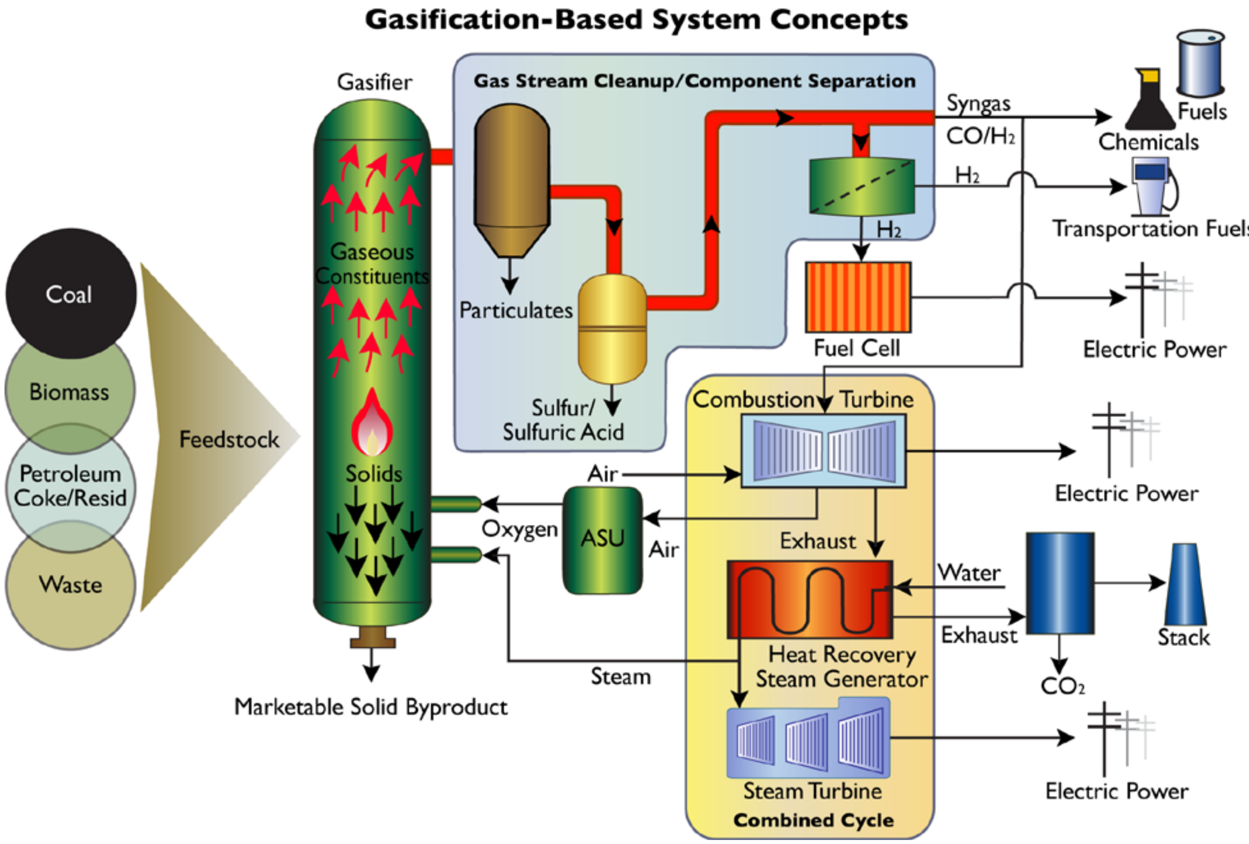


Figure 14. Coal gasification process.[50]

The syngas fuels a combustion turbine to produce electricity and waste heat is recovered and used to generate steam for a steam turbine, which also produces electricity. This is known as an integrated gasification combined cycle (IGCC) process, which achieves higher efficiencies compared to a single turbine process.

6.2.1.1.2.7 Coal Liquefaction (Coal-To-Liquid)

Coal can be converted directly to a liquid or indirectly to a liquid through the gasification and Fischer-Tropsch processes. This is called coal liquefaction and is sometimes known as coal-to-liquid (CTL). However, the products of this process are mostly used for transportation fuels and thus the process is not considered in any further detail herein.

6.2.1.1.3 Summary of Coal Plant Costs and Performance

In general, new coal plants cost between $1,000 and $1,200 per kW capacity and the electricity costs between $36 and $39 per MWh. Other performance and cost factors for newer coal plant designs are summarized in Table 9.

Table 9. Summary of coal plant cost and performance factors.[40, 41]

Factor	Pulverized Coal Plant	Fluidized Bed Combustion[xviii]	Integrated Gasification Combined Cycle
Typical capacity, MW/unit	250 – 800	30 – 300	300 – 600
Fuel	Coal	Coal, Biomass, Municipal Waste	Coal
Construction period, years	3	3	3
Operations and Maintenance			
Total staff, personnel/MW	0.31	0.46	0.33
Availability			
Planned outage, %	11.1	5.7	4.7
Forced outage, %	3.7 – 3.9	4.1	10.1
Equivalent availability, %	85.4 – 85.7	90.4	85.7
Cooling water, m^3/hr/MW	236 – 244	249	185
Efficiency and Heat Rate			
Efficiency, % (HHV)	34.4 – 37.7	34.6 – 35.6	39.3 – 41.1
Heat rate, kJ/kWh (HHV)	9,050 – 9,930	9600 – 9870	8310 – 8680
Pollutants and Waste			
Pollution emissions, kg/MWh			
SO_2	0.62 – 0.68	0.66 – 0.68	0.04 – 0.22
NO_x	0.62 – 0.68	0.66 – 0.68	0.23 – 0.24
CO_2	786 – 862	834 – 857	723 – 754
Particulates, kg/MWh	0.1	0.1	0.01
Solid waste, kg/MWh			
Ash	45 – 48	44 – 47	42 – 44
Spent sorbent	11 – 66	11 – 94	0
Costs			
Total plant cost, $/kW	1040 – 1090	1030 – 1060	1150 – 1190
O&M cost			
Fixed, $/kW-year	23.9 – 24.4	22.3 – 22.7	25.6 – 26.3
Variable, $/MWh	2 – 3.1	2.1 – 4.4	1.5 – 1.7
Cost of electricity, $/MWh	36 – 38.4	36 – 39.2	37.1 – 38.2

6.2.1.1.4 Risks Associated with Dependence on Coal

Aside from the known environmental effects of the mining, transportation, and combustion of coal, and the limitations of coal as an energy source (i.e., it is nonrenewable), there are several risks associated with depending on coal for power.[51]

- Mining delays due to litigation and permitting
- Fires and accidents
- Tighter transportation restrictions
- Fluctuation in the prices of other fossil fuel sources affect coal prices
- Policies implementing carbon taxes can cause a substantial rise in cost of power from coal

[xviii] Atmospheric (i.e., non-pressurized)

6.2.1.2 Petroleum (Crude Oil)

Crude oil or petroleum is a natural, but nonrenewable fossil fuel primarily composed of a mixture hydrocarbons, including alkanes, cycloalkanes, and aromatic compounds. Nitrogen, sulfur, and oxygen are also present in the hydrocarbon compounds, and small amounts of iron, nickel, copper and vanadium are present in the petroleum.

Petroleum is refined by fractional distillation process to convert the crude liquid to refinery gas, gasoline, kerosene, and fuel oils including diesel fuel, as depicted in Figure 15. The liquids and solids remaining after distillation are lubricating oils, paraffin wax, asphalt and bitumen.

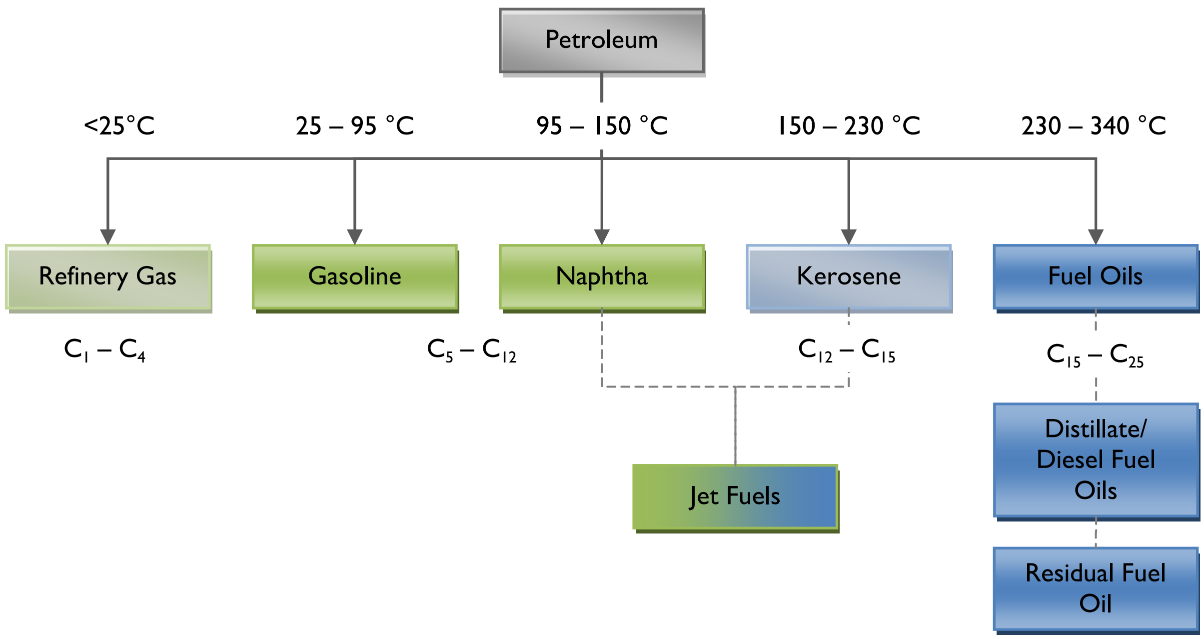


Figure 15. Products yielded from the fractional distillation of petroleum.[52]

One barrel of crude oil (42 gallons) will yield approximately 44 gallons of petroleum products. The approximate percent yield for these products is provided in Figure 16 and are described in the following sections.

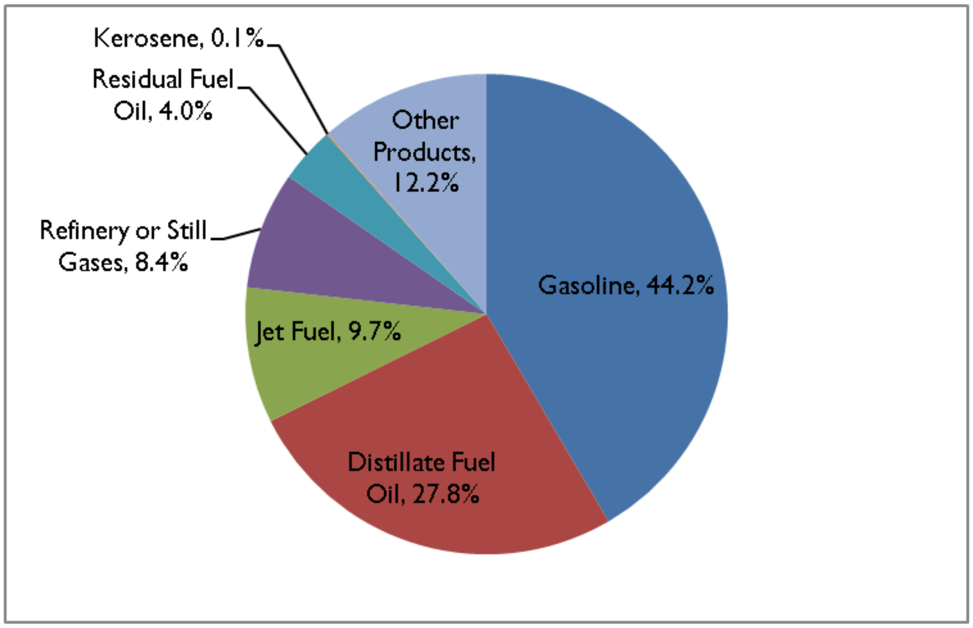


Figure 16. Petroleum refinery product yield based on crude oil input (2008).[xix, 53]

6.2.1.2.1 Refinery or Still Gases

Refinery gas, which is also known as still gas, is a mixture of gases produced in during petroleum refining by distillation, cracking, reforming, and other processes. These gases include methane, ethane, ethylene, normal butane, butylene, propane, and propylene, among other products. Refinery gases are used directly as fuels or as the petrochemical feedstock to manufacture other products.[54] (See also *Natural Gas, Section 6.2.1.3*)

6.2.1.2.2 Gasoline

A common fuel derived from petroleum is a composition of aliphatic[xx] compounds enhanced with isooctane or benzene and toluene. Gasoline is refined from petroleum and contains a mixture of hydrocarbons that have chain lengths ranging between 4 and 10 carbon atoms. The composition can vary significantly depending on environmental regulations which determine the blending requirements, but a sample composition is provided in Table 10.

[xix] These values are based on the total volumetric output compared to the input for a given period of time. The total output exceeds 100 because of processing gains. This difference is because the products in total have a lower density than the crude oil input.
[xx] Aliphatic compounds are organic molecules comprised of hydrogen and carbon atoms bonded together in the form of a straight chain.

Table 10. Sample composition of gasoline.[55]

Component	Percent Composition by Volume
$C_4 - C_8$ Straight Chain Paraffins	15%
$C_4 - C_{10}$ Branched Paraffins	25-40%
Naphthenes[xxi]	10%
Aromatics[xxii]	<25%
Olefins[xxiii]	10%

Like many fuels, gasoline releases its energy during combustion. For combustion to occur effectively, however, gasoline must readily mix with oxygen or air. Therefore an important property is its vapor pressure, which is dependent on temperature. Adjusting the butane (C_4H_{10}) content of the fuel can help control the vapor pressure. Under sufficient compression, gasoline can spontaneously combust without supplying a spark. This premature ignition or pre-detonation can damage internal combustion engines (ICEs), however. The octane rating of gasoline refers to the mixture's propensity or resistance to pre-detonation. A higher octane rating indicates a greater resistance to pre-detonation.

6.2.1.2.3 Fuel Oil

Fuel oil is derived from petroleum and is less volatile than gasoline. Fuel oil is generally classified as a distillate, diesel, or residual fuel oil, but is further categorized into grades 1 through 6.

6.2.1.2.3.1 Distillate Fuel Oil

Distillate fuel oils include diesel fuel and fuel oils for heat and power generation.[56] There are several grades of distillate fuel oil, and they are categorized as No. 1, No. 2, and No. 4 diesel or fuel oil grades. No. 1 fuel oil is a light distillate that is used mainly for outdoor stoves and heaters. No. 2 fuel oil can be atomized for combustion and is used for moderate capacity burner units. No. 4 fuels are blends of fuel oils and residual fuel oil stocks and are primarily used in large capacity generating plants.[56]

6.2.1.2.3.1.1 Diesel Fuel

Diesel is another refinery product of petroleum. Diesel contains longer-chain hydrocarbons than gasoline, typically with 10 to 15 carbon atoms, and thus has a higher density. Diesel also has a higher boiling point and a higher energy density than gasoline. No. 1 diesel fuel is a light distillate that is used in buses. No. 2 diesel is used in high speed diesel engines (e.g., locomotives, trucks, and cars) and has a low-sulfur grade. No. 4 diesel fuel is used in low and medium speed diesel engines.[54]

6.2.1.2.3.2 Residual Fuel Oil

Fuel oils Nos. 5 and 6 are residual heavier oils that are left over after the lighter, distillate fuel oils and hydrocarbons are distilled out during refining.[56] Fuel oil No. 5, which is also known as Navy Special, is a medium viscosity residual fuel oil that is used in steam-powered vessels and onshore power plants.[56] No. 6 fuel oil is used in space heating, sea vessels, and industrial applications. It is also used to generate electricity. Fuel oil No. 6 includes Bunker C, which is a common fuel for sea vessels.[56]

6.2.1.2.4 Kerosene

Kerosene is a light distillate from petroleum that has a final boiling point of 572°F and a minimum flash point of 100°F.[56] It is primarily used in space heaters, cook stoves, water heaters, and wick-fed lamps.[56]

[xxi] Naphthenes, also known as cycloalkanes, are saturated hydrocarbons containing at least one ring of carbon atoms.

[xxii] Aromatics are hydrocarbons that have hexagonal ring structures with alternating single and double bonds between the carbon atoms.

[xxiii] Olefins, also known as alkenes, are unsaturated hydrocarbons containing at least one double carbon-carbon bond.

Kerosene has properties similar to those of No. 1 fuel oil.[56] Several jet fuels for commercial and military turbojet and turboprop aircraft engines are based on kerosene, as described in the following section.

6.2.1.2.5 Jet Fuel

Aviation fuel is refined from petroleum and specially formulated to operate in aircraft or turbine engines on ground vehicles. Similar to gasoline and diesel, aviation fuels contain paraffins, olefins, naphthene, and aromatic hydrocarbons, as well as additives that impart chemical stability and other properties to the formulation. Important properties of aviation fuels include flash point, freezing point, energy density, density, stability (e.g., thermal, storage), volatility, lubricity, fluidity (e.g., viscosity), resistance to microbial growth, and inhibition of corrosion.[57] Aviation fuels are primarily based on kerosene, which is a mixture of hydrocarbons with 12 to 15 carbon atoms. The energy density for several aviation fuels is presented in Table 11.

Table 11. Energy density of aviation fuels.[57]

Aviation Fuel	Volumetric Energy Density (MJ/m^3)
Jet A	35,000
Jet A-1	35,000
JP-8	35,000
JP-9	39,573
JP-10	39,434

6.2.1.2.5.1 Jet A

The formulation known as Jet A is the standard commercial aviation fuel in the US. It is a kerosene-based fuel with a flash pointxxiv of 38°C and a freezing point of -40°C.

6.2.1.2.5.2 Jet A-1

Jet A-1 aviation fuel is used by commercial airlines outside the US. Like Jet A fuel, Jet A-1 has a flash point 38°C, but it has a freezing point of -47°C.[57]

6.2.1.2.5.3 Jet Propellant-5

Jet propellant-5 (JP-5) is a kerosene-based jet fuel formulated to meet military specifications for certain properties. For instance, JP-5 has a higher flash point (minimum of 60°C) than commercial aviation fuels and a maximum freezing point of -46°C. The US Navy stores JP-5 aboard its aircraft carriers because of its relatively high flash point and low volatility, which makes it safer and less susceptible to ignition.

6.2.1.2.5.4 Jet Propellant-8

Jet propellant-8 (JP-8) is a common kerosene-based military aviation fuel with a minimum flash point of 38°C and a maximum freezing point of -47°C.

6.2.1.2.5.5 Jet Propellent-8+100

Based on JP-8, jet propellant 8+100 (JP-8+100) has an additive package (consisting of a detergent, dispersant, metal deactivators and antioxidant) used to improve its thermal stability by 100°F.

6.2.1.2.5.6 Jet Propellant-9 and Jet Propellant-10

Jet propellant-9 (JP-9) and jet propellant-10 (JP-10) are specialty fuels primarily for missile applications and are composed almost entirely of high-density naphthenes.[57] The JP-9 formulation is a blend of

[xxiv] Flash point is the minimum temperature needed for the vapor above a volatile liquid to form an ignitable mixture with air. At the flash point there is just enough vapor in the air above the liquid to make the mixture flammable and able to release its energy through combustion.

methylcyclohexane, perhydronorbornadiene dimer, and exotetrahydrodiclyclopentadiene.[57] The JP-10 formulation consists of a single hydrocarbon, exotetrahydrodiclyclopentadiene.

6.2.1.2.5.7 Other Jet Fuels

Other jet fuels include aviation gasoline (avgas), jet propellant-4, and Jet B, which are blends of kerosene and naphtha or gasoline.

6.2.1.2.6 Other Products from Petroleum

Other products that result from crude oil include naphtha, other oils (with a boiling point equal to or greater than 401°F), lubricants, waxes, petroleum coke, asphalt and road oil, petrolatum, aromatic extracts and tars, absorption oils, ram-jet fuel, petroleum rocket fuels, and synthetic natural gas feedstocks.[56]

6.2.1.3 Natural Gas

Natural gas is a naturally occurring, nonrenewable fossil fuel, and unrefined it is a mixture of gaseous hydrocarbons, primarily methane (CH_4). Natural gas can be collected from a variety of sources, including landfills and the anaerobic digestion of organic waste (i.e., decaying of biomass), but most commonly it is collected from crude oil and natural gas fields.

Natural gas is an abundant natural resource, especially in the US (see Figure 17), and is therefore relatively affordable. Most natural gas deposits are a few thousand feet beneath the Earth's surface, but some can be more than 15,000 feet below the surface. Natural gas associated with crude oil can exist as a dissolved gas or free gas. Nonassociated natural gas exists in deposits absent of crude oil.

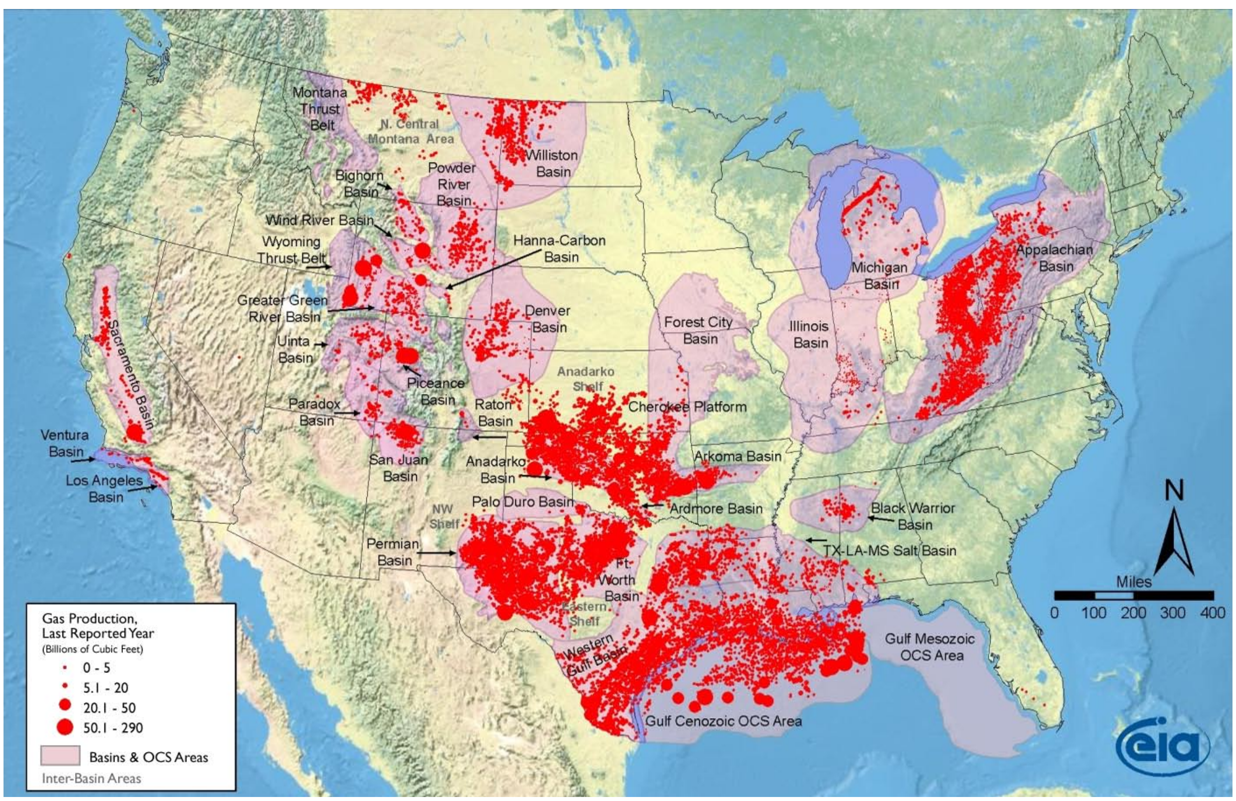


Figure 17. US natural gas production.[58]

Methane hydrates are being studied as a possible alternative source of natural gas. Clathrate compounds are formed when water molecules bond in such a way as to encapsulate another molecule. A methane clathrate, also known as a methane hydrate, is an example of this unique molecular structure in which water molecules surround a methane molecule. These compounds have been found embedded in the ocean floor, sedimentary layers and in permafrost.

6.2.1.3.1 Properties

Natural gas is a colorless, odorless, non-poisonous, flammable substance. An odorant, typically butanethiol (also known as t-butyl mercaptan) or tetrahydrothiophene, is added in small amounts to aid the detection of natural gas leaks.

Prior to refining, the typical composition of natural gas is 70 to 90 percent methane, by volume, but also includes ethane, propane, butane and other alkanes (see Table 12). Other contents found in this fossil fuel include nitrogen, helium, carbon dioxide, water vapor and hydrogen sulfide (H_2S). After refinement, commercial grade natural gas is almost entirely composed of methane.

Table 12. Typical composition of unrefined natural gas.[50]

Component	Formula	Percent
Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulfide	H_2S	0-5%
Rare gases	He, Ne, Xe	trace

Methane is in gaseous form at room temperature, condenses at -164°C, and freezes at -183°C. The density of methane is 0.67 kg/m^3 at standard temperature and pressure (STP) compared to the density of dry air: 1.29 kg/m^3.[59, 60] Methane is slightly soluble in water; for instance 3.5 ml of methane dissolves in 100 ml of water at 17°C. It is also soluble in alcohol, ether, and other organic solvents.[61]

Methane reacts with oxygen to produce carbon dioxide, water vapor and heat according to Equation 1.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) + 890\text{ kJ} \qquad \textbf{Equation 1}$$

When fuel is mixed with air combustion occurs when natural gas concentration is between 5-15%.[61] The autoignition temperature of methane is 650°C.[61]

The products after combustion of natural gas are primarily carbon dioxide and water, whereas other fuels have a notable amount of additional byproducts. Therefore, natural gas results in a cleaner combustion than gasoline or diesel. Potential emissions reductions by using natural gas instead of gasoline have been estimated and are shown in Table 13.

Table 13. Potential emissions reductions through the combustion of natural gas instead of gasoline.[62]

Pollutant	Percent Reduced
Carbon monoxide	90-97%
Carbon dioxide	25%
Nitrogen oxides	35-60%
Hydrocarbons (non-methane)	50-75%

In addition to reductions in these compounds, combustion of natural gas results in a reduction in carcinogenic pollutants and particulate matter compared to combustion of gasoline. Natural gas is considered to have an octane rating higher than gasoline.

6.2.1.3.2 Processing

Natural gas harvested from petroleum wells and other sources must be processed and refined to remove many of the unnecessary components and impurities to produce a commercial grade fuel. Alkanes other than methane are removed and collected for other uses.

Particulates, such as sand, are removed by scrubbers. In the case of natural gas dissolved in crude oil, it must be separated using a gravity separator, for example. Some water can be condensed out of the natural gas during refining, but dissolved water must be removed through absorption or adsorption.

Organic contents other than methane, such as ethane, propane, and butane are also extracted and subsequently separated as byproducts for other uses. Absorption is the method commonly used to extract the heavier organic compounds from the unrefined natural gas, while cryogenic expansion is used to extract compounds, such as ethane, which is close in molecular weight to methane. Separation of the hydrocarbons is then accomplished by fractionation methods.

Hydrogen sulfide is removed from unrefined natural gas by an absorption process. Amine compounds can be used to absorb hydrogen sulfide, thereby extracting it from the natural gas stream. Elemental sulfur can subsequently be recovered for use in other applications.

6.2.1.3.3 Applications

As a combustible substance that can provide thermal energy, natural gas is commonly used for heating and cooking. However, there are several other applications of natural gas, such as fuel for vehicles and as a source of hydrogen for hydrogen production.

Natural gas vehicles (NGVs) use compressed natural gas (CNG) or liquid natural gas (LNG). This is because if natural gas is used in its unpressurized, gaseous form, a large volume is needed to power a vehicle for an acceptable distance. Even with CNG or LNG, NGVs have a more limited range than vehicles powered on conventional fuels. However, the power output of engines fueled by natural gas is comparable to those powered by conventional fuels. Natural gas vehicles can be powered by dedicated natural gas engines or bi-fuel engines, which can run on either natural gas or a conventional fuel.[63]

6.2.1.3.4 Distribution

Small diameter pipelines are typically used to transport unrefined natural gas from the collection point to the processing plant or storage facility. The US has a network of interstate and intrastate pipelines (see Figure 18) that are used to transport natural gas from processing plants to the point of final distribution and consumption. Interstate pipelines are high pressure lines and are kept pressurized by compressing stations. Metering stations are also placed along the pipeline to monitor the natural gas in the line.

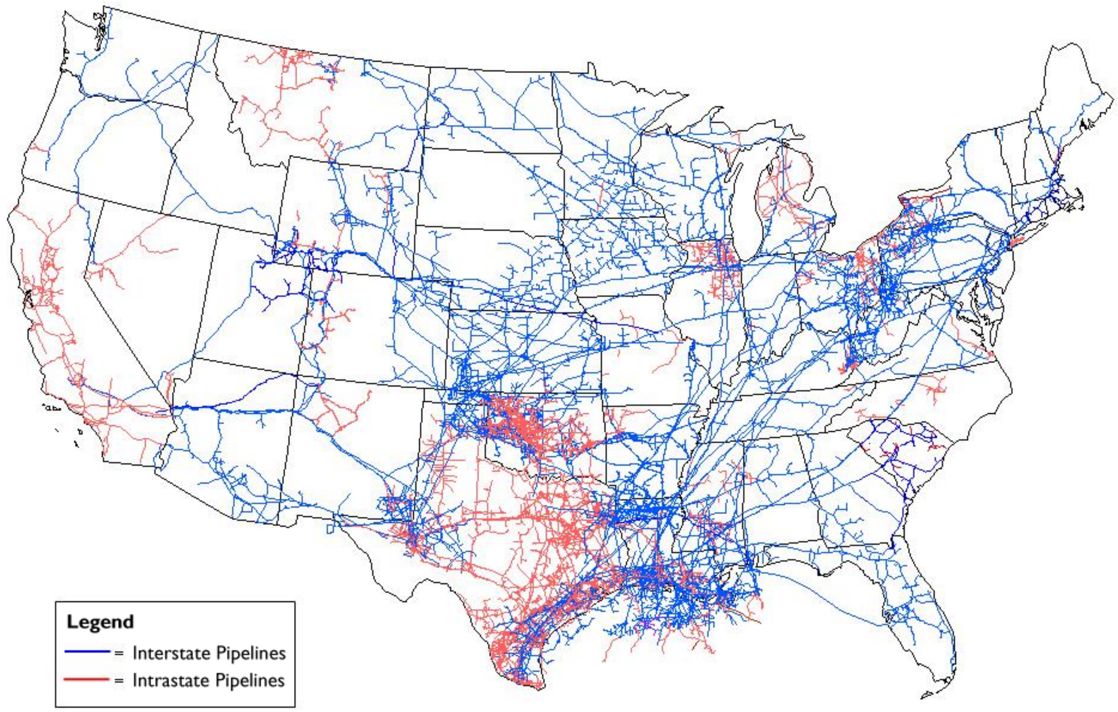


Figure 18. US natural gas pipeline network.[64]

6.2.1.3.5 Storage

Depleted gas reservoirs are used to store large volumes of natural gas underground. For instance, when a natural gas well becomes exhausted it can be used to store refined natural gas. In a similar way, underground salt caverns can be used to store natural gas. Natural water aquifers also can be reconditioned and used to store natural gas underground.

6.2.1.4 Propane and Liquefied Petroleum Gas

Propane is commonly used in residential applications as fuel for thermal utilities and outdoor cooking, and it accounts for approximately two percent of the energy consumed in the US.[65] It can also be used to power vehicles and electricity generators.

Propane is colorless, odorless, and has a high octane rating. Under pressure (e.g., approximately 300 pounds per square inch, psi), propane can be stored as a liquid. It is sometimes referred to as liquefied petroleum gas (LPG)[xxv], since as liquid propane is released from storage it converts into a gas to be combusted efficiently. The liquid form has an energy density 270 times that of gaseous propane; however liquid propane is has 25 percent less energy than an equivalent volume of gasoline.[66] The energy content of LPG is compared to liquefied natural gas in Table 14.

Table 14. Energy content comparison of liquefied petroleum gas and liquefied natural gas.[67]

	Lower Heating Value (BTU/gal)	Higher Heating Value (BTU/gal)
Liquefied Petroleum Gas	84,950	91,410
Liquefied Natural Gas[xxvi]	74,720	84,820

[xxv] Liquefied petroleum gas is a pressurized gas and is often a mixture of propane and other short carbon chain gases, such as methane. However, propane comprises the majority of the composition.
[xxvi] Natural gas can be liquefied under cryogenic conditions.

Propane is produced as a by-product of natural gas and petroleum processing. Similar to methane, propane is a relatively clean burning fuel since it can be relatively pure and thus there are few by-products of the combustion process. Its combustion generally releases carbon dioxide, water vapor, and thermal energy. Unlike methane, propane has a relatively short lifetime when emitted to the atmosphere since it is chemically unstable in the presence of oxygen and sunlight.[68]

6.2.1.5 Methanol

Methanol, like methane, is a relatively clean burning fuel that has been used for automotive, cooking, and more recently fuel cell applications. It is composed of a methane molecule with an alcohol functional group. It is chemically very similar to ethanol, and is typically produced during steam reforming of natural gas. However, it can also be produced using coal, biomass, or other hydrocarbon sources. It is relatively inexpensive to produce and has a low flammability compared to gasoline. (See *Section 13.1.2*.)

6.2.1.6 Ethanol

Ethanol is used extensively as a fuel and as an additive to gasoline and other fuels. It is composed of an ethane molecule with an alcohol functional group. Although it can be produced from petroleum feedstocks, it is of significant importance since it can also be produced by the fermentation of biomass. It is discussed in more detail in *Section 10.3.1*.

6.2.1.7 Summary of Fossil Fuel Products

Fossil fuels are currently the most useful energy resource available. They abundantly provide fuel, electricity, and thermal utilities, however, fossil fuels are a finite and nonrenewable resource. The energy content of some of the common fossil fuel products is shown in Table 15. Table 16 shows the energy consumption and efficiency derived from several fossil fuels powering distributed generation power generators. Table 17 provides a comparison of the level of carbon dioxide emitted upon combustion of various fossil fuels.

Table 15. Summary of fuel properties.[67]

	Main Fuel Source	Physical State	Energy Content		
			LHV (BTU/gal)	HHV (BTU/gal)	Gasoline Equivalent[xxvii]
Gasoline	Petroleum	Liquid	116,090	124,340	100%
Diesel (No. 2)	Petroleum	Liquid	128,450	137,380	113%
Compressed Natural Gas	Underground reserves	Gas (pressurized)	20,268 (BTU/lb)	22,453 (BTU/lb)	100% at 5.66 lbs or 126.67 ft^3
Liquefied Natural Gas	Underground reserves	Liquid (cryogenic)	74,720	84,820	64%
Liquefied Petroleum Gas	By-product of petroleum and natural gas processing	Liquid (pressurized)	84,950	91,410	73%
Methanol	Natural gas, coal, biomass	Liquid	57,250	65,200	49%

[xxvii] Energy compared to one gallon of gasoline. This is given as percent energy content on a gallon-to-gallon basis unless other units are specified.

Table 16. Energy efficiency data for several fossil fuels in electrical generators.[xxviii, 68]

Fuel	Electrical Efficiency, HHV (%)	Energy Use (MMBTU/Unit/Year)[xxix]
30 kW Prime Microturbine		
Diesel	22.7	1151
Natural Gas	23.6	1107
LPG	23.6	1107
100 kW Standby Genset		
Diesel	33.5	20.3
Natural Gas	31.0	22.0
LPG	32.7	20.9
200 kW Prime Genset		
Diesel	38.8	4493
Natural Gas	32.5	5359
LPG	34.2	5091

Table 17. Carbon dioxide released during combustion of various fossil fuels.[xxx, 68]

Fuel	Mass of CO_2 Emitted Upon Combustion (kg/MMBTU)
Natural Gas	52.8
LPG	62.7
Ethanol (E85)	66.6
Gasoline	70.5
Kerosene	70.7
Diesel	72.5
Residual Fuel Oil	78.6
Bituminous Coal	92.1

6.2.2 Nuclear Energy

Nuclear energy is the energy contained within the nucleus of an atom, specifically the energy that binds the nucleus together. Some of this energy can be released when nucleons (i.e., protons or neutrons) are split apart (fission) or fused together (fusion). Fission and fusion occur naturally. Radioactive materials are inherently unstable and decay over time by releasing packets of matter, energy, or both. In some cases, the unstable nucleus of a radioactive material fissions and releases nucleons to achieve a more stable material. Fusion occurs naturally, for example, under the immense pressure and temperature of stars, such as the sun. Although fusion reactions convert mass into enormous amounts of energy, only fission is currently a viable source of power for conventional applications.

Nuclear power is based on an abundant resource of energy, and generates electricity essentially by extracting energy from the atomic nucleus. Heat from the fission of atomic nuclei is used to create steam, which powers a turbine and ultimately converts the energy into electricity. However, since fission reactions in most stable matter do not readily occur (i.e., consume more energy than they produce), nuclear reactors use radioactive uranium or plutonium as fuel.

Nuclear power is known to produce electricity without the carbon emissions and other greenhouse gas emissions associated with the use of petroleum and coal. However, it is the inherent danger associated

[xxviii] Gensets operating at full load, 60 Hz, and seven hours per day (prime) or 20 hours per year (standby).
[xxix] MMBTU = 1,000,000 BTUs
[xxx] Assumes complete combustion of fuel.

with nuclear reactions as well as the challenge of handling and disposing of nuclear waste that has kept nuclear power from becoming the primary energy resource in the US.

At the end of 2007, there were 104 operational commercial nuclear reactors in the US.[69] However, nuclear power is not only limited to stationary facilities. The US Navy has ten aircraft carriers and more than sixty submarines powered by nuclear reactors.[70]

6.2.2.1 Nuclear Fission

Nuclear power is derived from nuclear fission reactions, in which a radioactive material is bombarded with matter to induce fission of the nuclei. As the nuclei fission, matter and energy are released. The ejected matter bombards other nuclei causing a chain reaction to occur. The energy is captured for conversion to useful work to ultimately generate electricity.

6.2.2.2 Nuclear Fusion

Light element nuclei can be fused to release energy. This process has the potential to produce a massive amount of energy. However, it is not a technically viable process and is not expected to be in the near future.

6.2.2.3 Fuel

Although the raw materials used to produce nuclear fuel are relatively abundant, they are finite and nonrenewable. The radioactive isotopes that produce energy for conventional nuclear power are found as a small percentage of the raw materials.

The fuel for nuclear reactors is commonly derived from uranium. Although the energy contained in the radioactive materials is considerable, only a fraction is able to be converted to useable power. Some nuclear energy systems reprocess the nuclear fuel to augment the fraction of energy extracted for useable power. These are termed closed fuel cycles. Open fuel cycles pass the nuclear fuel through the system once and afterwards is waste radioactive material. Typically the fuel resides in the reactor for one to two years.[40] Only the open fuel cycle is used in the US since there reprocessing fuel has not been shown to be beneficial.

6.2.2.3.1 Uranium

Uranium is naturally found in the earth's crust. As of 2004 there were 5,469,000 metric tons of known recoverable uranium.[71] Uranium-235 (^{235}U) is a commonly used nuclear fuel but is only found in approximately 0.73% concentration of uranium deposits. Table 18 lists the concentration of uranium found in typical resources.

Table 18. Concentration of uranium found in various resources.[71]

Resource	Concentration (Parts Per Million, ppm)
Very High Grade Ore	200,000
High Grade Ore	20,000
Low Grade Ore	1,000
Very Low Grade ore	100
Granite	4 – 5
Earth's Continental Crust (average)	2.8
Sedimentary Rock	2
Seawater	0.003

The refining process involves the extraction of uranium oxide (U_3O_8) from the ore. U_3O_8 is chemically converted to uranium hexafluoride (UF_6), which is used for the enrichment process.

The enrichment of uranium refers to increasing the ratio of ^{235}U to uranium-238 (^{238}U), a less radioactive isotope. Either gaseous diffusion or gas centrifugation can be used to enrich the ^{235}U concentration to 3 to 5%, although the centrifuge process is more efficient than the diffusion process. As uranium is enriched, the leftover uranium is called depleted uranium. Once the UF_6 is enriched, it is chemically converted to uranium dioxide (UO_2) or metallic uranium, which is used as nuclear reactor fuel.

A nuclear plant with a capacity of 1,000 MW_e will consume approximately 27,000 kg of UO_2 per year. The energy content of uranium is approximately 24 megawatt-hours (MWh) per gram of uranium fuel (3.71×10^{10} BTU/lb).[40] Reactors produce approximately 790 MWh of energy per kg of fuel fed into the reactor. This means the reactor energy efficiency is only approximately 3.3 percent, and 96.7 percent of the energy is contained in waste fuel. However, the US abandoned the concept of reprocessing spent fuel due to security and nuclear proliferation concerns.[40]

6.2.2.4 Reactors

There are many variations of nuclear reactors, but two of the more common types are the pressurized water reactor (PWR) and the boiling water reactor (BWR). Other types of reactors include gas-cooled reactors, advanced gas-cooled reactors (AGRs), light water graphite-moderated reactors, and liquid metal-cooled fast breeder reactors (LMFBRs).

6.2.2.4.1 Pressurized Water Reactor

The PWR consists of a pressure vessel that contains UO_2 pellets and control rods. The nuclear core is cooled by highly pressurized water. The heated water coming out of the reactor is circulated through steam generators, and the steam, which is isolated from the radioactive reactor cooling water, is used in a steam generator to produce electricity.

The PWR was used in the world's first large-scale nuclear power plant.[40] These reactors are typically light-water reactors (LWRs) that use enriched UO_2 as fuel. Alternatively, pressurized heavy water reactors (PHWR) use natural UO_2. The PHWR can be refueled while in operation. PWRs range in power capacity from 400 to 1,500 megawatt-electric (MW_e).[40] A newer, smaller PWR is the international reactor innovative and secure (IRIS), which has a capacity of 335 MW_e. The IRIS has the steam generator and cooling system integrated into the pressure vessel.

6.2.2.4.2 Boiling Water Reactor

Boiling water reactors differ from PWRs in that the steam is generated directly from the cooling water rather than in a separate exchange process. The water to steam conversion takes place inside the concrete containment structure. Similar to the light water PWRs, BWRs use enriched UO_2 as fuel. BWRs range in power capacity from 400 to 1,200 MW_e. The advanced boiling water reactor (ABWR) is a newer reactor design that can operate at a 1,300 MW capacity and it exceeds NRC safety goals. There is also an economic and simplified boiling water reactor (ESBWR) that has a capacity of 1,500 MW_e.[40]

6.2.2.4.3 Gas-Cooled Reactors

Conventional gas-cooled reactors were designed to utilize uranium metal as fuel, however the advanced gas-cooled reactor uses enriched UO_2 as the nuclear fuel. AGRs use CO_2 as the cooling fluid and graphite to control the nuclear reaction. The CO_2 circulates through the reactor core and is then moved to a steam generator.[40] The gas turbine-modular helium reactor (GT-MHR) utilizes helium to cool the reactor and power a gas turbine rather than a steam generator.[72]

6.2.2.4.4 Other Types of Reactors

There are many variants of nuclear reactors. The LMFBR uses sodium as the cooling fluid, which transfers thermal energy to a secondary sodium fluid that is pumped through a steam generator. The LMFBR uses either plutonium oxide (PuO_2) or UO_2 as fuel.[40]

The advanced passive (AP) reactor has passive safety features that substantially reduce the number of components and thus complexity. The AP reactor is modular and takes 36 months to construct at a cost of approximately $1,200/kW. The power output costs are estimated at $0.035/kWh with a life expectancy of 60 years.[40]

6.2.2.4.5 Future Reactor Technologies

The Generation IV International Forum (GIF) is a multi-national collaborative effort to focus on and develop the next generation nuclear energy systems. These systems are being designed to be safer, more sustainable, more economical, and more secure.[73] The GIF selected six reactor designs to focus development efforts:

- Gas-cooled fast reactor (GFR)
- Very high temperature reactor (VHTR)
- Supercritical water-cooled reactor (SCWR)
- Sodium-cooled fast reactor (SFR)
- Lead-cooled fast reactor (LFR)
- Molten salt reactor (MSR)

The goal of the GIF is to develop these systems such that they are deployable before 2030.

6.2.2.5 Waste

One of the primary drawbacks of nuclear power is the waste that is generated, since it is radioactive waste. Waste is generated during all aspects of the nuclear cycle, including mining, milling, conversion, enrichment, and reaction.

During mining and milling the radioactive decay of elements in the ore produces radon gas. Objects or materials that are in proximity to nuclear fuel during any point in the process collect radiation and thus must be disposed of properly. Some radioactive gases, including krypton-85, xenon-133, and iodine-131, are emitted to the atmosphere during power production. The krypton and xenon gases are chemically inactive and the iodine gas has a short half-life; they do not pose any considerable danger.

Spent fuel and any wastes from the reactor itself are the most problematic due to their high levels of radiation. In addition the fuel has a high thermal energy and must be cooled. Spent fuel is initially cooled in storage pools at the reactor site and then transferred to dry storage in concrete or steel structures that are passively air-cooled. For disposal, spent fuel is transported to deep geological storage facilities. For maximum safety and protection the fuel is transferred in lead-lined containers and can be transported safely via ground, rail, or sea.

6.2.2.6 Costs

The cost of electricity produced from nuclear generation is approximately $0.03 to $0.04 per kWh. The primary costs associated with nuclear power include capital, fuel procurement, operation and maintenance, waste management, and decommissioning costs. Decommissioning costs are approximately 9 to 15 percent of the capital costs of the nuclear plant, and typically contribute to approximately five percent of the total cost of electricity or $0.0015 to $0.002 per kWh.[40] Waste management costs are approximately ten percent of the total cost of electricity or $0.003 to $0.004 per kWh. Operations and maintenance costs and fuel procurement costs are relatively stable. The bulk of the cost of electricity is related to the construction of the plant.

6.2.2.7 Advantages

Nuclear power plants are scalable to some extent, and they can reach very high power capacities. Nuclear plants typically have a long life expectancy in the range of 40 to 50 years.[74] In addition to the relatively large power capacity, nuclear power plants can be upgraded and the life of the plant can be extended. Some plants can be upgraded to increase power capacity by 20 percent.[40] Most nuclear plants are built with a 40 year operating lifetime. However, this life can be extended through engineering assessments performed by the Nuclear Regulatory Commission (NRC). This can extend the life expectancy to 60 to 70 years.[40] Stability of fuel costs is an attractive feature of nuclear power. There is minimal volatility in the nuclear fuel market compared to most fossil fuels.

6.2.2.8 Disadvantages

There are essentially three key disadvantages to nuclear power that are related to economics, waste management, and safety, which is in part perception. High capital costs drive the cost of the power generated by a nuclear plant. The capital costs to design and construct a nuclear power plant can be prohibitive. However, if the capital funding is available and long-term power is needed, the cost of electricity over a period of several decades is reasonable. Traditionally, licensing has been problematic due to uncertainties in obtaining the appropriate approvals. The licensing period can extend the length of the design and construction phase, which could have a significant impact capital costs.

Since nuclear fuels and the objects and materials in close proximity to the fuels are the subjects of significant levels of radiation, waste management is critical. The disposal of the fuel and these objects and materials is not ideal since the only solution is to dispose of them in deep geological facilities.

The other key disadvantage is the security and public perception of the safety of a plant. Security, safety measures and backup systems are critical elements to prevent a catastrophic event. Natural disasters must be planned for to prevent failure of any of the security, safety, or backup systems. Finally, the general public does not like to be in close proximity to a nuclear plant due to the potential consequences of an accident.

6.3 Nonrenewable, Alternative Energy Sources

Many alternative energy sources are renewable and are discussed in another part of this handbook. One important alternative energy source that is nonrenewable, based on current technology, is synthetic fuel. Synthetic fuels are defined and described in the following sections.

6.3.1 Synthetic Fuels

Synthetic fuel is technically defined as "a fuel that is artificially formulated and manufactured."[75] However, synthetic fuels are commonly described as liquid fuels derived from "coal, natural gas, or other solid carbon-containing feedstocks."[76] Synthetic fuels can also be extracted from oil shale and tar sands.[76]

6.3.1.1 History

Synthetic fuels were first made possible when the Fischer-Tropsch process was developed in the 1920s by Franz Fischer and Hans Tropsch. This process formulates hydrocarbon fuels from carbon monoxide and hydrogen gas (H_2), which allows carbon-based products to be transformed into useful hydrocarbon fuel and lubricant products. The hydrocarbon product is formed when the reactants are passed through a catalyst under heat.

6.3.1.2 Advantages

During combustion synthetic fuels produce less carbon dioxide, particulate matter, and sulfur compared to petroleum products refined from crude oil. This is because synthetic fuels are fabricated from less contaminated reactants than petroleum products that are typically contaminated with nitrogen, sulfur, iron, nickel, copper, and vanadium. Good low temperature properties and excellent thermal stability are also noted as advantages of synthetic fuels.[76] Raw materials that are used as feedstocks for formulating synthetic fuels (e.g., coal and natural gas) are naturally occurring in US territory. Synthetic fuels that can be produced include gasoline, diesel, kerosene and various formulations of aviation and jet fuel. Synthetic fuels can also be used in existing engines and can be distributed using the existing infrastructure.

6.3.1.3 Disadvantages

Although the combustion of synthetic fuels produces less carbon dioxide than the combustion of fuels from petroleum products, the production of synthetic fuels still results in high carbon emissions. The sulfur from petroleum-based fuels helps in the lubrication of moving engine parts. In addition, aromatic hydrocarbons, which are present in petroleum-based fuels, cause elastomeric seals to swell and therefore provide enhanced sealing capability. Finally, the mining of coal, which is one of the primary raw materials for synthetic fuels, is hazardous and can be environmentally damaging.

6.4 Renewable, Traditional Energy Sources

Renewable energy sources are as old as the earth. The ability to convert many of these sources into useable power is much more recent with few exceptions. Power derived from water (i.e., hydropower) is one and wind is another. Power generated from hydroelectric plants is considered renewable, yet the capability has been in use for centuries. Similarly, the capability to convert wind to power has been around a long time, yet it has not become a significant source of energy until recently and thus it is discussed in *Chapter 9*.

6.4.1 Hydropower

An estimated 4×10^{16} watts (W) of power exist as a result of the flow of the hydrological cycle[xxxi]. Only 0.01 to 0.015 percent of this total power, however, is considered to be available for the production of electricity through hydropower, thus resulting in a theoretical hydropower potential of approximately 44×10^{12} kWh/yr.[77]

Hydropower is the largest source of economically viable renewable energy; it produces more than 42 percent of the United States' renewable energy.[78] Energy derived from hydropower can cost as low as $0.01 per kW; the initial capital investment, however, remains high compared to other sources primarily due to dam construction costs.

Although it the most mature renewable energy resource, hydropower has experienced limited growth since there are few untapped sources that remain.[78, 79] The US has approximately 80,000 dams, but only 2,400 are used to produce power.[80] During the 1950s, hydropower accounted for 30 percent of the electricity produced; this declined to ten percent by 2000.[81] In 2001, hydropower projects contributed 81 percent of the nation's renewable electricity generation and approximately ten percent of the total electricity produced. The majority of this electricity resulted from large scale (greater than 30 MW capacity) hydropower plants.[82] Figure 19 and Figure 20 show the extensive potential of hydropower in the US alongside existing generation sites.[83]

[xxxi] The hydrologic cycle is the continuous movement of water on, above, and below the surface of the earth.

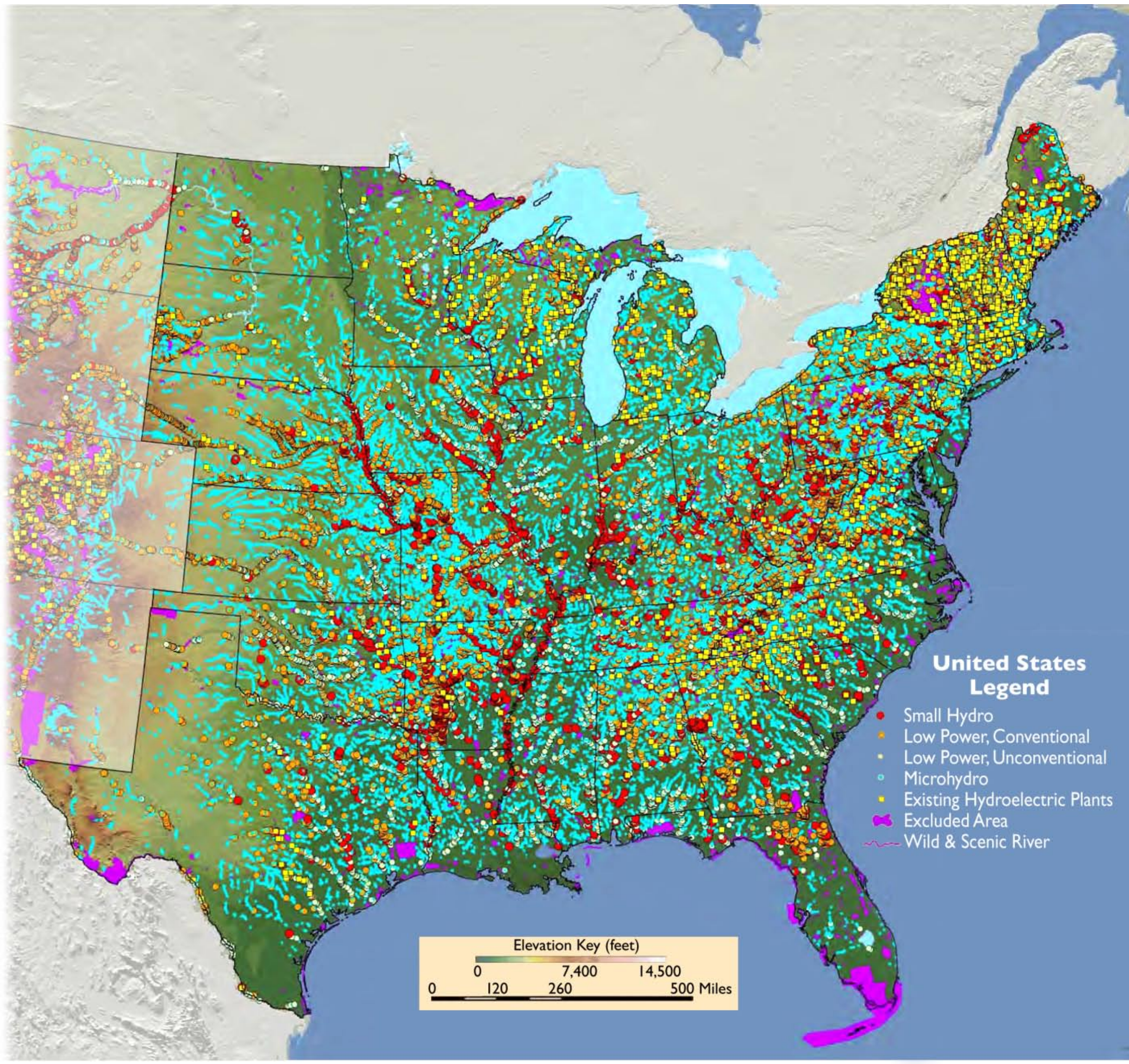


Figure 19. Existing hydroelectric plants and feasible hydropower projects in the Eastern US.[83]

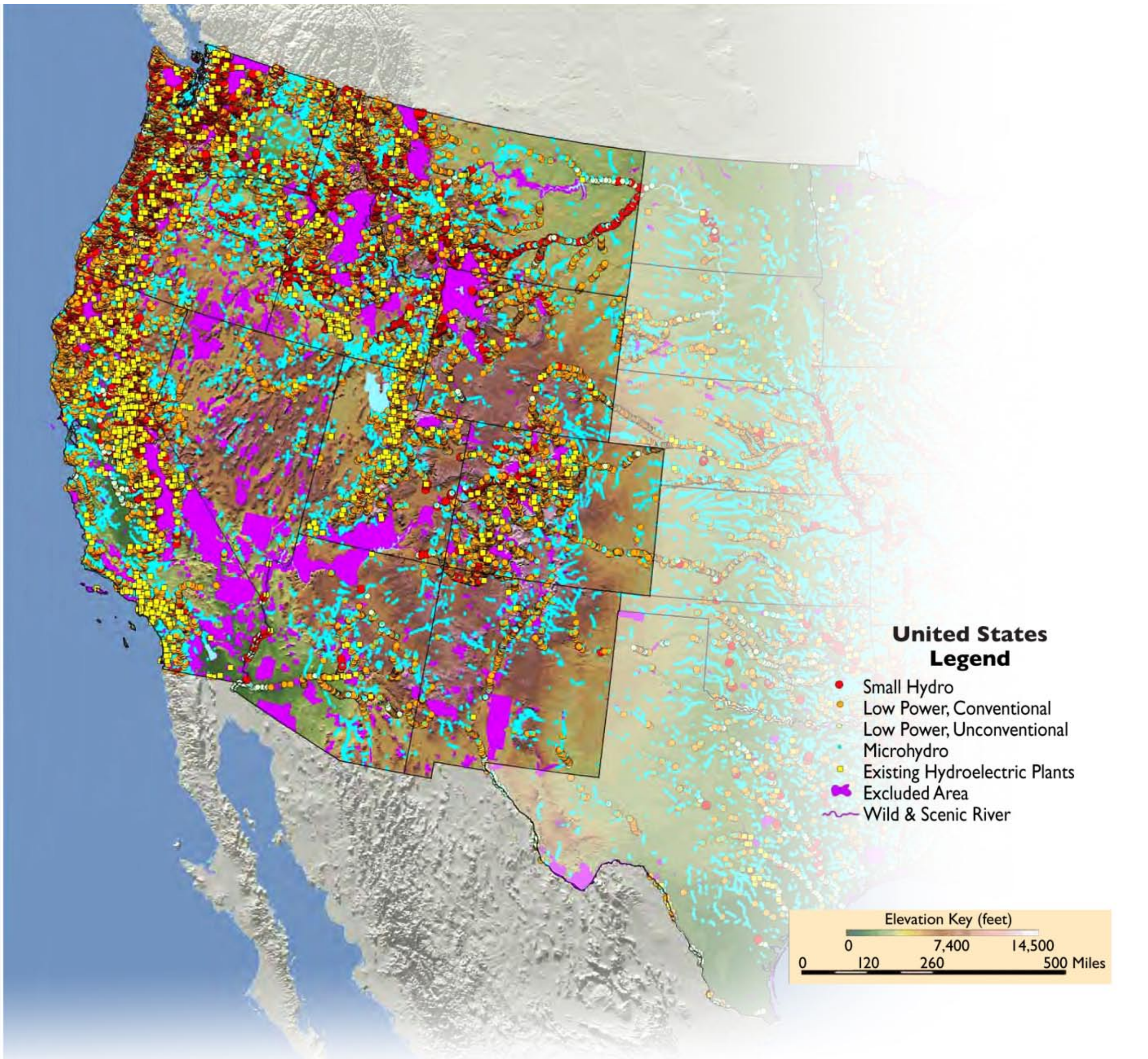


Figure 20. Existing hydroelectric plants and feasible hydropower projects in the Western US.[83]

6.4.1.1 History of Hydropower

Hydropower has been used for centuries, beginning more than 2000 years ago when the Greeks used water wheels to grind wheat to flour. It was first implemented for the production of electricity in the United Kingdom, although credit for having the first hydropower plant is often given to the US for its Appleton, Wisconsin, 12.5 kW hydroelectric plant that began operation in 1882.[77, 84] Hydropower was utilized as early as 1880 when Sir William Armstrong created a small, less than five kW, hydroelectric plant to light his picture gallery that was 1.5 km away. In 1881, the waters of the River Wey were used to light the streets of Godalming.[77] In that same year, a hydroelectric generation station was built on the Niagara River in the United States. Electricity was generated to power the machinery of local mills and for street lighting. By 1896, electricity was provided to Buffalo, NY, by the Niagara station through long distance transmission lines.[85] This project is considered the world's first large-scale hydroelectric plant. It consisted of two turbines, each of which had a 4,100 kW capacity. This project was later followed in 1903 by the construction of a 9.3 MW power plant in Niagara Falls, Ontario.[77]

By the 1920s an estimated 40 percent of the world's electricity was generated from hydropower. The US and Canada had more than 13 GW in potential operating capacity with France, Japan, Norway, Sweden, and Switzerland having more than 1 GW in potential operating capacity. However, by the 1990s, the world share of hydropower had dropped to 25 percent.[77]

6.4.1.2 Generation of Electricity from the Hydrologic Cycle

Fluids, which have the ability to flow, naturally store energy that is proportionally relative their position, mass, and velocity. Therefore, large volumes of water can store a large amount of energy. This energy can be converted relatively easily into useful energy by various methods. The most common method of conversion is through the use of a turbine to harvest the kinetic energy of flowing water. The turbine when connected to a generator can produce electricity. Dams are used to regulate the water flow. In addition to aiding in the production of power, dams also provide a downstream water source.[78, 88]

Since hydropower facilities harvest the kinetic energy of flowing water, the resource water must either already be in motion or water's potential energy must be converted into kinetic energy. In order to convert the potential energy of water to kinetic energy, the water must be released from one height to a lower height. A dam is used to retain water causing it to accumulate and store its potential energy. Gates of a dam can be opened, which opens a path for water to flow from one height to a lower height. In effect, this converts the water's potential energy to kinetic energy. This energy can then be recovered through the use of a turbine-generator combination. The basic process is illustrated in Figure 21.

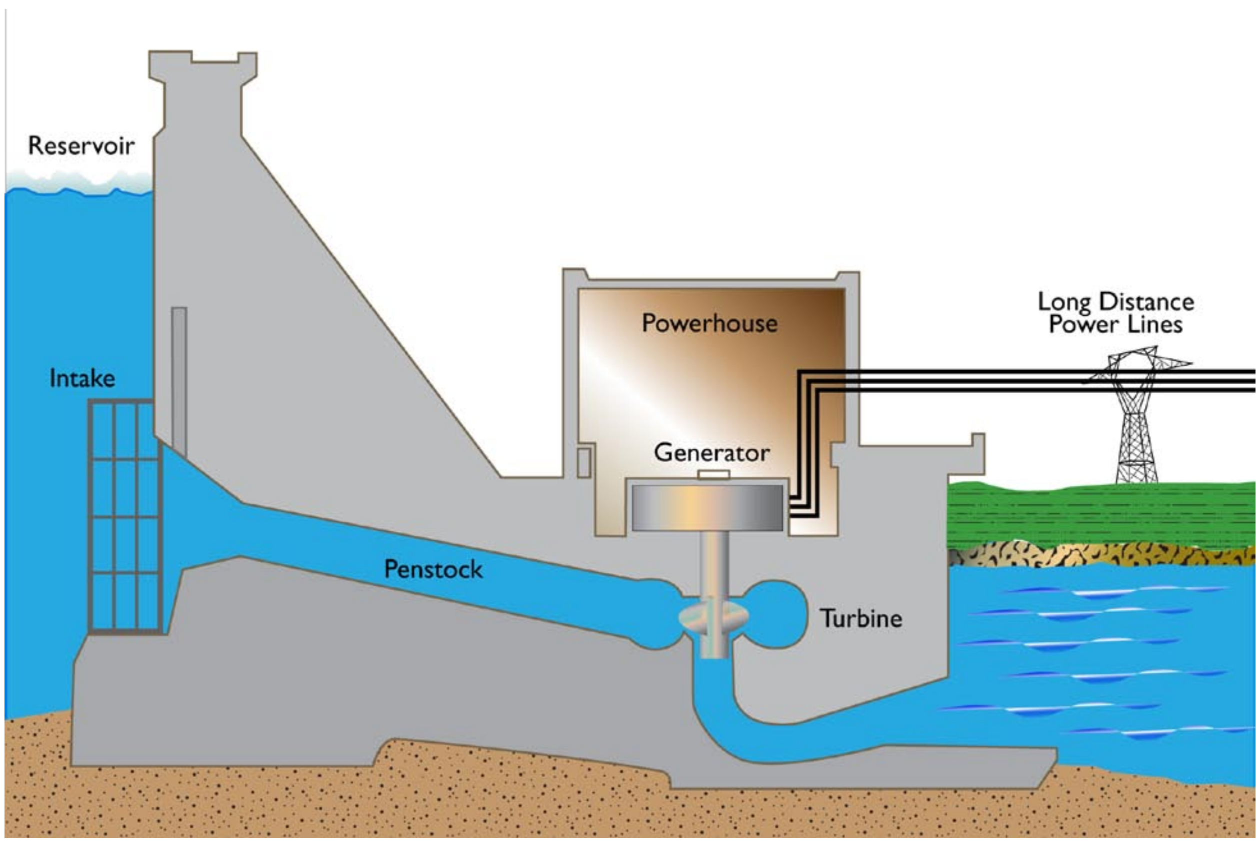


Figure 21. Hydropower plant.[86]

As the water flows through the penstock[xxxii], the water's potential energy is converted to kinetic energy. The kinetic energy causes the turbine to rotate. A shaft that extends from the turbine to a generator is used convert this mechanical energy into electricity, as illustrated in Figure 22.[82]

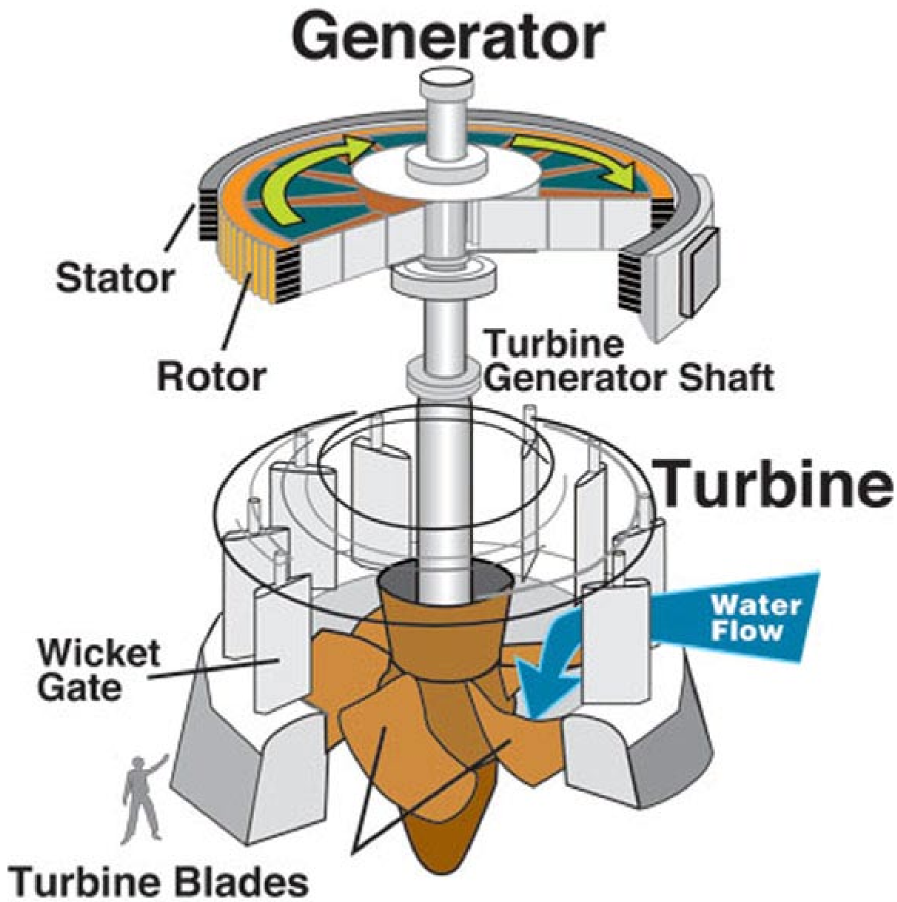


Figure 22. Hydraulic turbine connected to a generator.[87]

The available power from a water resource can be calculated from the volumetric flow rate and the change in height, which is known as the head.[82] Equation 2 presents the basic formula for calculating power output.

$$P_{max} = \rho \times \dot{Q} \times g \times \Delta h$$ **Equation 2**

Where

P_{max} – maximum power output, —— or W

ρ – density, kg/m^3

– volumetric flow rate, m^3/s

g – gravitational acceleration, m/s^2

Δh – change in height or head, m

[xxxii] Penstock is a traditional term that denotes a physical intake and conduit through which water flows. It may also include the gate or water intake and management system.

The two factors that dictate the amount of energy that can be generated at a hydroelectric plant are the head and flow rate of the water. Head refers to the distance that the water drops, whereas the flow rate indicates the volume of water that moves through the system over a certain period of time. In general, if the plant has a high head, it will require less flow when compared to a low-head plant to produce the same amount of electricity.[88]

6.4.1.3 Types of Hydropower Plants

Hydropower facilities can be classified based upon their type or upon their size. The two main types of hydropower plants are impoundment and diversion. There are three size classes: micro, small-scale, and large-scale, as shown in Table 19.

Table 19. Hydropower Plant Classification.[80]

Size Classification	Capacity
Micro	< 100 kW
Small	> 100 kW to < 30 MW
Large	> 30 MW

6.4.1.3.1 Impoundment

Impoundment plants are the most common type of hydropower plant. Larger than other types of hydropower plants, impoundment plants consist of a dam and turbine as shown in Figure 21. The dam creates a blockade to flowing water, causing it to accumulate behind one of its sides. As the water is allowed to flow through the dam, its energy is used to spin a turbine and shaft connected to a generator to produce electricity. The quantity of water allowed to flow through the dam can be increased or decreased depending on electricity demand and water level. However, it is critical to ensure that the turbine can handle the flow being passed through.[80]

6.4.1.3.2 Diversion

Diversion plants, as with impoundment plants, utilize a turbine. However, with a diversion plant, a portion of the water is redirected through a separate channel where its kinetic energy is converted to electricity.[80] An example diversion hydropower plant is shown in Figure 23.

Figure 23. Diversion hydropower plant.[89]

6.4.1.4 Types of Hydropower Turbines

A turbine may be defined as a device that is used to extract energy from a flowing fluid; in this case, the fluid is water and therefore the turbines are referred to as hydraulic turbines.[90] Turbines can be classified based upon the direction of flow through the blades: axial, radial, or combined flow. However, it is more common to classify them as either reaction or impulse turbines as most fit into one of these two categories. Table 20 lists the conditions for which each turbine type should be selected.

Table 20. Turbine selection.[90]

Turbine Type	Head		Flow Rate
Reaction	Low	3 – 30 m	High
Impulse	High	> 400 m	Low

6.4.1.4.1 Reaction Turbines

Reaction turbines are most efficient under high flow rate, low head conditions and consist of a rotor that is enclosed by a casing. With this type of turbine, the water flows within the casing to spin the turbine.[90] A reaction turbine creates power from the action of both the pressure and the motion of the water. As the water flows over the turbine's rotor, the angular momentum, velocity, and pressure of the fluid decrease. Because of their design, reaction turbines are most frequently found in hydroelectric plants that utilize dammed rivers.[90]

For low head (3 to 30 m) applications, reaction turbines have comparatively inexpensive, fixed blades. They also have relatively high conversion efficiencies when used at conditions below the system design limits. However, the conversion efficiency decreases under partial loading. The average efficiency when operating at a third of the full-rated power output is only 50 percent.

The two most common types of reaction turbines are the axial-flow Kaplan turbines and the radial- and mixed-flow Francis turbines. The low efficiency under partial loading condition can be improved via the use of the Kaplan turbine. This turbine has adjustable pitch blades and can produce at an efficiency of approximately 90 percent when operating at a third of its full-rated power output.[77] The Kaplan turbine was developed in the Czech Republic by Victor Kaplan.[90, 91]

The Francis turbine was developed in Lowell, MA, by an American engineer, James B. Francis, in 1848.[90, 91] The radial-flow Francis turbine has inlet guide vanes that are used to direct water into the rotor. These guide vanes may be adjusted for optimum performance. With this type of turbine, the fluid applies a torque to the rotor in the direction of rotation, and the rotor subsequently extracts energy from this fluid.[90] For medium head applications (5 to 400 m) mixed-flow, radial turbines are often used, the most popular of which is the Francis turbine. This turbine is similar to the fixed-blade propeller type; however, its speed is controlled by adjusting the guide vane angle.[77]

6.4.1.4.2 Impulse Turbines

An impulse turbine uses a nozzle to convert water pressure into velocity. The resulting stream of water impacts a rotor (also known as a runner) that has buckets to capture the kinetic energy of the water.[92] The impulse turbine works well for high head applications.[90]

The most commonly known impulse turbine is the Pelton Wheel, which was designed by an American engineer, Lester Pelton, in 1870.[90, 91] (A Pelton Wheel for micro-hydro is illustrated in Figure 24.) This type of turbine is typically used when the head is greater than 50 m. At one tenth of its full-rated output, the Pelton Wheel has an efficiency equal to 60%.[77] The Pelton Wheel can have an efficiency as high as 90%.[82] The speed is controlled by a variable inlet nozzle to ensure, when used under constant head conditions, that the torque on the generator is proportional to the flow rate. Additionally, it ensures that the turbine speed can be maintained for synchronous generation at a specific grid frequency.[77] Figure 25 shows a Pelton Wheel installed at a hydropower plant.

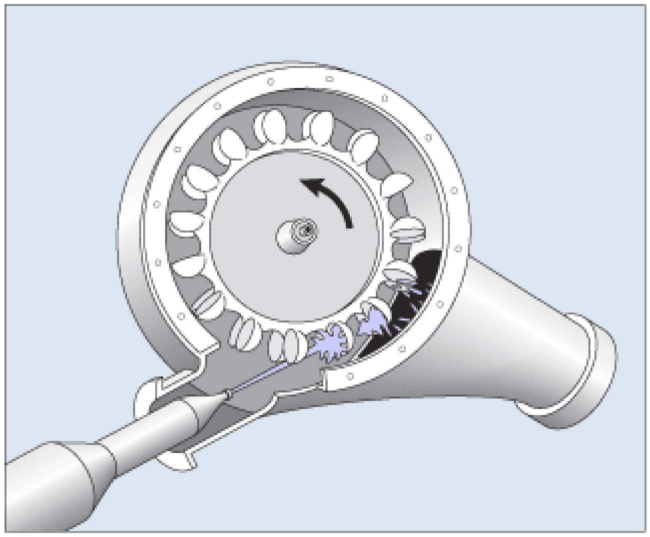


Figure 24. One-nozzle Pelton Wheel turbine.[93]

Figure 25. Pelton Wheel impulse turbine.[94]

The Turgo turbine is an enhanced version of the Pelton wheel. This turbine is designed so that the incoming water jet stream impacts at an angle such that its spray is captured in three buckets nearly simultaneously. This causes the Turgo wheel to move twice as fast as the Pelton wheel. Although the Turgo wheel can operate under low flow conditions, it does require a medium to high head.[93]

The cross-flow turbine is another type of impulse turbine and it is designed to allow the water to flow through the blades twice. On the first pass, the water flows from the outside of the blades to the inside, and on the second pass this process is reversed. This type of turbine is shaped like a drum and uses a rectangular nozzle directed against the vanes to force its rotation. It was developed to accommodate large water flows at lower heads than the Pelton wheel.[92]

Overall, impulse turbines offer the least complex design and are most commonly used in high head micro-hydro systems, relying on the water velocity to turn the wheel. Alternatively, reaction turbines depend on pressure for movement and are often used in large-scale hydropower plants.[82] Table 21 presents the various types of turbines and their corresponding head capability.

Table 21. Turbine selection criteria.[95]

Turbine	Range of Head (m)
Kaplan	2 – 40
Francis	10 – 350
Pelton Wheel	50 – 1300
Turgo Wheel	50 – 250
Cross-Flow	3 – 250

6.4.1.5 Plant Costs

Conventional hydropower facilities have high initial capital investments, but they are economically competitive with other electricity generation methods, such as coal and nuclear power. Hydropower plants have an average capital cost of approximately $1,700 to $2,300 per kW. The average operation cost is approximately $0.004 per kWh. The average maintenance costs are approximately $0.003 per kWh. The total cost is approximately $0.024 per kWh and the total operating life is greater than fifty years at a 40 to 50 percent capacity factor. The average plant size is 31 MW.[96]

6.5 Other Important Secondary Energy Sources (Energy Carriers)

An energy carrier is a source that delivers energy for an end use. A secondary energy source, which is sometimes referred to as an energy carrier, is energy derived from another energy source. For instance, electricity that is derived from the kinetic energy of flowing water is an example of a secondary energy source or energy carrier. Gasoline and other refined fuels can be categorized as a secondary energy source. Many of these sources have been described in other sections, but two other important secondary energy sources are electricity and hydrogen, which are described below. In some cases, there may be a tertiary energy source. For example, coal can be used to produce synthetic gas that is subsequently converted to electricity. In this case, electricity is a tertiary energy source.

6.5.1 Hydrogen

Hydrogen in its elemental state, protium, is composed of a single proton and a single electron, while its isotopes deuterium and tritium contain an additional one and two neutrons, respectively. It is the most abundant element in the universe and is the lightest (i.e., smallest atomic mass). It is estimated that three quarters of the mass in the universe is composed of hydrogen atoms.[97] Hydrogen is very chemically reactive and readily combines with many other elements, particularly carbon and oxygen; on its own hydrogen is found in its relatively stable, diatomic gaseous form, H_2.[97]

Hydrogen gas is highly flammable and when undergoing combustion (i.e., reaction with oxygen) it produces water and heat, as shown in the combustion reaction given in Equation 3.[98]

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) + 572\ \text{kJ} \qquad \text{Equation 3}$$

Since the only product is water and heat, hydrogen is a very clean burning fuel.

Hydrogen is not considered an energy source, but rather, an energy carrier like a spring, because the combustible gas is not abundantly occurring on its own in nature and therefore must be produced from other compounds. Hydrogen can be produced by leveraging other renewable energy sources, such as wind, solar, and hydroelectric power, and therefore it can be supplied from a variety of geographical regions. Once produced, most commonly by steam methane reforming, hydrogen as a fuel can be used in internal combustion engines and fuel cells. Liquid hydrogen is also used as a propellant, and is well known for its use to launch the Space Shuttle. Selected physical and thermodynamic properties of hydrogen are given in Table 22.

Table 22. Physical and thermodynamic properties of hydrogen.[99, 100, 101, 102]

Density[xxxiii]	0.08375 kg/m^3	0.005229 lb/ft^3
Specific Volume[xxxiii]	11.94 m^3/kg	191.3 ft^3/lb
Viscosity[xxxiii]	8.813 x 10^{-5} g/cm-s	5.922 x 10^{-6} lb/ft-s
Specific Heat (constant pressure)[xxxiii]	14.29 J/g-K	3.415 BTU/lb-°R
Specific Heat (constant volume)[xxxiii]	10.16 J/g-K	2.428 BTU/ lb-°R
Thermal Conductivity[xxxiii]	0.1825 W/m-K	0.1054 BTU/ft-h-°R
Enthalpy[xxxiii]	3,858.1 kJ/kg	1,659.8 BTU/lb
Internal Energy[xxxiii, xxxiv]	2,648.3 kJ/kg	1,139.3 BTU/lb
Autoignition temperature[xxxv]	585°C	1,085°F
Flame Temperature in Air[xxxiii]	2,045°C	3,713°F
Flammable Range in Air	4.0 – 75.0 vol.%	
Ignition Energy in Air[xxxiii]	2 x 10^{-5}	1.9 x 10^{-8} BTU
Higher Heating Value[xxxiii]	141.86 kJ/g	61,000 BTU/lb
Lower Heating Value[xxxiii]	119.93 kJ/g	51,500 BTU/lb

Energy density is the amount of energy contained in matter per unit mass or unit volume, and is often used to compare different types of fuels. The mass-based energy density of hydrogen is very high, but the volume-based energy density is low compared to other fuels. One pound of H_2 has 44.4% of the energy contained in one gallon of gasoline.[67] The energy densities of hydrogen gas and liquid at several pressures are given in Table 23.

Table 23. Volumetric and gravimetric energy density of hydrogen gas and liquid.[102]

	Volumetric Energy Density		Gravimetric Energy Density	
	MJ/m^3	BTU/ft^3	MJ/kg	BTU/lb
At 1 atm and 15°C (60°F)	10.1	270	120	51,700
At 3,000 psig and 15°C (60°F)	1,825	48,900	21,791	9,354,570
At 10,000 psig and 15°C (60°F)	4,500	121,000	53,730	23,147,300
Liquid	8,491	227,850	101,383	43,587,705

6.5.1.1 Hydrogen Production

Hydrogen as a resource is mostly contained in water and organic matter (i.e., hydrocarbons), and therefore must be extracted to be useable as a fuel. The following are some of the common processes used for hydrogen production.

6.5.1.1.1 Steam Methane Reforming

Approximately 95% of the hydrogen currently produced in the US is made via steam methane reforming, a process in which high temperature steam (700°C to 1000°C) is used to produce hydrogen from a methane source, such as natural gas which is mostly methane gas. In steam methane reforming, methane

[xxxiii] At normal temperature and pressure = 20°C (68°F) and 1 atm
[xxxiv] Reference state: Internal Energy U = 0 at 273.16 K for saturated liquid; Entropy S = 0 at 273.16 K for saturated liquid.
[xxxv] The autoignition temperature depends on hydrogen concentration (minimum at stoichiometric combustion conditions), pressure, and even the surface characteristics of the vessel. Reported figures range from 932 – 1085°F.

reacts with steam under 3 to 25 bar pressure (1 bar = 14.5 psi) in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide.[103]

6.5.1.1.2 Electrolysis

Electrolysis involves decomposing water into its base components of hydrogen and oxygen. This is accomplished by applying an electrical current through water via electrodes.

6.5.1.1.3 Gasification

Hydrogen can be produced by other organic feedstocks, such as coal and biomass. Using high temperature and pressure to gasify coal or biomass, the gasified organic product is then converted to synthetic gas, which is then reacted with steam under temperature and pressure to produce hydrogen. Syngas is primarily carbon monoxide and hydrogen (more than 85 percent by volume) and smaller quantities of carbon dioxide and methane. Syngas can be used as a fuel to generate electricity or steam, or as a basic chemical building block for a multitude of uses. When mixed with air, syngas can be used in gasoline or diesel engines with few modifications to the engine.[104]

6.5.1.1.4 Other Production Processes

Other processes used to produce hydrogen include renewable liquid reforming, nuclear high-temperature electrolysis, high-temperature thermochemical water splitting, and photobiological and photoelectrochemical processes.

6.5.1.2 Hydrogen Storage

In addition to its production, another technical challenge for hydrogen revolves around its storage. Even though hydrogen has a high energy density by mass, its energy density by volume is low. Therefore, storage of hydrogen fuel requires a sizable container that is also safe and reliable, since hydrogen is highly flammable. Hydrogen can be stored in tanks as a compressed gas or cryogenic liquid, or it can be stored on the surface or within other materials, such as metal hydrides and carbon-based materials.

6.5.2 Electricity

Similar to hydrogen, electricity is a secondary energy source, since it has to be generated (converted) from other energy sources. Electricity is the presence or movement of electric charge, and it is an extremely useful source of energy since it can be used to perform a variety of types of useful work.

6.5.3 Summary of Properties

Although hydrogen has the energy content to be a highly effective energy carrier, there are some obstacles to its widespread use. Conversely, electricity is the ultimate energy carrier. The energy content of these two secondary energy sources is provided in Table 24.

Table 24. Summary of energy carrier properties.[67]

	Main Fuel Source	Physical State	Energy Content: LHV	Energy Content: HHV	Energy Content: Gasoline Equivalent[xxxvi]
Electricity	Fossil fuel, nuclear, and renewable sources	Electricity	3,414 (BTU/kWh)	3,414 (BTU/kWh)	100% at 33.40 kWh
Hydrogen	Natural gas, methanol, water	Gas or liquid (pressurized)	51,585 (BTU/lb)	61,013 (BTU/lb)	100% at 1 kg

[xxxvi] Energy compared to one gallon of gasoline. This is given as percent energy content on a gallon-to-gallon basis unless other units are specified.

6.6 Important Energy Conversion Technologies

Energy is never created nor destroyed, and since it is not often present in a relatively useful form the vast majority of the energy used must be converted into a useful form. Many methods have been developed to convert energy into a form that is useful and for specific purposes. Since this handbook is focused on renewable energy resources (i.e., solar, wind, biomass, geothermal), the methods of energy conversion related to these resources are presented in *Part III*. Methods pertaining to conversion of coal are presented in *Section 6.2.1.1*. Methods pertaining to the conversion of nuclear energy are presented in *Section 6.2.2*.

It is important to note a few other important energy conversion methods as well as energy conversion technologies that are used as an alternative to or in addition to renewable energy conversion technologies. These conversion methods, which are described briefly in the following sections, can be used to serve as a distributed energy resource (DER, see *Sections 7.3.2* and *14.4*).

6.6.1 Internal Combustion Engine

The internal combustion engine (ICE) is one of the most common and easily recognizable energy conversion systems used. These engines are commonly divided into two groups: continuous-combustion and intermittent-combustion. Internal combustion engines commonly serve as the primary power source in vehicles including automobiles, trucks, motorcycles, locomotives, boats and aircraft. This array of vehicles that utilizes the internal combustion engine illustrates the advantages of this engine type. Both the high power-to-weight ratio, and the overall reliability of ICEs, makes these engines ideal for mobile applications. However, they are also commonly used in fixed settings to provide power from combustible fuels.

An internal combustion engine is able to provide power using the energy converted through combustion of fuel and oxidizers (typically air). The heat generated during combustion causes a rapid expansion of gases and thus pressure that can perform work on the mechanical components of the engine. This work is used to move pistons, turbine blades or other components within the engine.

Most ICEs are designed to be powered by either diesel or gasoline fuel. The mechanics of both engine designs are similar, but they employ a different ignition mechanism. The ignition process in gasoline engines typically relies on the combination of a lead acid battery and an induction coil which provides a high-voltage electrical spark to ignite the air-fuel mixture within the engine cylinder. Ignition in a diesel engine is driven by the compression process that occurs in the engine. The heat and pressure created in this stage allows the fuel-air mixture to spontaneously ignite without the aid of a spark. The compression ratio[xxxvii] is one the primary ways to characterize the difference in operating environments of the gasoline and diesel engines. Generally, gasoline engines operate with a compression ratio in the 8 to 12 range, while the diesel engine operates over a higher range from 14 to 25.

The ability of diesel engines to operate at these higher compression ratios is the primary factor that dictates why diesel engines are typically more efficient than gasoline engines. In fact, diesel engines are less efficient than gasoline engines when operated at the same compression ratio. Modern gasoline engines are approximately 20 to 25% efficient on average while diesel engines are capable of efficiencies approaching 40 percent.

The internal combustion engine is the most common type of generator for distributed applications, such providing power at forward operating bases and remote locations. They are commonly used as a backup, emergency, or auxiliary power supply. Power capacity more than 10 MW is possible using ICEs.

[xxxvii] Compression ratio is a value that represents the ratio of the volume of a combustion chamber from its largest capacity when the piston is at the high point to its smallest when the piston is at its low point. It is one of the fundamental specifications given for modern combustion engines.

These larger generator units can be used for base load generation (see *Section 7.3.5.1*), grid augmentation, and peak shaving.[105] Types of fuels that can be used in ICEs include gasoline, diesel, fuel oil, natural gas, and biofuel. Startup times for ICEs are short. A summary of the characteristics of ICEs is presented in Table 25.

6.6.2 Turbine Based Engines

Turbines are critical components in energy conversion systems and are commonly found in automobiles, aircraft, refrigeration systems, generators, and power plants. Despite their wide application, turbines are primarily part of a larger machine. For example, a gas turbine may refer to an internal combustion engine with a turbine, ducts, compressor, combustor, heat-exchanger, fan and (in the case of one designed to produce electricity) an alternator. The most common turbine-driven systems are steam, gas, and/or jet turbines.

In general, a turbine-powered engine converts the energy of a moving stream to mechanical work. In the simplest systems, the stream flows across blades attached to the turbine (rotor) and the blades then are forced to rotate which generates energy that can be used to do work. Turbines are also valuable in energy conversion systems because they can operate at high speeds and are able to provide a high power density source.

6.6.2.1 Gas Turbine

The major components of gas turbines or combustion turbines include a compressor, combustion chamber, and a turbine. Compressed air and fuel are sent to the combustion chamber and pressurized gases exit and pass through the turbine to generate mechanical work and ultimately electricity. Gas turbines are ideal for cogeneration since the combustion process generates excess thermal energy. Types of fuels that can be used in gas turbines include natural gas, fuel oil, diesel, propane, jet fuel, kerosene, methane, and biofuels.[105] A summary of the characteristics of gas turbines is presented in Table 25.

6.6.2.2 Microturbine

Microturbines are modified, small versions of gas turbines. These systems are reliable and offer high quality power at relatively low GHG emissions and at a relatively low cost. Microturbines produce high frequency power (e.g., 2 kHz) and thus must have the electrical current that is generated converted and synchronized to the required frequency (e.g., 60 Hz).[105]

A variety of fuels can be used in microturbines, including gasoline, diesel, natural gas, propane, kerosene and biofuels. The efficiency of microturbines is typically near 30 percent, but if used for cogeneration it can be closer to 85 percent.[105] A summary of the characteristics of microturbines is presented in Table 25.

6.6.3 Stirling Engine

Although very uncommon, the Stirling engine is notable because of its potential application to distributed generation and solar generation. Unlike an ICE, the thermal energy that drives the pistons in a Stirling engine is supplied external to the piston chamber. A Stirling engine consists of a closed system where the gaseous working fluid is heated and cooled to enable expansion and contraction of the fluid to drive the pistons. A summary of the characteristics of Stirling engines is presented in Table 25.

6.6.4 Fuel Cell

Fuel cells convert energy from fuels to generate power through electrochemical processes. Fuel cells are modular and can be used to build systems ranging in size from small to large. They are a relatively clean technology and can operate based on a variety of fuels. Table 57 provides a summary of the different types of fuel cells. A summary of the characteristics of fuel cells is presented in Table 25.

6.6.5 Cogeneration

Cogeneration, which is also known as combined heat and power, is a useful method to maximize the efficiency of converting energy from a fuel to useful work. The method applies a conversion technology, such as a gas turbine, to generate electricity and produce heat that can be recovered and used to provide thermal utilities to a facility. Cogeneration is very scalable and can be applied to a small building or a large power plant. *Section 10.3.4* describes the use of biomass to provide combined heat and power.

6.6.6 Summary

Internal combustion and turbine engines are mature technologies that are reliable for providing distributed generation power. Advances in technology can improve efficiency and output but only marginally. Microturbines are gaining in applications because of their suitability for distributed generation and relative low cost. Fuel cells are the least mature, but offer the potential of high efficiency and clean operation (i.e., low emissions). Figure 26 presents a comparison of the energy efficiencies at a range of power capacity for various energy conversion technologies. Table 25 presents a summary of several important characteristics of the energy conversion technologies described briefly above.

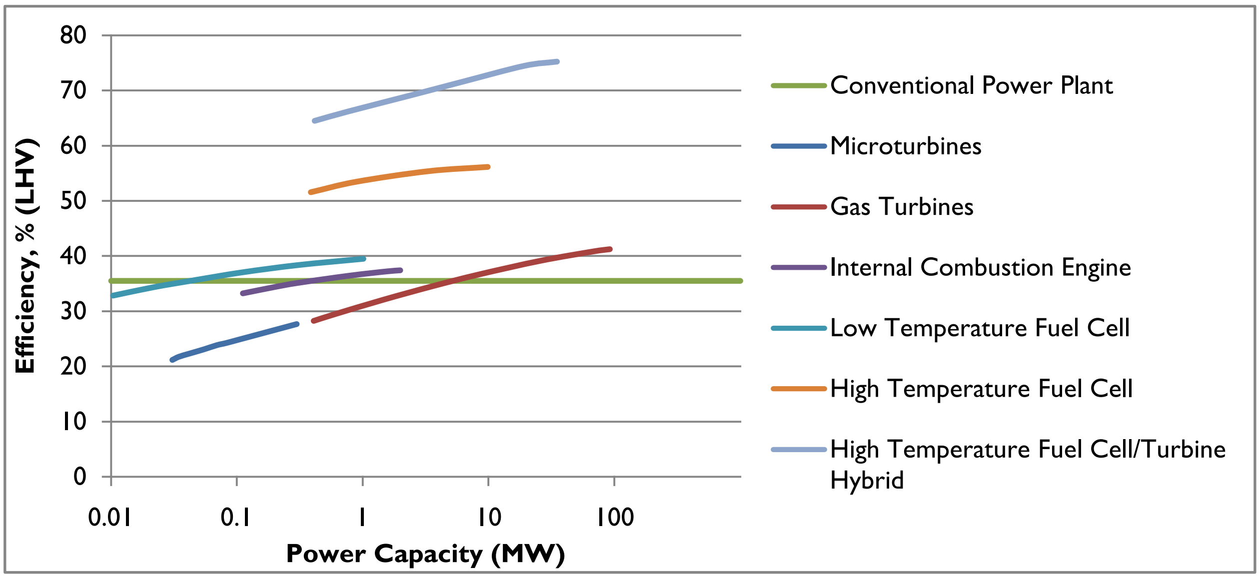


Figure 26. Comparison of efficiency range for several energy conversion technologies.[105]

Table 25. Summary of characteristics of various energy conversion methods and technologies.[105]

Conversion Method or Technology	Fuel	Power Capacity (MW)	Efficiency[xxxviii] (%)	Life (Years)	Purchase Cost ($/kW)	O&M Costs ($/kWh)	Energy Costs ($/kWh)	Environmental Issues	Commercial Availability	Cogeneration Possible
Internal Combustion Engine	Biofuels, natural gas, diesel, gasoline, and other fossil fuels	0.005 – 50	25 – 45	15 – 20	400 – 1,200	0.007 – 0.020	0.092 – 0.198	Emission controls needed, high noise	High	Yes
Gas Turbine	Biofuels, natural gas, and other fossil fuels	0.5 – 250	25 – 45	20 – 25	400 – 1,300	0.005 – 0.013	0.066 – 0.198	Low emissions, high noise	High	Yes
Microturbine	Biofuels, natural gas, hydrogen, propane, and other fossil fuels	0.025 – 0.5	20 – 30	10	900 – 1500	0.007 – 0.021	0.066 – 0.198	Low emissions, moderate noise	Moderate (Increasing)	Yes
Fuel Cell	Various	0.001 – 10	30 – 70	20	>5,000	0.007 – 0.040	>0.198	Low noise	Low	Yes
Stirling Engine	Any heat source (e.g., fossil fuel, solar energy)	0.001 – 0.025	12 – 30	Long	>2500	Not available	Not available	Low emissions, low noise	Low	Yes

[xxxviii] Based on lower heating value

7 FACILITY ENERGY USAGE

7.1 Overview

By nearly any standard, the Department of Defense is not only the largest department in the federal government but the largest entity in the US. With almost two million active and civilian military personnel, the DoD is the nation's largest employer. The DoD is also the largest consumer of energy in the US.

7.1.1 Total Energy Consumption

In FY09, the federal government consumed 1,095.7 trillion BTUs of energy, which is approximately 10 trillion BTUs less than what was consumed in FY08. The DoD's energy consumption represented 80.3 percent of this total energy consumed by the federal government.[106] Figure 27 shows the total energy consumption by agency. The history of energy consumption by the DoD since 1975 is shown in Figure 28.

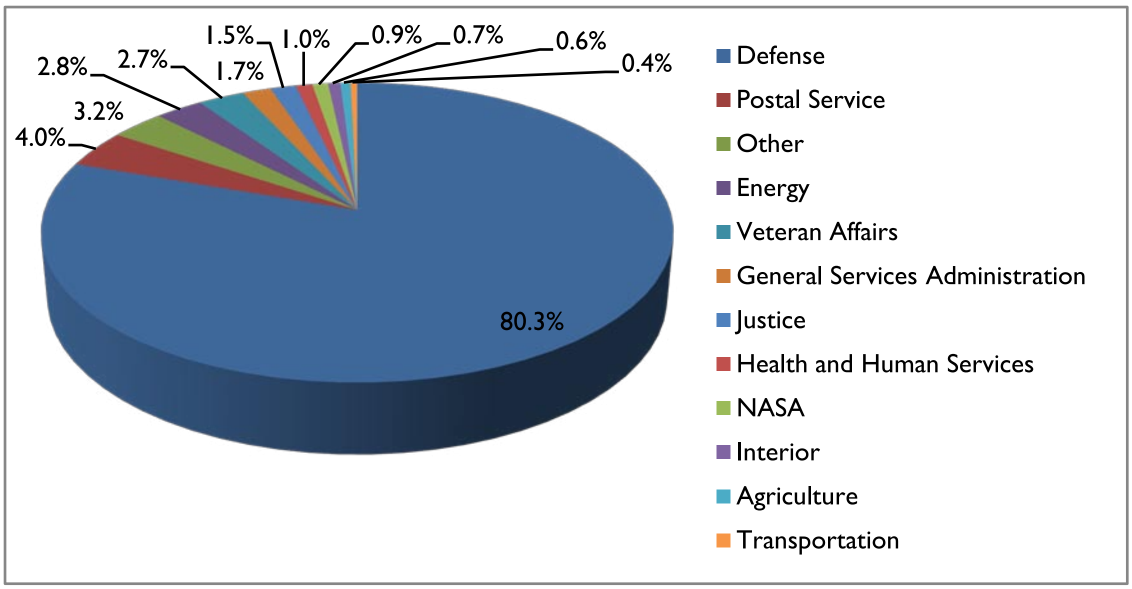


Figure 27. Total energy consumption by federal agency.[106]

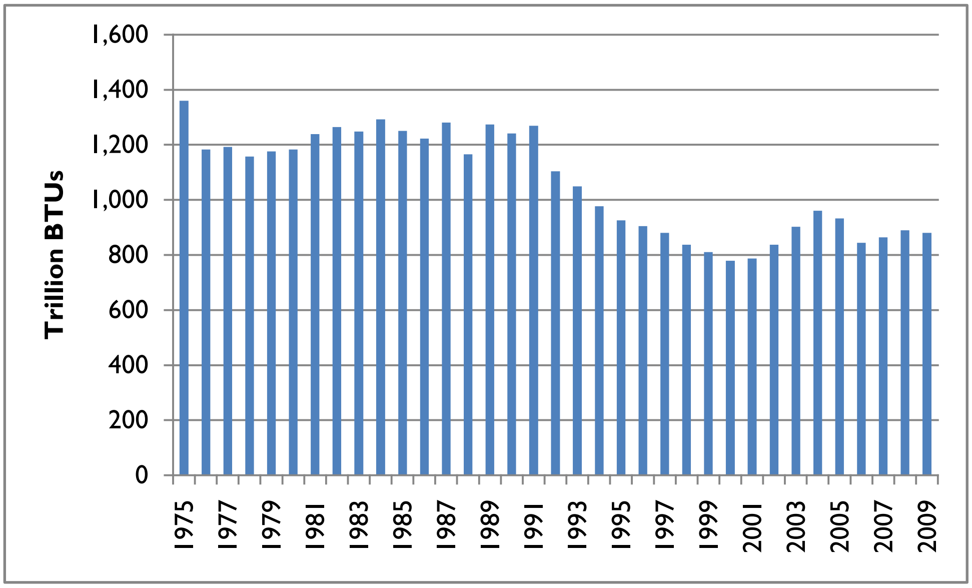


Figure 28. Total DoD energy consumption (1975 to 2009).[xxxix, 106]

7.1.2 Total Energy Consumption By Source

The total energy consumption categorized by source is presented in Figure 29. The DoD's total annual energy consumption by source of energy is provided in Figure 30. The figure shows that DoD energy consumption is dominated by petroleum use. As would be expected, jet fuel dominates the petroleum category. For instance, 74 percent of the petroleum consumed is in the form of jet fuel (approximately 500 trillion BTUs). Motor gasoline accounts for a small percentage, less than three percent (approximately 19 trillion BTUs), while fuel oils (residual and distillate) account for slightly more than 22 percent (approximately 149 trillion BTUs).[106]

[xxxix] 2009 data is listed as preliminary. For 1975 and 1976, the US Government's fiscal year was July 1 through June 30. Beginning in 1977, the fiscal year was changed to October 1 through September 30. Conversion factors used to develop data are provided in reference [106]. Data include energy consumed at foreign installations and in foreign operations, including aviation and ocean bunkering, primarily by the DoD. US Government energy use for electricity generation and uranium enrichment is excluded. Totals may not equal sum of components due to independent rounding.

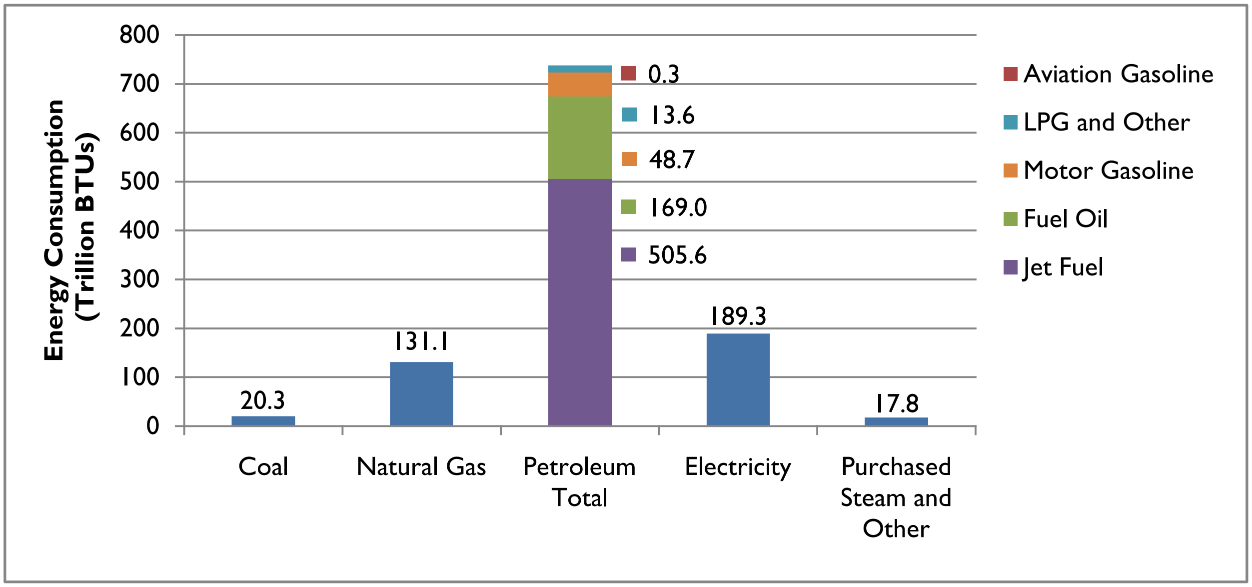


Figure 29. Total federal energy consumption by source.[xl, 106]

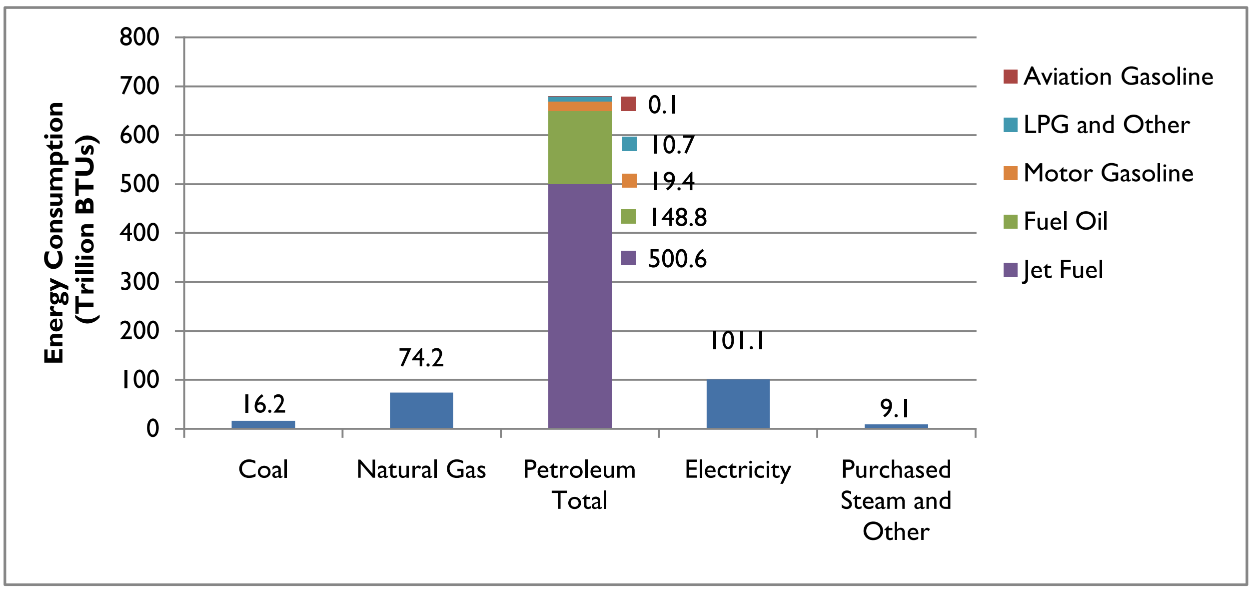


Figure 30. DoD energy consumption by source.[xl, 106]

Electricity is the second highest form of energy consumed by the DoD, followed by natural gas and coal. Electricity is a secondary energy source because it is derived from primary sources, such as fossil fuels, nuclear power, hydroelectric, and other renewable energy sources. The figure is intended to show only energy consumption and not generation. Hence, the coal consumption shown in the figure may have been used in part to generate electricity, however any of the subsequent electricity that is consumed is not accounted for in the electricity consumption column.

[xl] Natural gas includes a small amount of supplemental gaseous fuels. Purchased steam and other includes chilled water, renewable energy, and other fuels reported as used in facilities.

7.1.3 Energy Consumption By End Use

The bulk of energy consumed by the federal government is for mobility and transportation, as shown in Figure 31. Correspondingly, but by a larger majority, the energy consumed by the DoD is for mobility, which primarily includes powering aircraft, ships, and ground vehicles. Figure 32 shows that approximately three quarters of energy consumed by the DoD is for mobility purposes. Exempted facilities are those that have been exempted from meeting goals set forth by the policies and legislation presented in Section 0. Since the focus of this handbook is on energy for facilities, the following sections will be oriented in that manner.

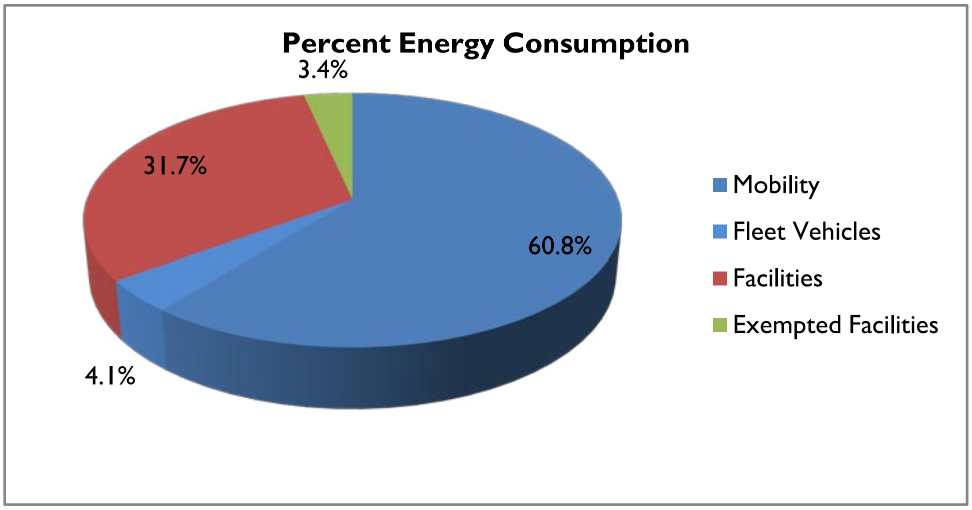


Figure 31. Federal energy consumption by end use.[107]

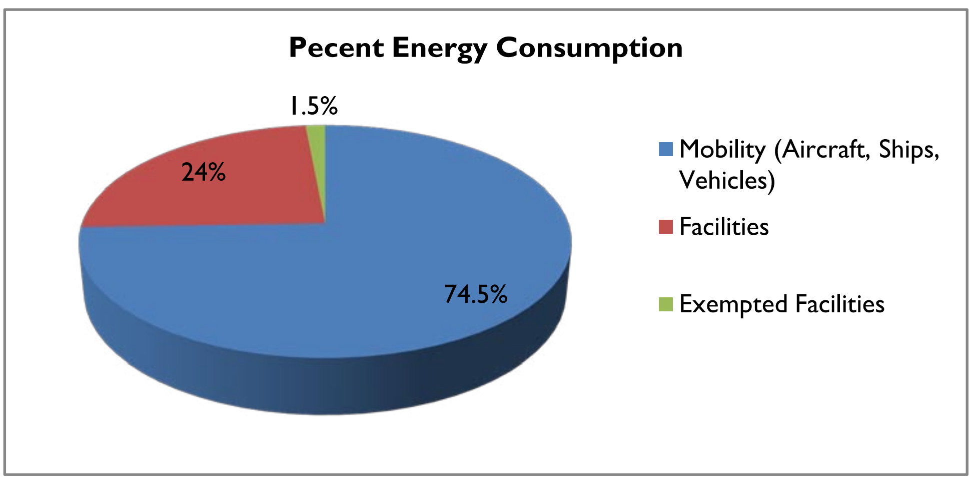


Figure 32. DoD energy consumption by end use.[108]

7.2 Facility Energy Consumption

The US government consumes 389 trillion BTUs per year for facility energy.[107] The DoD consumes approximately 60 percent of the energy used for buildings in the federal government on more than 65 percent of the gross square footage.[109] Figure 33 shows facility energy consumption by agency.

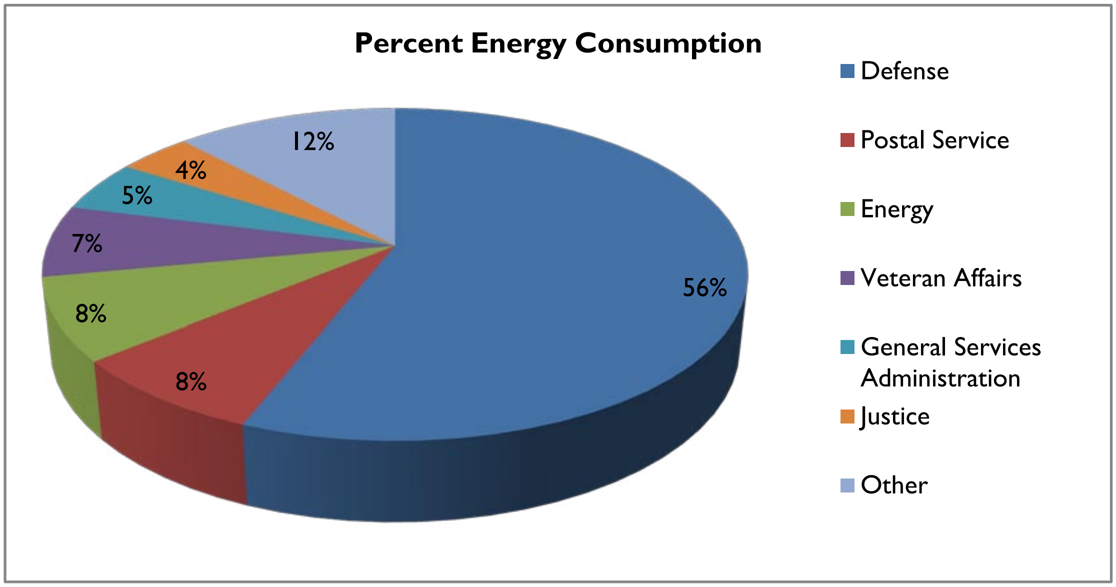


Figure 33. Facility energy consumption by agency.[107]

7.2.1 Total DoD Facility Energy Consumption

The DoD has 539,353 facilities[xli] located on more than 5,570 sites[xlii] covering 29 million acres (426,016 facilities are in the US).[110] This comprises 57 percent of the federal government's real property portfolio. At the end of FY09 the DoD had 1.93 billion square feet of facilities.[111] The DoD spent $3.6 billion on energy for facilities in FY09.[111]

The DoD consumed approximately 209 trillion BTUs of energy in its non-exempted facilities in FY09. The Army had the largest facility energy consumption, as shown in Figure 34, followed by the Air Force and Navy.

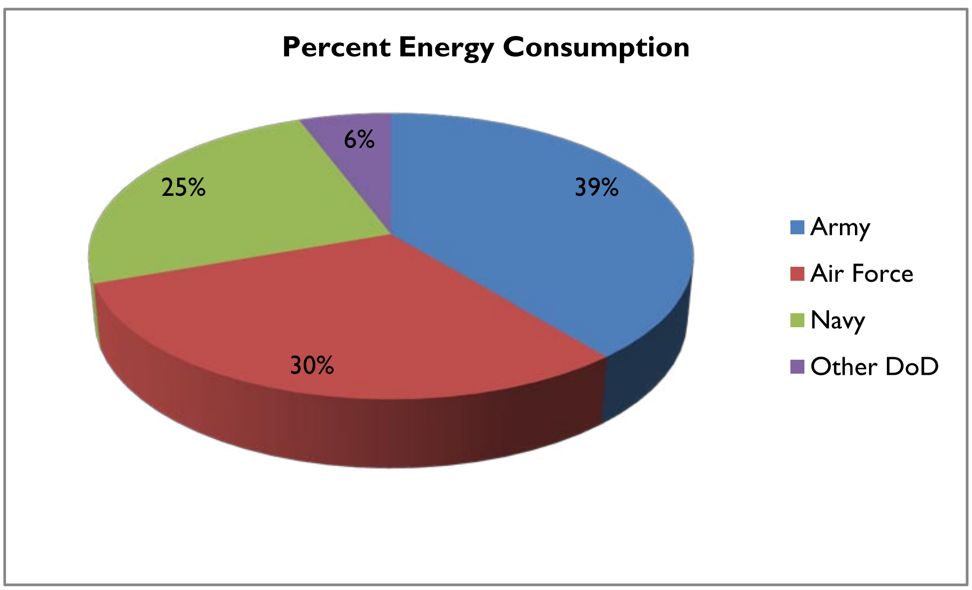


Figure 34. DoD facility energy consumption by military component.[111]

[xli] Facilities in this context includes buildings, structures and linear structures.
[xlii] A site is "a specific geographic location where the DoD owns or manages: land, buildings, structures, or linear structures."

7.2.2 DoD Facility Energy Consumption by Source

Approximately 45 percent of the energy consumed by the DoD for facilities is from electricity, while 34 percent is from natural gas. Approximately 19 percent of the energy consumed by the DoD for facilities is from fuel oil, coal, and purchased steam. The remaining two percent is from LPG and renewable sources. This is illustrated in Figure 35.

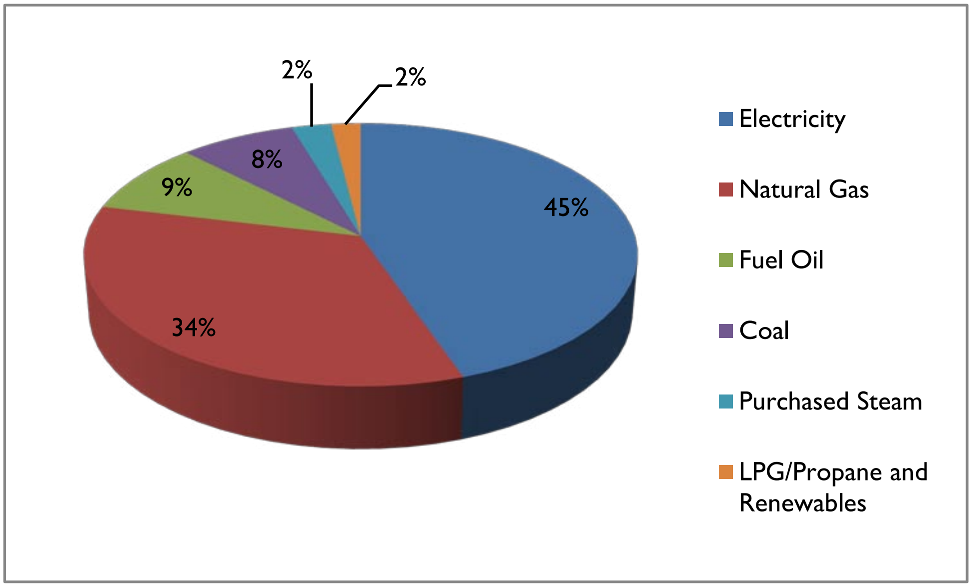


Figure 35. DoD facility energy usage by source.[111]

The total electricity consumed by the DoD in FY09 was 29,861 GWh. Of the total electricity consumed by the DoD, approximately 1,085 GWh (3.6%) was from renewable sources in FY09. For comparison, in FY08 the amount of electricity consumed from renewable sources was 2.9 percent. The electricity consumed from renewable sources for the DoD and services is presented in Table 26.[111]

Table 26. Electricity consumed from renewable sources by DoD and services in FY09.[111]

	Electricity Consumed From Renewable Sources
DoD	3.6%
Army	2.1%
Navy[xliii]	0.6%
Air Force	5.8%

In FY09, the DoD produced or procured 6.8% of the electric energy it consumed.[111] This is the progress toward the 25 percent renewable energy by 2025 as stated in the NDAA for FY07 (see *Section 4.2.2.1*). This progress as well as progress toward the EPAct requirement is shown in Figure 36.

[xliii] Does not include 270 MW China Lake geothermal plant since power is not consumed by the Navy.

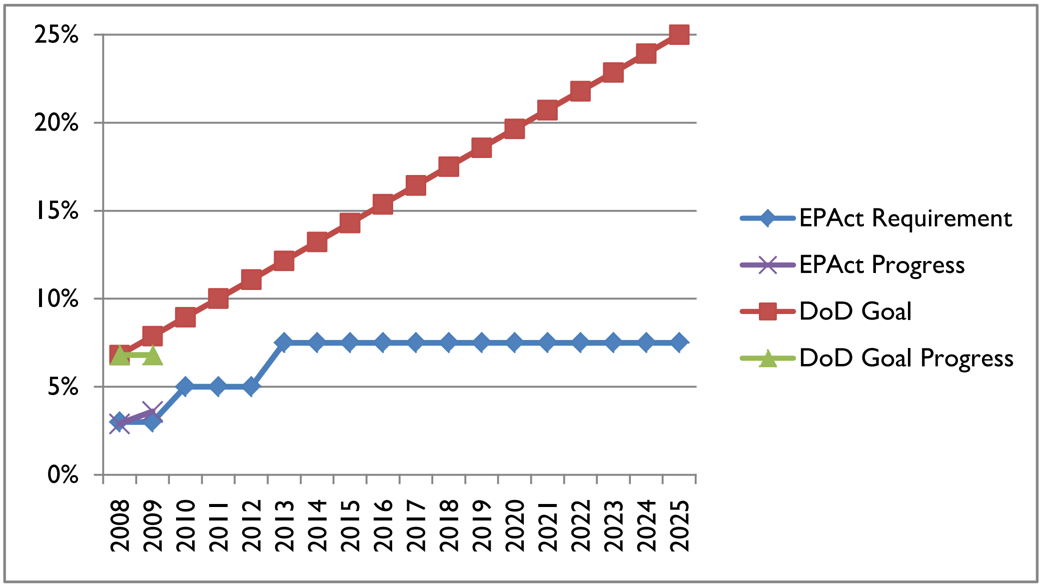


Figure 36. DoD's progress toward renewable energy goals.[111]

7.2.3 DoD Facility Energy Intensity

Energy intensity is a calculated value of the energy use per area, and for facilities it is typically represented as BTUs per gross square foot (GSF).[xliv] This value enables a comparison between facilities, and perhaps more importantly it aids in the identification of facilities that have a comparatively high energy consumption. Moreover, agencies can subsequently target these energy intense facilities for reducing energy consumption. The DoD established a benchmark for facility energy consumption in order to track performance toward achieving goals set by various energy policies. The 2003 baseline is 116,134 BTUs/GSF. In FY09 the total energy intensity of the DoD was 104,527 BTUs/GSF. Figure 37 and Figure 38 show graphical representations of the progress toward reducing facility energy intensity in the DoD to meet the EISA goal of 30 percent reduction by 2015.

[xliv] Gross square foot is generally defined as the total area in a building for all floors to the outer surface of exterior walls, including elevator shafts, vertical penetrations, equipment areas, ductwork shafts, and stairwells; and excluding areas having less than a 6'-6" clear ceiling height.

Table 27. DoD facility energy consumption.[111, 112, 113]

	Facility Energy Consumption (BTU/GSF)		
	FY2003 Baseline	FY2008	FY2009
Department of Defense (Total)	116,134	103,692	104,527
Army	100,260	91,879	93,051
Air Force	136,437[xlv]	113,368	116,529
Navy	120,230	109,550	101,955
Defense Contract Management Agency	104,425	126,999	130,494
Defense Commissary Agency	146,051	139,623	136,703
Defense Finance and Accounting Service	151,807	101,445	93,338
Defense Intelligence Agency	229,108[xlvi]	216,622[xlvii]	216,972[xlvii]
Defense Logistics Agency	51,385	60,832	49,587
Missile Defense Agency[xlviii]	-	-	-
National Geospatial-Intelligence Agency	177,040	195,803	218,140
National Security Agency	263,456	256,728	281,260
Tricare Management Agency	196,400	172,629	152,465
Washington Headquarters Services	161,044	176,053	213,963

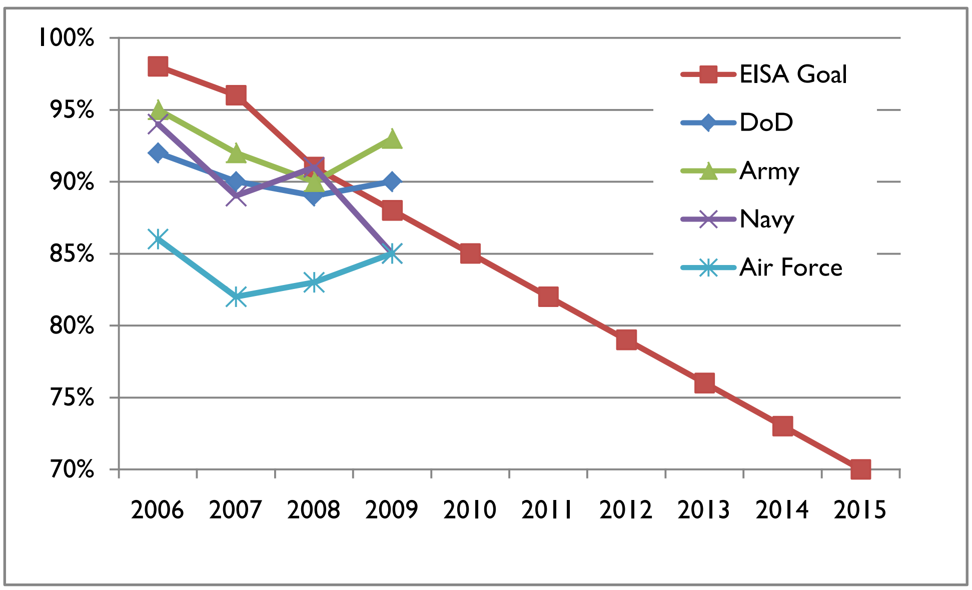


Figure 37. Percent energy intensity reduction compared to EISA goal.[111, 114]

[xlv] The Annual Energy Management Report for 2008 cites a FY2003 baseline of 137,931.
[xlvi] Based on old Defense Intelligence Analysis Center facility with 864,000 GSF.
[xlvii] Based on new facility with 1,325,610 GSF.
[xlviii] The Missile Defense Agency does not own any buildings or real property.

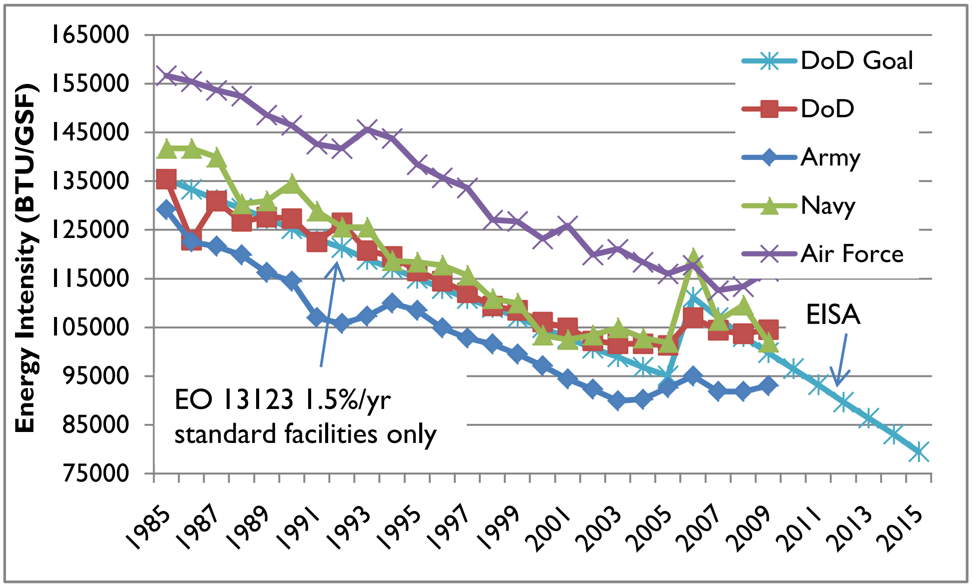


Figure 38. Historical energy intensity progress for DoD and services.[115]

7.2.4 Air Force Facility Energy Consumption

Air Force facilities consumed approximately 31 trillion BTUs in 2009, which is approximately 12 percent of the total energy consumed by the Air Force.[116] Figure 39 shows the energy consumption by end use for the Air Force. Figure 40 and Figure 41 show the facility energy costs and consumption by source.

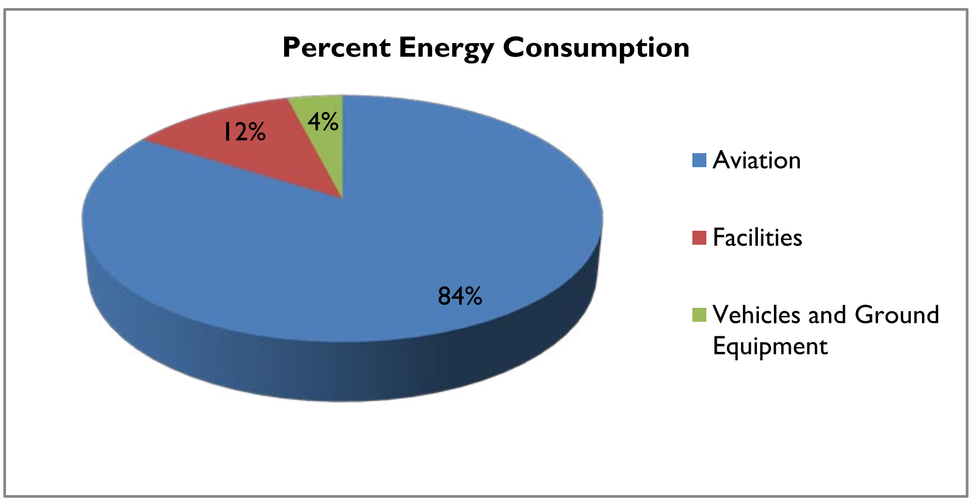


Figure 39. Air Force energy utilization by end use (percent of total energy costs).[21]

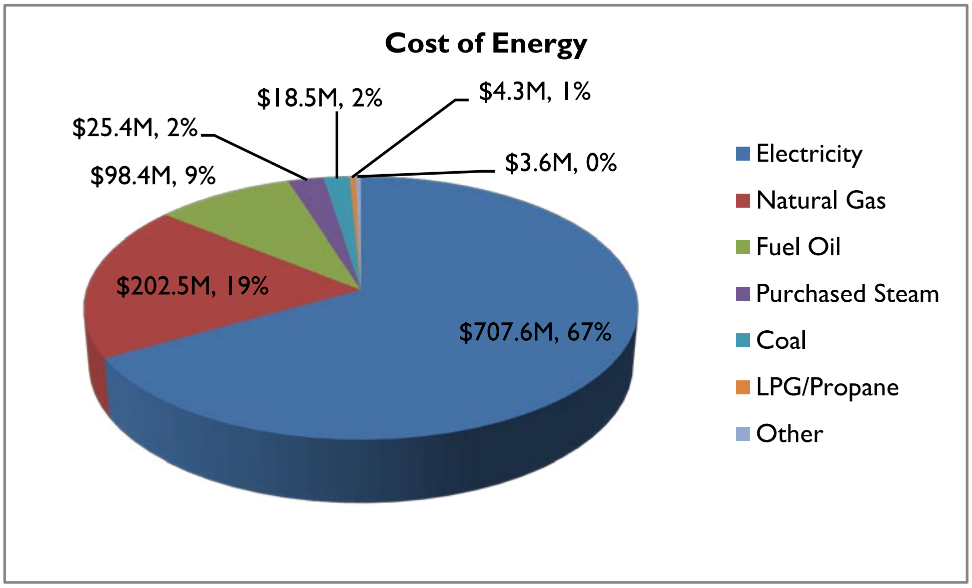


Figure 40. Air Force facility energy cost by source.[117]

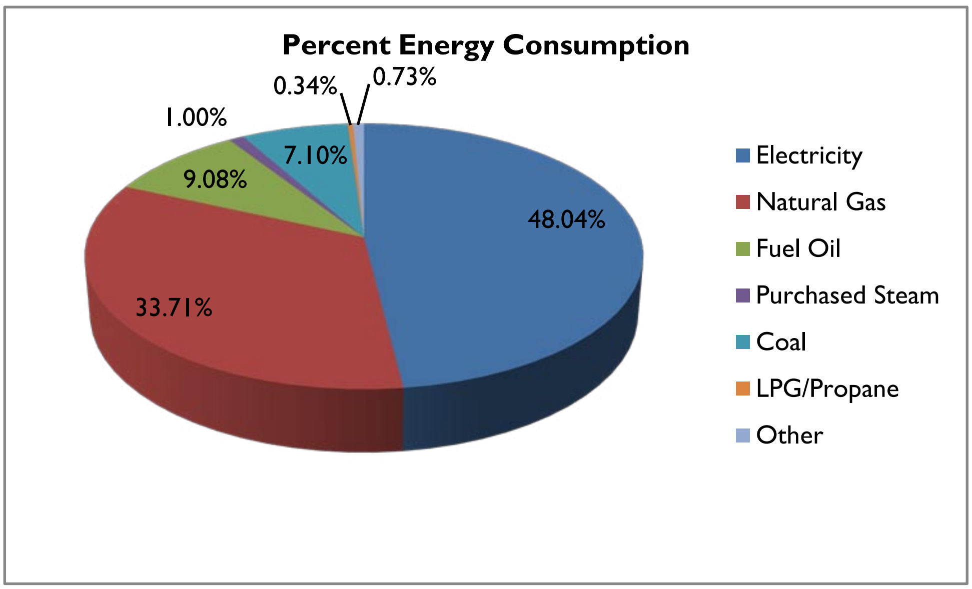


Figure 41. Air Force facility energy consumption by source.[117]

The Air Force has estimated that it will require approximately one GW of electricity to be generated from renewable energy sources by 2025 to meet its goals. The Air Force further estimated that it would require approximately 60 to 70 commercial-scale renewable energy projects to meet this electricity generation requirement.[118]

7.2.5 Army Facility Energy Consumption

The US Army spends more than $800 million per year for facility energy, the majority of which is for electricity.[119] Army facilities consume more than 80 trillion BTUs per year, which is more than 20 percent of the energy consumed by the federal government.[119] The Army accounts for 39% of the facility energy that is consumed by the DoD.[111] The Army's energy consumption for facilities by source is presented in Figure 42. As of 2007, the US Army had seven coal-fired power plants. These produced more than 7.6 million BTUs of energy.[43]

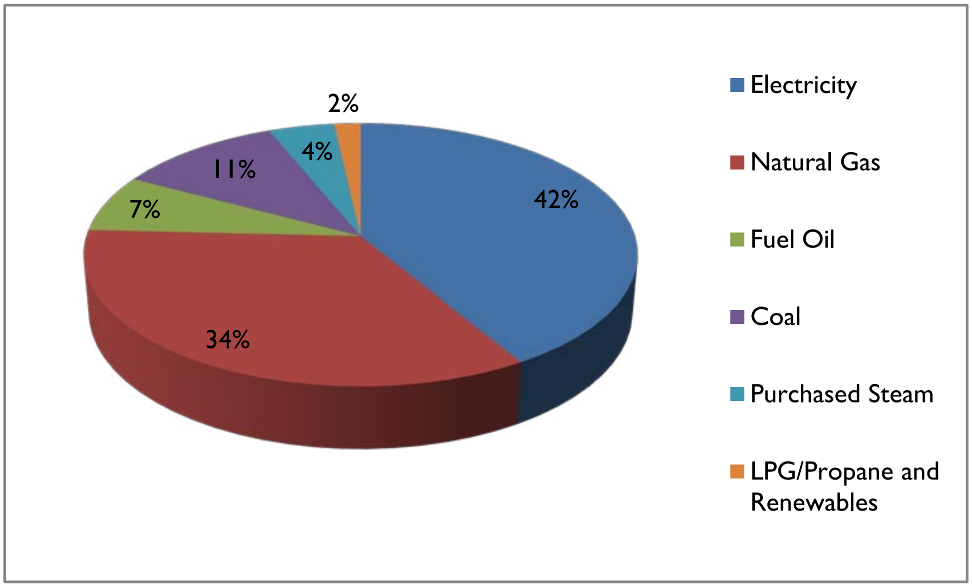


Figure 42. Army facility energy consumption by source.[111]

7.2.6 Navy Facility Energy Consumption

Congruent with the other services the bulk of the Navy's facility energy usage is from electricity followed by natural gas and coal. The facility energy usage by source is shown in Figure 43.

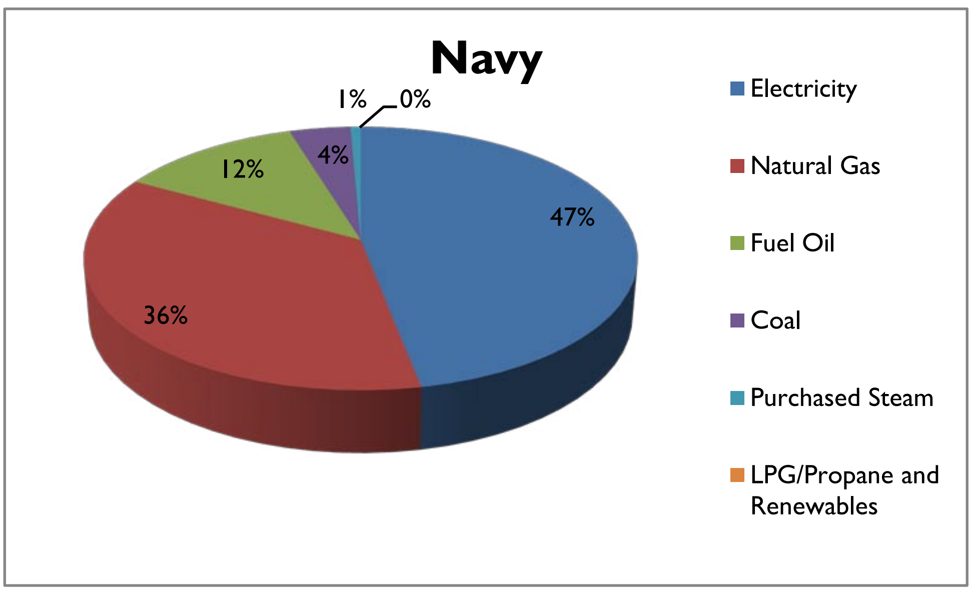


Figure 43. Navy facility consumption by source.[111]

7.3 Power Generation and Consumption Patterns

Without energy storage, power generation must meet power consumption at any given time. To aid in predicting power consumption, patterns in consumption are developed for time of day, day of week, and season, as well as for weather forecasts. The following sections describe some of the basic elements of power generation and consumption.

7.3.1 Centralized Generation

Most electrical power is delivered from centralized plants, which deliver energy via a transmission and distribution or grid system. These central plants are typically large scale and generate and distribute power to meet the demand.

One of the primary advantages of centralized power generation is the economy of scale. Once the infrastructure is in place, central power plants can generate a large amount of power and deliver it to many end users on demand. There are, however, several drawbacks including transmission losses, reliability, and security. Centralized power generation and distribution is provided by utility companies, which can be publically owned, investor owned, cooperatively owned, or nationalized. From a broad perspective electrical grids are split into several different regions as shown in Figure 44. The transmission system is shown in Figure 45.

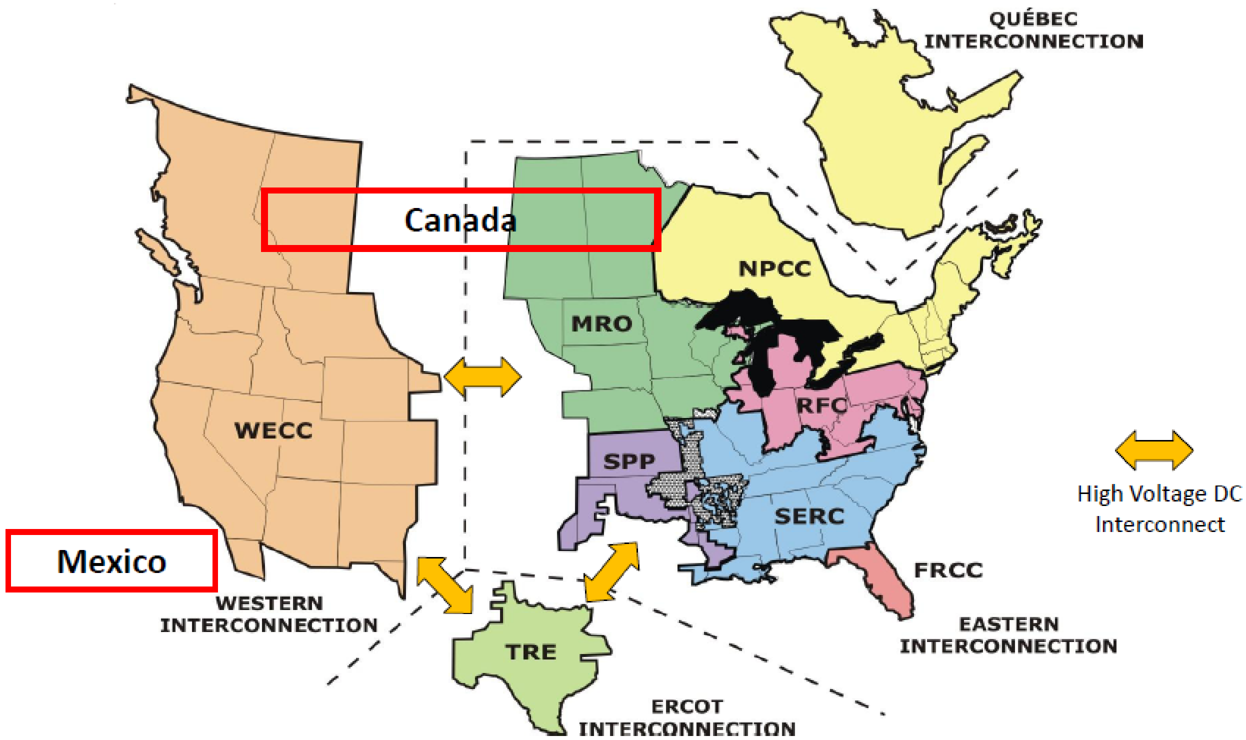


Figure 44. US electrical grid regions and interconnects.[120]

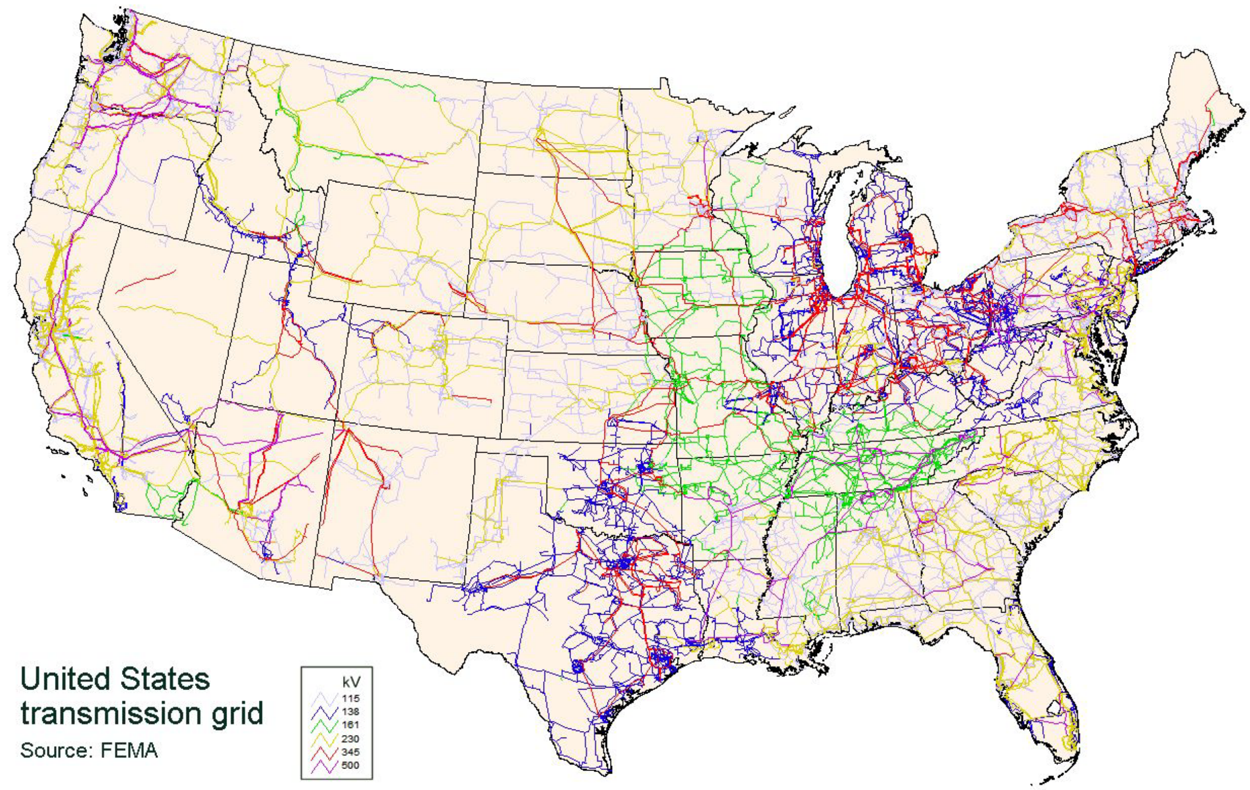


Figure 45. US power transmission grid.[121]

7.3.2 Distributed Generation

Distributed or decentralized generation (DG) is production of energy that occurs on-site near the point of use, as opposed to energy that has to be transmitted from the point of generation to a substation. This can be generation that occurs at the facility or, even more specifically, at the site of use. For example, a rooftop photovoltaic array can be used to supply auxiliary power to the heating and cooling systems within the building. Alternatively, a large PV array can be used to power multiple buildings at the same facility. Both of these are examples of distributed generation.

Distributed generation is typically an efficient and reliable methodology for supplying power demand. Power generation systems that are installed for DG can be small scale and thus relatively low cost. DG systems can be used as the sole power source or as a supplemental source of power. The power quality and outages can be more readily controlled through DG. Distribution losses are also reduced due to the shorter transmission distances that are required. Moreover, DG systems are modular and can be added or taken off line as needed. They can be used to improve redundancy and thus another level of power security.

There are various types of generation systems that can be used for decentralized power and some use traditional nonrenewable energy resources, while others use renewable energy resources. These systems include:[105]

- Internal combustion engines
- Gas turbines
- Steam turbines

- Combined-cycle turbines
- Microturbines
- Stirling engines
- Fuel cells
- Solar power systems
- Wind power
- Geothermal power
- Biomass systems

7.3.2.1 Standby Charges

One of the disadvantages to a distributed generation system that is not owned by the user is the standby charge, which is a fee from the DG provider. The DG provider may charge a fee when the system is not generating power. This has the adverse effect of reducing any cost savings associated with the system.[122]

7.3.2.2 Peak Shaving

Utilities rates are variable. They may change based on season, and in some cases, time of day. For instance, during peak usage periods the utility may charge at an increased rate. Peak shaving is the practice of operating distributed generation during peak consumption periods to minimize the purchase of energy from the utility during the highest rate periods. Figure 46 illustrates the concept of peak shaving in which distributed power generation units are operated by a facility during a utility's peak power demand period to avoid paying higher rates.

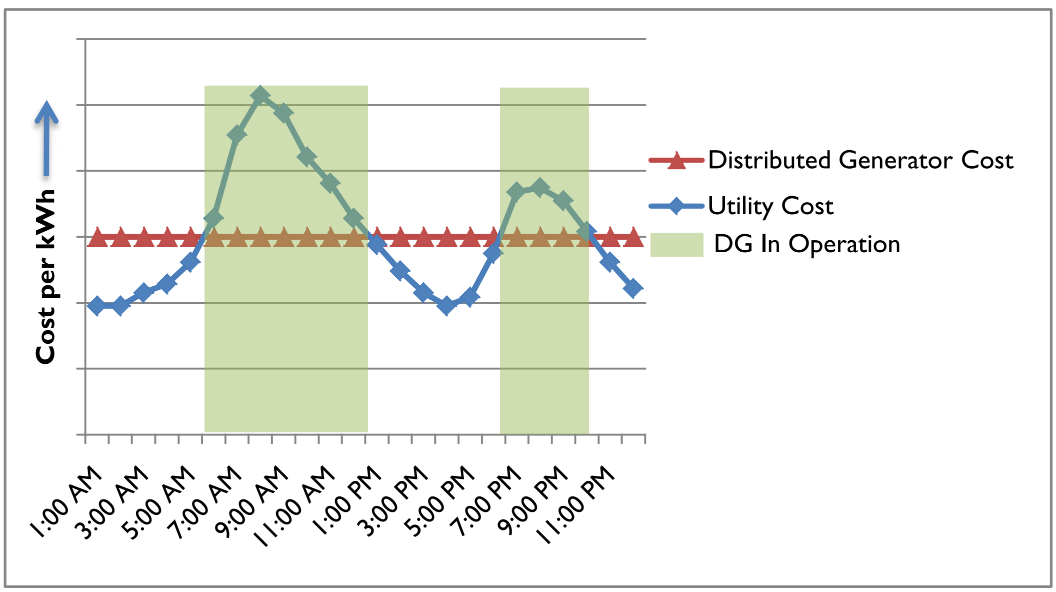


Figure 46. Operation of distributed generation units to avoid high rates during peak power periods.

7.3.3 Plant Parameters

Some of the important parameters that are used to describe a power generation plant include power, energy, power capacity, capacity factor (CF), load factor, heat rate, thermal efficiency, and economic efficiency. These are described briefly in the following sections.

7.3.3.1 Power and Energy

Power, which is measured in watts, is the instantaneous rate of energy conversion. It can also be considered in units of energy per time, such as BTU per second. While power is the instantaneous output, energy is the cumulative output. For instance, a plant that produces 10 MW of power for one hour would have produced 10 MWh of energy.

7.3.3.2 Power Capacity

A plant's capacity is a description of the maximum power output at any given time. For instance a 30 MW plant is rated to generate 30 MW of power at 100% capacity at a given time. For any particular grid, the power generating units supplying the demand on the grid must have a cumulative capacity that meets or exceeds the peak demand.

7.3.3.3 Capacity Factor

The capacity factor is essentially the fraction of time that a power generation plant operates at its maximum capacity. Otherwise stated, it is the ratio of energy produced for a given period to the energy that could have been produced if the unit operated continuously at full-power during the same period.[123] This is sometimes referred to as the operational efficiency. For instance, a capacity factor of 0.90 indicates that a plant would operate at maximum capacity for 90 percent of the hours in a year. The CF can be calculated using Equation 4.

$$CF = \frac{E}{C\,p} \qquad \text{Equation 4}$$

Where

E – energy produced during period, Wh

C – capacity of plant, W

p – period, h

For example, the Fort Carson 2 MW solar photovoltaic array generates approximately 3.2 GWh over the course of a year. This means it has a capacity factor of approximately 0.18.

7.3.3.4 Load Factor

The load factor is similar to the capacity factor in that it compares energy produced to the maximum capacity of the plant over a period of time. Some use these interchangeably, but load factor can be calculated as an average power produced (i.e., average load) during a period divided by the plant capacity. It can also be calculated as the average load divided by the peak load during a period.[124] The latter definition differentiates the load factor from the CF and gives an indication of how close to peak output the power generation unit operates on average, as shown in Equation 5.

$$LF = \frac{P_{avg}}{P_{peak}} \qquad \text{Equation 5}$$

Where

LF – Load factor

P_{avg} – Average power output over period of time

P_{peak} – Peak power output during period of time

For example, if over the course of a day a plant produces an average power output of 1.2 MW but it reaches its peak output of 2 MW, the load factor is 0.60.

7.3.3.5 Heat Rate

Heat rate is a quantity often used to describe the thermal efficiency of a power generation unit or plant. It is essentially is a ratio of the energy content of the fuel to the net energy produced. The heat rate is typically presented as BTUs per net KWh, which is dimensionless but has more meaning when the units are retained. The heat rate can be calculated according to the formula shown in Equation 6. Examples of some heat rates are given in Table 28.

$$HR = \frac{E_f}{E} \quad \text{Equation 6}$$

Where

HR – heat rate, BTU/kWh

E_f – energy content of the fuel, BTU

Table 28. Typical heat rates for several energy sources.[125]

Energy Source	Heat Rate (BTU/kWh)[xlix]
Petroleum	10,730
Nuclear	10,400
Coal	10,350
Natural Gas	8,900

7.3.3.6 Thermal Efficiency

The thermal efficiency of a power generating unit can be described as the net energy produced (i.e., converted to usable energy) divided by the heat absorbed by the working fluid as shown in Equation 7. Alternatively, this is the inverse of the HR using a conversion factor to convert the energy to the same units. Depending on the type of power plant that is used, variations of the HR and thermal efficiency equations may be used.

$$\eta_{th} = \frac{E}{E_f}(3.412) \quad \text{Equation 7}$$

Where

η_{th} – thermal efficiency

1 Wh = 3.412 BTUs

7.3.3.7 Economic Efficiency

The economic efficiency quantifies the production costs per energy production. For instance, it can be calculated by the sum of production costs, which includes fuel, labor, materials, services, and divide this total by the cumulative energy produced during the period over which the costs were summed, as shown in Equation 8.[126]

[xlix] Heat rate is the average value from 2001 – 2008.

$$\eta_{ee} = \frac{c_p}{E}$$ **Equation 8**

Where

η_{ee} – economic efficiency

c_p – production costs, $

7.3.4 Plant Costs

The costs associated with power generation units can be categorized as fixed or variable. The total cost can be calculated and quantified in terms of energy output. These are described briefly in the following sections.

7.3.4.1 Fixed

Fixed costs are those that are independent of the daily production output of energy. Capital cost, or the cost of construction, is a fixed cost and is typically presented in terms of dollars per unit capacity. For instance, the capital cost is often $/MW for large power generating units or $/kW for smaller units. Some examples of capital costs are presented in Table 29. Operations and maintenance costs are also considered fixed costs since they do not vary with energy generation.

Table 29. Examples of capital costs for power generation and storage units.[127]

Power Generation or Storage Unit	Capital Cost per Capacity ($/kW)
Internal Combustion Engine	580 – 910
Combustion Turbine	700 – 1,075
Pumped Hydro Storage	2,000 – 3,500
Battery Storage	2,500 – 3,000
Wind (land)	1,600 – 2,200
Thin Film Photovoltaic Solar	3,000 – 3,500

7.3.4.2 Variable

Variable costs are those that are directly related to the energy production. For instance, for many power generation units, fuel is required to produce energy. Fuel is a variable cost since the amount of energy produced is dependent on the amount of fuel consumed. Pollution costs are also variable costs since the quantity of pollutants emitted is generally dependent on the amount of energy produced.

7.3.4.3 Total

Once a power generating unit has been constructed, commissioned, and in normal operation, a total cost of electricity can be determined. This total cost may be calculated by summing all costs over the expected service life of the plant and dividing it by the cumulative energy expected to be generated during the service life.

7.3.5 Classification of Load Types

Power generation plants are often categorized according to capacity factor. To operate efficiently, effectively, and reliably grids must have a power plant to serve a base load, a plant to serve an intermediate load, and a plant to serve a peak load. A summary of load types is presented in Table 30 and some typical capacity factors for various power plant types are presented in Table 31. When considering the construction of a plant to supply a particular grid, it is important to know what portion of the load that the new plant will supply.

Table 30. Summary of load type classes.[127, 128]

Type of Power Generation	Typical Annual Capacity Factor[l]	Types of Plants
Base Load	0.75 – 1.00	• Fossil fuel • Nuclear • Geothermal • Biomass • Hydropower
Intermediate Load	0.40 – 0.60	• Fossil fuel • Hydropower • Offshore wind • Concentrated solar • Wave
Peak Load	0.05 – 0.15	• Fossil fuel • Wind • Concentrated solar • Photovoltaic solar • Tidal

Table 31. Typical capacity factors for various plant types.[127, 129, 130, 131]

Plant Type	Typical Annual Capacity Factor
Nuclear	0.72 – 0.92
Biomass	0.80 – 0.85
Coal	0.67 – 0.73
Wind (offshore)	0.34 – 0.47
Hydropower	0.31 – 0.51
Wave Energy	0.30 – 0.45
Natural Gas (combined cycle)	0.34 – 0.42
Concentrated Solar Power	0.25 – 0.40
Natural Gas (other)	0.11 – 0.38
Wind (land)	0.20 – 0.30
Tidal Power (current technology)	0.25
Photovoltaic Solar Power	0.20 – 0.25
Petroleum	0.09 – 0.24

[l] A power plant that has a capacity factor that falls in between classes may be considered in the class above or below.

7.3.5.1 Base Load Power

Base load power is the most consistent form of power generation and most important since it supplies the bulk of the power demand. This type of power supplies the base demand, which is the minimum or continuous demand. The capacity factor for base load power plants is greater than 75 percent and typically is between 90 to 98 percent.[127] Power generation plants that can provide base load power include coal, natural gas, fuel oil, nuclear, geothermal, biomass, and some hydropower.[127] Hydropower may not be considered base load in cases where there may be droughts and therefore a low supply of energy to convert to usable power. Base load plants generally have a capacity greater than 400 MW.

Base load power plants typically provide reliable power at low cost per kWh. These power supply units are operated to maximize the mechanical and thermal efficiencies of a system, while minimizing system operating costs. However, plant start up is relatively long and thus cannot be started up and shut down easily. Hence, the high load factor. These types of plants are best suited for long-term power purchase agreements (PPAs, see *Section 15.1*). Base load power typically is 35 to 40 percent of the maximum load on a grid.[128]

7.3.5.2 Intermediate Load Power

Intermediate load power fills the gap between base load and peak load. Power plants that supply intermediate loads are typically smaller and able to respond to changes in demand faster than base load plants. These plants typically operate 30 to 60 percent of the time.[128] The capital cost for constructing intermediate load power plants is typically less than base load but more than peak load.

7.3.5.3 Peak Load Power

Peak load power supplies energy during the highest demand periods. Power plants that supply peak loads are highly responsive to changes in demand and can be started and shut down relatively quickly. The power output of a peak load plant can essentially be varied on demand. These plants are relatively small especially compared to base load plants and typically operate 10 to 15 percent of the time.[128] The cost of electricity per kWh is higher than base load power, however, the capital cost is typically less than that for base load power plants.

7.4 Energy Usage and Consumption Patterns

On the other side of energy generation is usage or consumption; whereas the generation is the supply, the consumption is the demand. Users of energy basically require the energy to be delivered in three forms: electricity, combustible fuel, and steam. Electricity can be used to directly power devices or to generate thermal energy. Similarly, fuel can be combusted to generate thermal energy, and if desired, the thermal energy can be subsequently converted to electricity. Likewise, steam inherently delivers thermal energy, which, if desired, can be converted to electricity.

7.4.1 Energy Usage

While this handbook is not focused on the end use of power, from an energy production perspective it is still important to consider the end use for which the energy is being generated. Knowing this can help predict the demand or the load on various systems.

Electricity is the bulk of the energy consumed in facilities. It is mainly used for lighting; heating, cooling, and ventilation (HVAC) systems; machinery and other directly powered systems; and plug power. Plug power is the power supplied to outlets. Plug power is typically used to power small devices, but collectively the load is significant. Examples of non-residential and residential energy use are presented in Figure 47 and Figure 48, respectively.

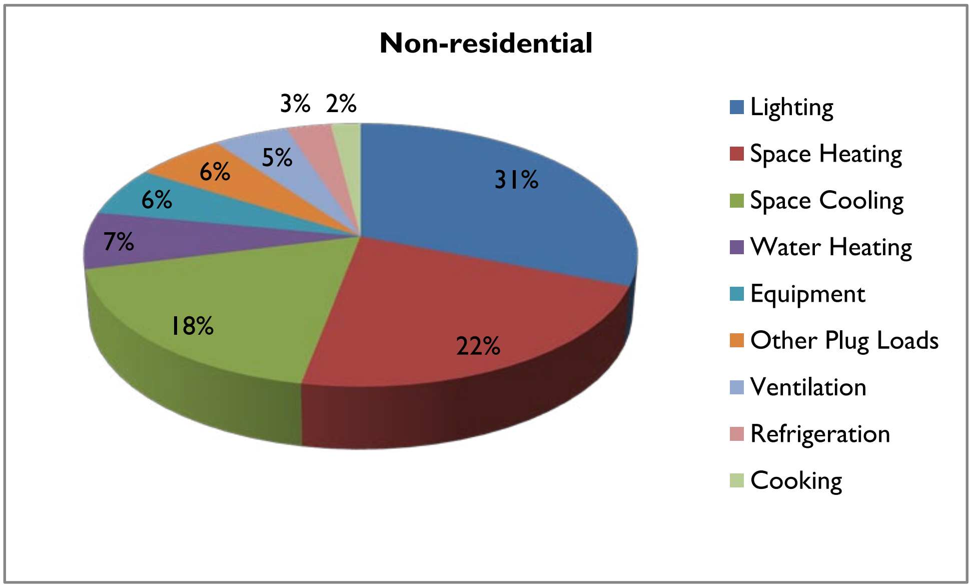


Figure 47. Non-residential energy use.[132]

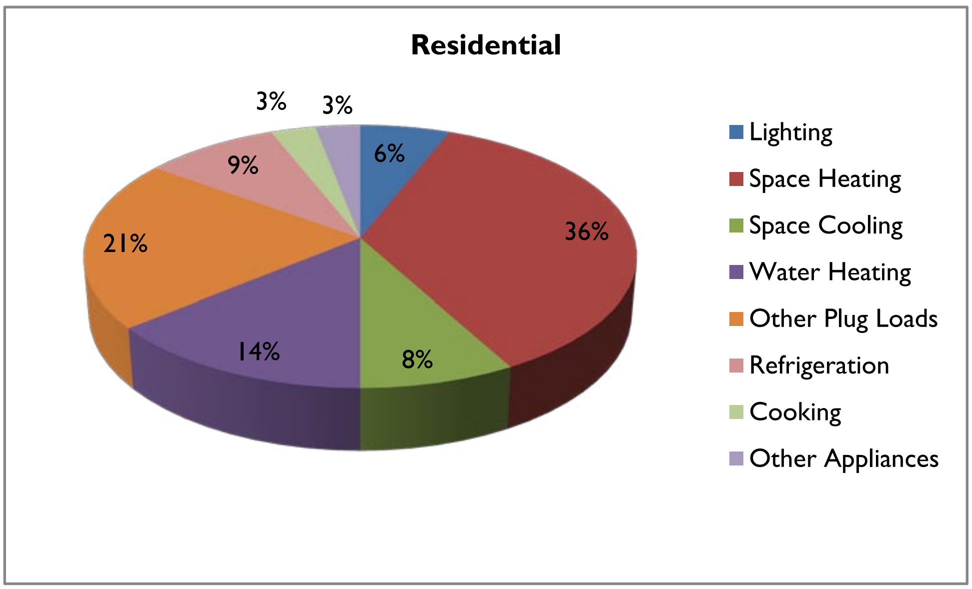


Figure 48. Residential energy use.[132]

7.4.2 Consumption Patterns

Although it is not possible to precisely predict power consumption, there are general patterns in the demand. In general, power demand is relatively low during early morning and late evening. This minimum load is the base load. Seasonal demand is dependent on geographical region and weather. An example of power demand during a summer season is presented in Figure 49. For comparison, the demand during a winter season is shown in Figure 50.

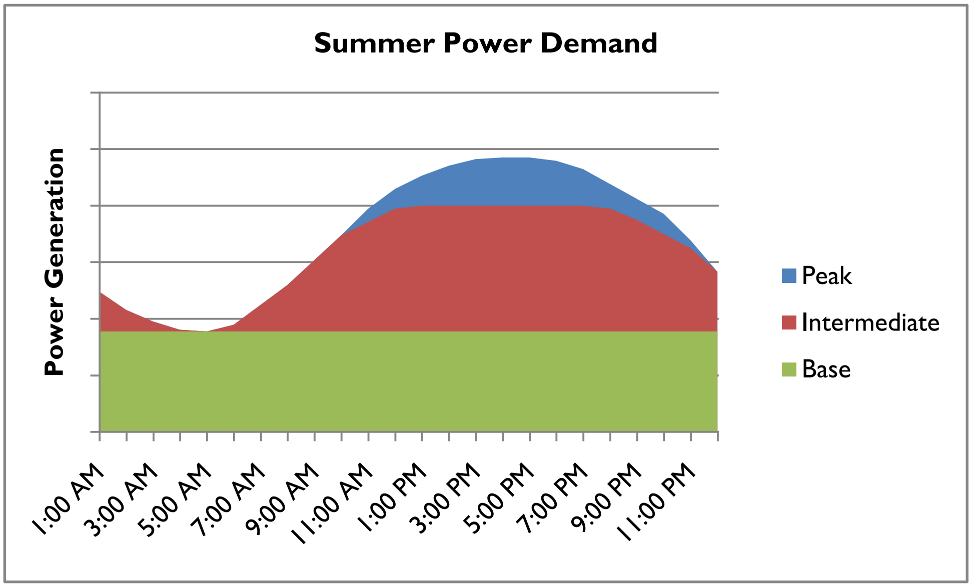


Figure 49. Summer power demand and corresponding generation type.

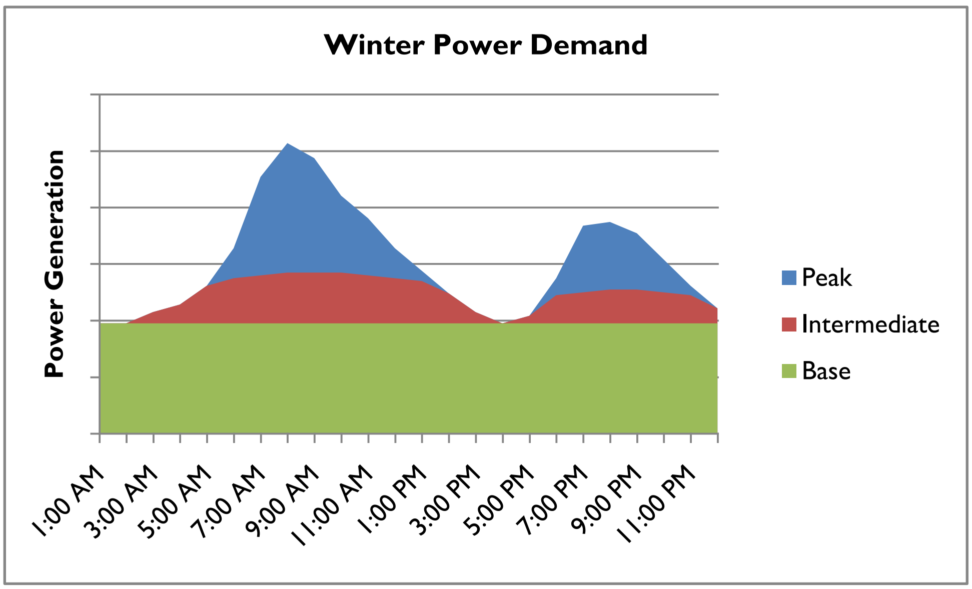


Figure 50. Winter power demand and corresponding generation type.

It is clear from these charts that the power demand varies significantly during the period of a day as well as during the period of a year. The daily power load during the summer season is typically characterized by a single peak, whereas the winter season has two distinct daily peaks. The total energy consumed can be calculated from the area under the curve.

7.4.3 Off-Peak

At its minimum, the power load is supplied by base load power generation units only. This is considered an off-peak period. During the transition from off-peak to peak, the base load units continue supplying power, while the intermediate load units are initiated. Both base load and intermediate load units are then providing power to supply the demand.

7.4.4 Peak

When peak periods arrive, peak load power generation units are quickly started to provide auxiliary power. During peak periods, power is supplied by base load, intermediate load, and peak load power generation units. As time progresses and the load returns to off-peak, the peak load units are shut down and more gradually the intermediate load units are shut down.

PART III:

RENEWABLE AND ALTERNATIVE ENERGY OPTIONS

8 SOLAR ENERGY

Solar energy is an abundant, widely available, and relatively clean resource making it attractive for numerous applications. It can be converted to electric power or thermal energy for industrial, commercial, and residential use. Solar energy has been proven to be life cycle cost effective in some applications, dependent upon the location, cloud cover, and cost of conventional fossil fuels. However, due to the variability in solar energy, along with energy security, solar energy is typically used in conjunction with additional energy resources for meeting facility energy requirements. There are current incentives to use solar energy that are driving new projects and rapidly evolving solar technologies. This section introduces various solar technologies used for facilities, the economic factors that drive cost effectiveness of solar power and energy, as well as a couple of case studies.

8.1 Introduction

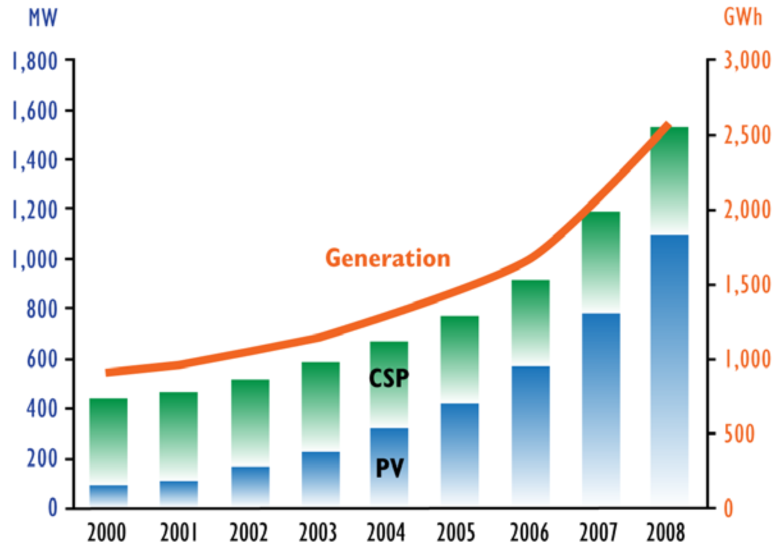
There are a number of different technologies that have been developed for capturing solar energy and converting for use as electricity, heating or cooling. Passive solar refers to harnessing solar energy, without any built-in controls, including natural lighting and radiant heating. Active solar incorporates technologies to harness and control solar energy, which include generating electricity, heating and cooling systems. There are two primary technologies that have been developed for harnessing solar energy, namely solar cells or photovoltaics (PV) and solar thermal, which uses solar energy to heat fluids or gases. Solar thermal applications are used for heat, hot water, cooling systems, and may also be used to produce electrical power using conventional steam generators.

8.1.1 History and Market Trends

The use of solar energy has been around for many centuries, although it is just starting to become widespread with incentives to decrease the use of fossil fuels. Some of the major achievements in solar power and energy are as follows:[133]

- Solar energy was used as far back as the seventh century B.C. when magnifying glasses were used to produce fire.
- Roman bath houses, in the period of the first through fourth centuries A.D., used large southern facing windows to capture the sun's heat.
- The first solar collector was built in 1767 by Horace de Saussure and was used for cooking during an expedition to South Africa in the 1830s.
- The first commercial solar water heater was patented in 1891.
- The first silicon (Si) solar cell capable of providing enough electricity to run everyday electrical equipment was developed in 1954 at Bell Labs.
- In 1958, the Vanguard I space satellite used a small PV array to power its radios.
- In 1977, the US DOE established the Solar Energy Research Institute, now the National Renewable Energy Laboratory.

A major development in photovoltaics occurred with their use in satellites. Later, they were implemented in facilities located in remote regions where no power grids existed. Starting in the 1980s, large scale solar projects were constructed in the US using concentrating solar power (CSP), which is a solar thermal technology used to produce electricity on the industrial and utility scale. Since then, solar electricity generation has more than tripled since the year 2000, as shown in Figure 51. The increasing trend in solar power usage is expected to continue at least for the near future, as shown in Figure 52.



	US Solar Energy Generation (Million kWh)	US Solar Energy Capacity (MW) and % Increase from Previous Year			
		PV	CSP	Total	Increase
2000	909	85	354	439	4.3%
2001	952	112	354	466	6.2%
2002	1,021	158	354	510	9.4%
2003	1,132	226	354	580	13.7%
2004	1,267	312	354	666	14.8%
2005	1,444	424	354	778	16.8%
2006	1,670	566	355	921	18.4%
2007	2,133	771	419	1,190	29.2%
2008	2,662	1,106	419	1,525	28.2%

Figure 51. Increasing trend in solar power capacity and energy production.[134]

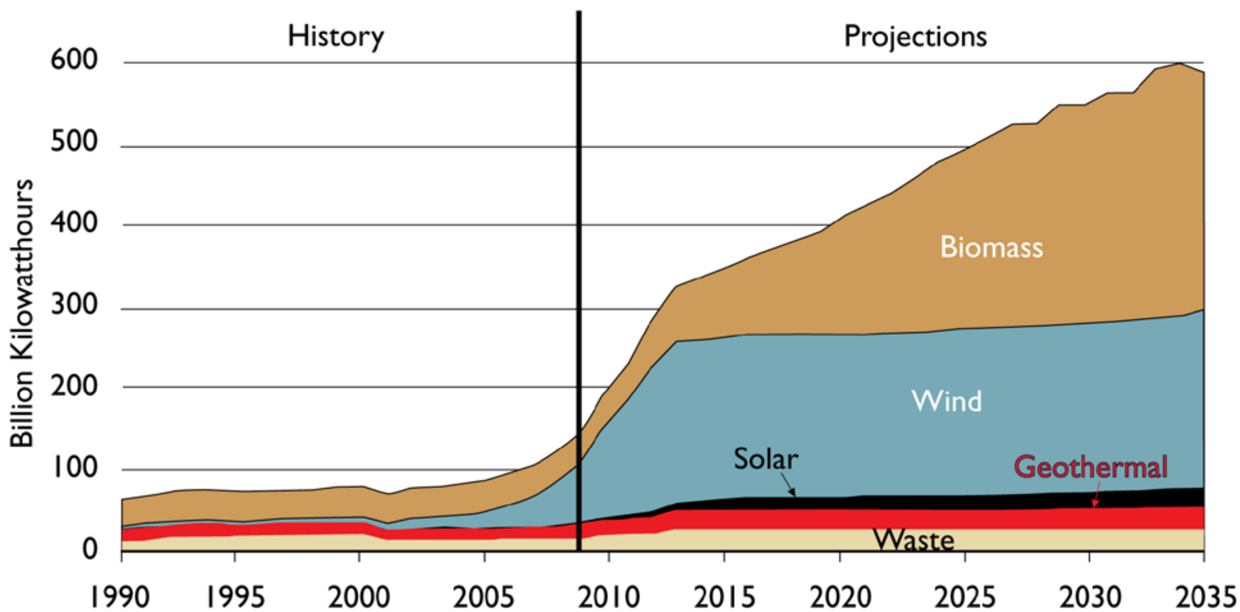


Figure 52. Renewable energy production projections up to 2035.[135]

Solar power and energy technologies are experiencing a decreasing trend in costs, as shown in Figure 53. This is attributed to decreasing silicon costs, as well as the research and development of lower cost designs, materials, and manufacturing methods. The increasing market demand is also anticipated to lower solar energy costs.

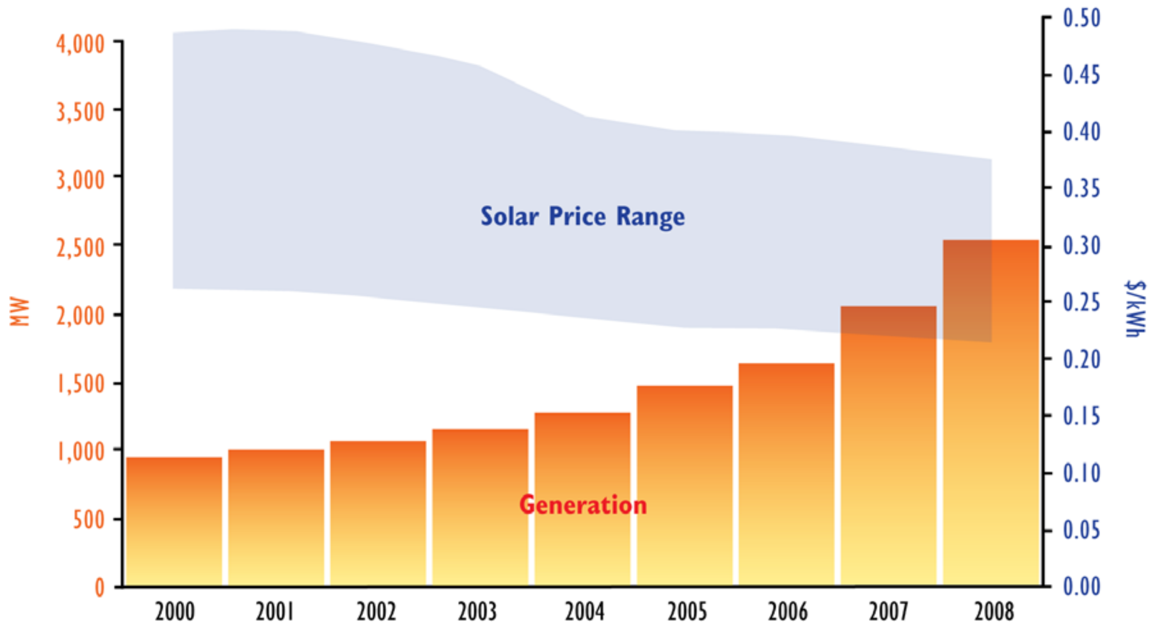


Figure 53. Solar costs versus generation.[134]

8.1.2 Challenges

There are two major hurdles that arise in harnessing solar energy. They are the variability of solar energy and the high cost of solar power technologies. The variability of solar energy generally makes it more economical for use in regions receiving more solar radiation, for instance, regions closer to the equator and areas that experience more sunshine per year (e.g., desert climates). The cost of conventional fossil fuels also factors into the economics of solar energy. Moreover, the variability of solar energy makes it unsuitable for providing continuous, reliable power to an electrical grid. Table 32 lists advantages versus disadvantages of solar power, including technical and nontechnical aspects.

Table 32. Advantages and disadvantages of solar power.[136]

Advantages	Disadvantages
• Vast resource available to virtually all of the Earth, and essentially infinite energy • No emission or combustion gases altering the atmosphere. • Low operating costs • Ease of installation • Can be implemented in new or existing facilities • The solar panels or mirrors themselves operate at ambient temperatures and have essentially no mechanical degradation • Excellent safety record • Good reliability	• low density energy source • high installation costs • poor reliability of auxiliary equipment • variability of energy – nighttime and cloudy conditions • high cost of energy storage • Standardization of policies and regulations • Installer training • Inspector training • Consumer knowledge

8.1.3 Effect of Incentives

Incentives have played a major role in transitioning solar power into the market place. Countries with the most aggressive solar incentives are leading the development and implementation of solar technologies. Figure 54 shows the world solar power production capabilities as of 2007. Similarly, within the US, states with aggressive solar incentives are leading the way, as illustrated in Figure 55.

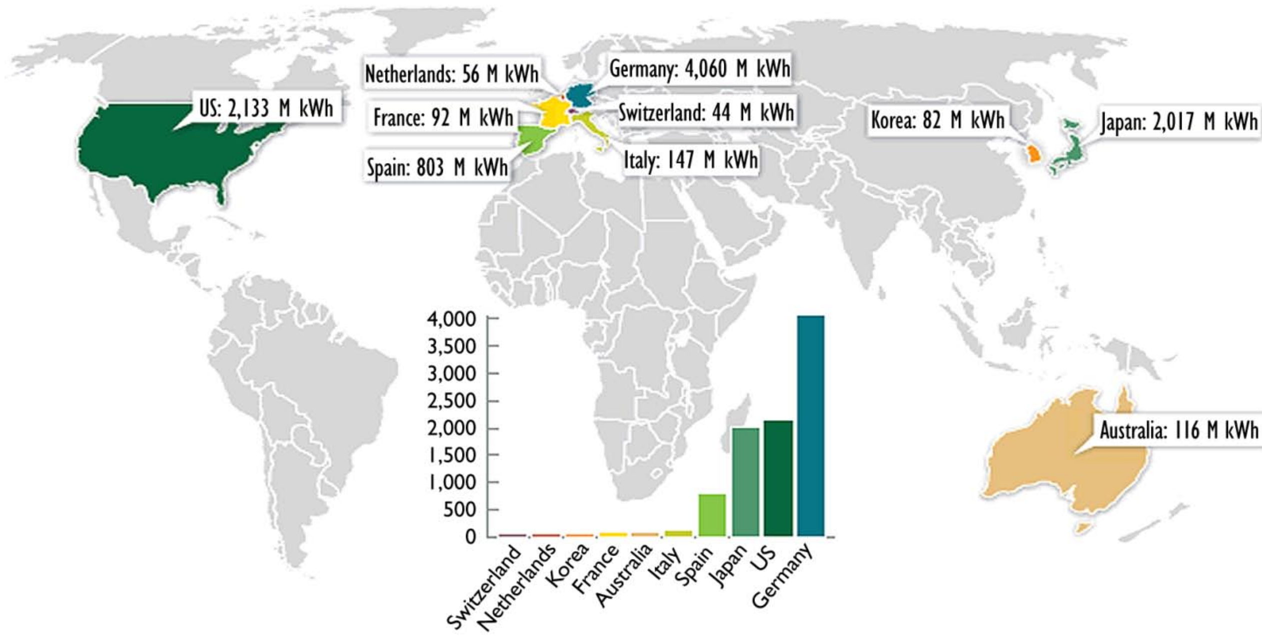
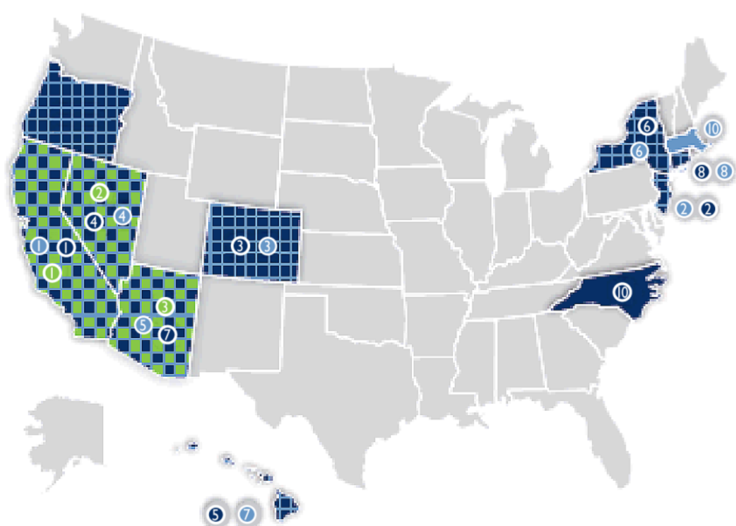


Figure 54. World solar power capability in 2007.[134]



PV Cumulative Capacity (2008, MW)	
1 California	528.5
2 New Jersey	70.2
3 Colorado	35.7
4 Nevada	34.2
5 Arizona	25.3
6 New York	21.9
7 Hawaii	13.5
8 Connecticut	8.8
9 Oregon	7.7
10 Massachusetts	7.5

PV Annual Capacity Additions (2008, MW)	
1 California	178.7
2 New Jersey	22.5
3 Colorado	21.7
4 Nevada	14.9
5 Hawaii	8.6
6 New York	7.0
7 Arizona	6.4
8 Connecticut	5.3
9 Oregon	4.8
10 North Carolina	4.0

CSP Cumulative Capacity (2008, MW)	
1 California	354.0
2 Nevada	64.0
3 Arizonia	1.0

Figure 55. US solar power capacity in 2008.[134]

8.2 Solar Energy Conversion Technologies

Solar collectors may be in the form of either flat-plates or concentrators. Flat-plate technologies provide lower cost, but less efficient energy conversion, and are used for lower temperature applications. Concentrators are high cost, more efficient, and applicable to high temperature applications. Flat-plate and concentrators may be used for PV or solar thermal applications. The primary technologies developed for use in facilities include photovoltaic solar panels, concentrating solar thermal, solar heating, solar cooling, and day lighting. A brief description of each technology is provided, followed by typical designs and economic aspects.

8.2.1 Photovoltaics

Photovoltaics is the technology of converting sunlight into electricity using semiconductor materials. There are a few different semiconductor materials that may be used, and they can be constructed into flat plate collectors or concentrating collectors. Solar cells refer to the individual semiconductor units, which are combined to construct solar panels. Solar panels may be further combined into a solar array. And solar arrays can be connected in series to provide the electrical power generation required for a particular application.

Solar cells convert solar energy into direct current (DC) electrical power, which is converted to alternating current (AC) using inverters for distribution and end use. Due to the variability of solar energy, battery storage systems may be used to optimize the applicability of PV systems. Peak watt (W_p) is the total power output under industry standardized conditions and is used to rate PV modules. This represents the power a module will produce under standard reporting conditions (SRC) when illuminated by 1 kW/m^2 solar power. However, SRC does not typically occur under real operating conditions. Thus, \$/kWh is an important measure of PV output as opposed to the \$/W_p that is often used. Photovoltaic cells are also rated by their efficiency or their ability to convert sunlight into electricity. The PV system efficiency, or net efficiency, is always lower than cell efficiency due to additional power losses in auxiliary equipment and distribution.

Semiconductor materials for use in solar cells include crystalline and amorphous silicon (a-Si), copper indium gallium diselenide ($Cu(InGa)Se_2$), cadmium telluride (CdTe), and III-V compounds, such as gallium arsenide (GaAs) and gallium indium phosphide (GaInP). Crystalline silicon (c-Si) is the most common material used to produce solar cells. Amorphous silicon, cadmium telluride, and copper indium gallium diselenide have been developed for thin-film solar cells, with the intent of lowering costs. The increased market share of thin film technologies through 2007 is shown in Figure 56, with amorphous silicon accounting for the majority of that growth.

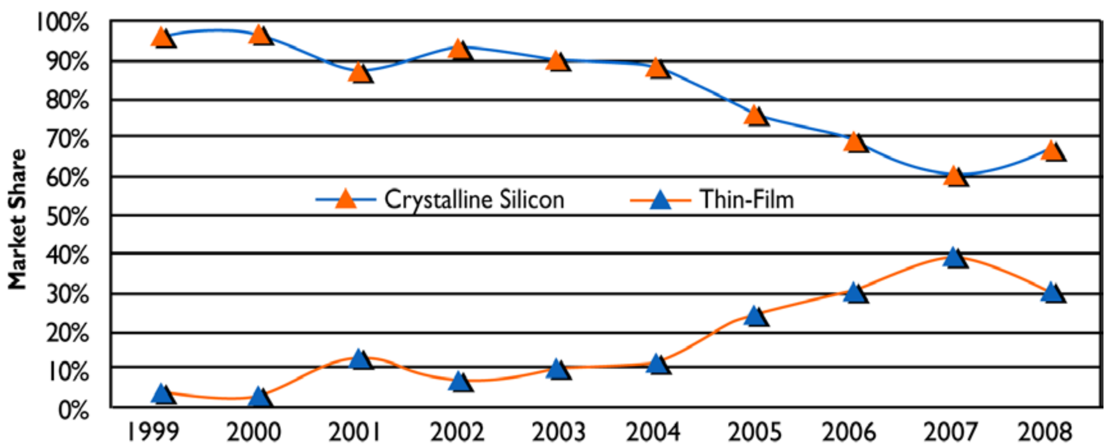


Figure 56. Thin-film versus crystalline silicon market trend.[137]

The III-V compounds are used due to their high cell efficiencies in multijunction cells, and to broaden the spectrum of solar energy conversion. Figure 57 represents the increase in solar cell efficiencies for the various materials through approximately 2003. Additional PV materials and designs, such as organics and nanostructured materials including dye-sensitized solar cells, are currently under research and development.

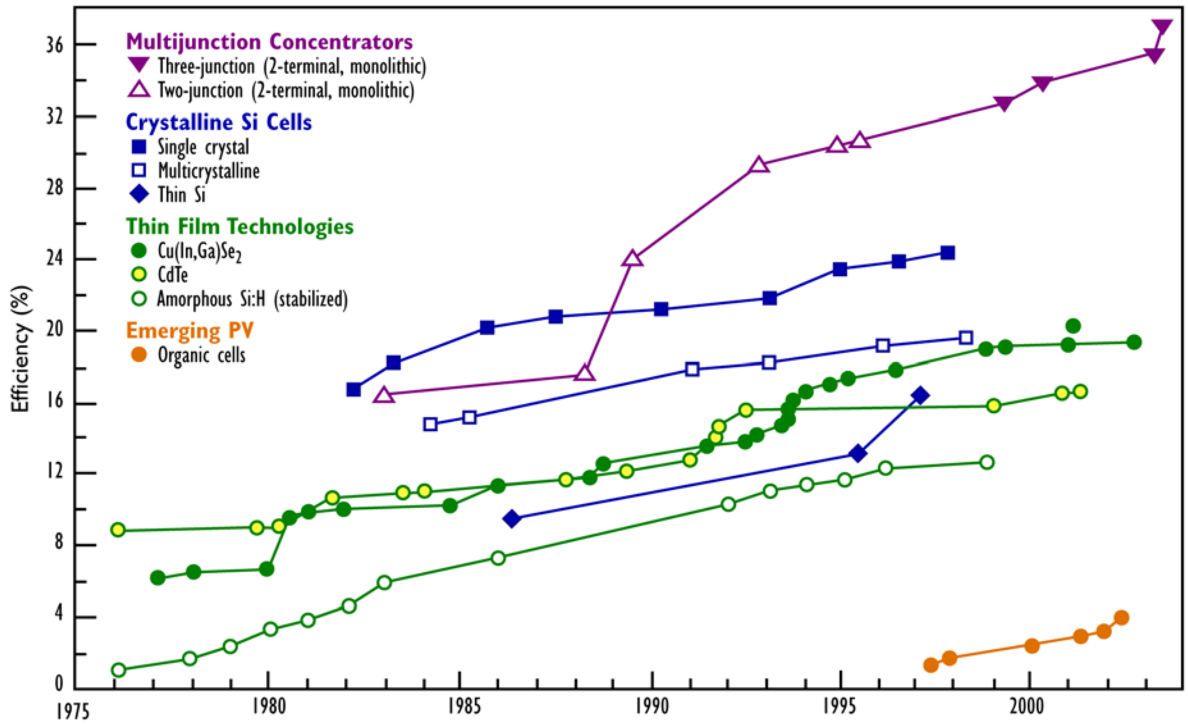


Figure 57. Trend in solar cell efficiencies.[138]

8.2.1.1 Crystalline Silicon

Crystalline silicon, including both single crystal and polycrystalline Si, account for a high majority of the solar cells in use. This can be attributed to the vast knowledge of silicon processing and material property data carried over from the electronics industry, and silicon's band gap of 1.1 electron-volts (eV), which makes it a good solar energy converter. Its downfall is that it is a brittle material requiring thicker films, on the order of 300 μm. Crystalline silicon also has an indirect band gap, as opposed to direct band gap solar cell materials. These factors lead to higher energy losses and thus higher quality (low impurity content) silicon is required in order to minimize energy losses. Research and development efforts have been conducted on alternate materials that provide better efficiencies, with the intent of developing lower cost systems.

8.2.1.2 Thin Films

Semiconductors that include gallium arsenide, cadmium telluride, copper indium gallium diselenide, and amorphous silicon can be produced into films, approximately 100 times thinner than c-Si. Their costs have been high, but are expected to drop dramatically if commercial-scale manufacturing resources are developed to offset the high material costs. Another hindrance is that their efficiencies have not surpassed c-Si technology, as shown in Figure 57. Only multijunction solar cells have higher efficiencies than c-Si.

8.2.1.2.1 Amorphous Silicon

Amorphous silicon is deposited from hydride gases using the process of plasma assisted chemical vapor deposition (PACVD). This process results in good uniformity of the coating, but only uses 10 to 30 percent of the available gases. Hydrogen, 1 to 10 percent, bonds to the Si which is why it is often designated as a-Si:H. The a-Si may be deposited onto glass, stainless steel, foil or plastics. Continuous "roll-to-roll" deposition can be performed on flexible foil and plastic substrates. The *pn* junction[li] in a-Si is produced by doping during deposition with either boron or phosphorous. Two to three junctions (layers) are deposited with a thickness of approximately 1 μm, not including the substrate. Although a-Si has lower efficiencies than other materials, it has a unique attribute of temperature independence. That is, a-Si produces essentially the same solar power at elevated temperatures (above room temperature), whereas all the other materials degrade in performance as temperature is increased above ambient. Current research in a-Si is focused on improving cell efficiency, increasing deposition rate, and increasing the percentage of gases utilized in the PACVD process.

8.2.1.2.2 Copper Indium Gallium Diselenide

Copper indium gallium diselenide, $Cu(InGa)Se_2$ also abbreviated CIGS, has higher efficiencies than the other thin-film solar cell materials, but suffers from a low band gap. Alloying with gallium, sulfur, or both can be used to increase the band gap and efficiency. There are a number of deposition methods that have been studied, although there are currently two methods under development for commercial production. One is a co-evaporation technique whereby the elements are simultaneously evaporated from sources and deposited onto a heated substrate material. The second is a process called selenization, whereby layers of Cu, Ga, and In are deposited by various methods, and then Se is introduced using either hydrogen selenide (H_2Se) or Se vapor and heat. The CIGS films are p-type materials with an n-type layer of cadmium sulfide (CdS) or zinc oxide (ZnO) providing the *pn* junction cell. A cell efficiency of 19.9 percent has been obtained with solar modules reaching ten percent efficiency. Research on this material includes studies on alternate alloying materials to increase the band gap and improve efficiency, improvements in deposition technologies, and alternate n-type materials other than CdS.

8.2.1.2.3 Cadmium Telluride

Cadmium telluride has been studied for PV applications since the 1970s. Like CIGS, CdTe is a p-type material that is deposited with layers of CdS to produce a *pn* photoelectric cell. There are a number of deposition methods that have been used with CdTe, with all requiring a post anneal process to improve efficiency, and a surface treatment for producing good contacts. CdTe is more sensitive to atmospheric interaction and thus good encapsulation is required. Another disadvantage of CdTe, is that Cd must be handled in a safe manner during processing, manufacturing, and recycling. The advantage is a higher efficiency is achieved, which is close to that of CIGS.

8.2.1.3 Multijunction Cells

The search for materials with greater efficiencies than silicon led to the development of multijunction cells using III-V materials, including gallium arsenide and gallium indium phosphide. These multijunction cells consist of layers of GaAs by itself or in combination with other III-V compounds, as depicted in Figure 58. Cell efficiencies greater than 35 percent have been obtained with these configurations. The disadvantage is high costs, and as such, research efforts are focused on lowering costs, primarily in fabrication and manufacturing the cells. The combination of high efficiency, thin films leading to less materials used compared to c-Si cells, and lowering costs give multijunction cells potential to lead to lower lifecycle costs than c-Si.

[li] *pn* junction refers to a boundary interface between a positively charged material, *p*-type, and a negatively charged material, *n*-type, in very close contact.

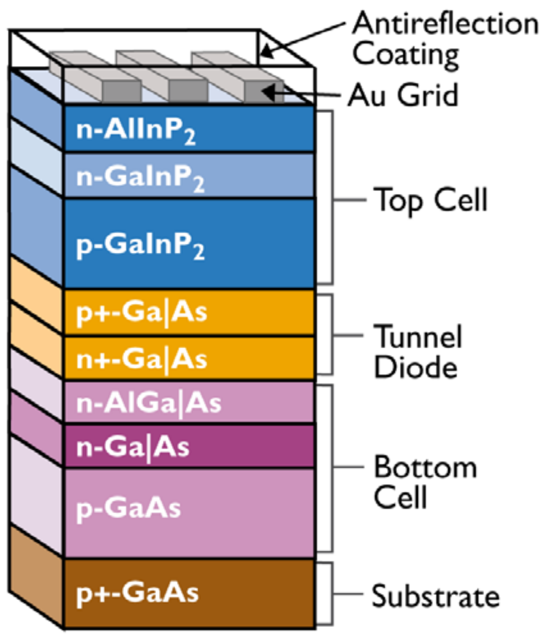


Figure 58. Multijunction solar cell.[139]

8.2.1.4 Photovoltaic Panel Designs

Photovoltaic cells are interconnected and encapsulated into a panel, also called a module. Panels may be constructed using flat plate or concentrator technologies. Flat plate technology has been widely used, although with the increased use of solar energy and interest in larger systems, concentrating PV designs are now on the commercial market.

8.2.1.4.1 Flat Plates

Flat plates are widely used compared to other PV designs due to their simplicity and lower costs. Solar cells, made primarily from c-Si, are encased in a rectangular box to protect the cells from the environment. High transmission glass plates allow the sun's radiation to transmit to the solar cells where the energy is converted to DC electric power. The flat plates may be combined into a single structure called a solar array. The flat plates are connected with electrical cables which distribute the electricity to a building or electric grid. The DC current must be converted to AC current prior to distribution, which is accomplished with an inverter. One or more inverters may be used depending upon the system size and application. Twenty-four solar panels mounted on the roof of the Fairfax Village Center (Fort Belvoir, VA) supplies 23 percent of the building electricity (see Figure 59). Solar modules covering 140 acres on Nellis Air Force Base powers approximately 25% of the entire base (Figure 60).

Figure 59. Rooftop solar panels on the Fairfax Village Center.[140]

Figure 60. Nellis AFB solar array.[141]

8.2.1.4.2 Concentrating Photovoltaics

Concentrating photovoltaics (CPV) is the technology of using mirrors or lenses to focus solar radiation onto PV cells. This technology has been around for some time but has proven to be difficult to implement to date. CPV technology offers the potential for lower cost systems by replacing some of the solar cells with lower cost mirrors or lenses to produce an equivalent amount of power to flat plate panels, as well as high efficiencies. CPV development had been slow due to a number of factors, but has now reached the commercial world due to the current increased demand for solar technologies. In the past, most of the R&D has revolved around the solar cells themselves rather than system development. CPV packaging has been difficult because of the high heat fluxes encountered. In addition, CPV systems have not been well suited to small scale power systems and building integrated designs, which have dominated the past market. With increased demand, however, CPV technology has been produced for land-mounted systems, as shown in Figure 61, as well as for rooftop panels. One particular system uses multijunction cells with an efficiency of approximately 39 percent and a net system efficiency of approximately 18 percent.[142]

Figure 61. CPV system.[143]

8.2.1.5 Photovoltaic System Designs

There are a number of PV designs based upon the specific location and system load. Rooftop, awning, and carport systems are used to produce power on a smaller scale for residential housing and commercial building loads. These are usually retrofit applications. Newly designed commercial buildings can incorporate PV panels into its structure, termed building integrated PV (BIPV). Photovoltaic systems mounted on pontoons have been constructed to make use of open ponds, such as those used for irrigation, which doubles as a power provider and reduces water evaporation. Portable systems provide small scale power for lighting and other temporary needs. Land-based systems are usually reserved for large scale systems, providing power for multiple facilities and grid connected systems. All PV systems require inverters to convert DC to AC current. Some systems may use tracking devices to optimize performance, and battery storage may also be implemented. A simple block diagram of a grid-connected PV system is shown in Figure 62.

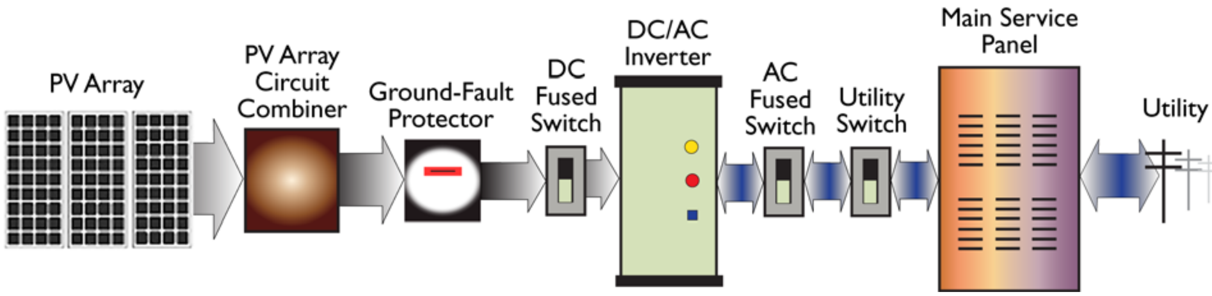


Figure 62. Grid-interactive PV system without battery backup.[144]

8.2.1.5.1 Inverters

An inverter is an electronic system that converts DC electrical power to AC. These typically include system controls to connect to the grid when sufficient power is being generated and to disconnect the system from the grid. Most inverters also include data monitoring electronics that are interfaced through computers to actively monitor the PV system performance. A single inverter may be used, primarily for small systems, and multiple inverters are typically used in larger systems. A single malfunctioning PV panel can affect the entire system, and as such, it is important to monitor and quickly isolate and correct problems. Multiple inverters have the advantage of monitoring sections of the system, which aids in localizing maintenance activities should a problem occur. Microinverters, which are connected to each individual panel, have also been developed. This isolates each panel for monitoring, but adds complexity. Inverter systems designs take into consideration the trade-offs in monitoring versus complexity and cost for the overall system. There is energy loss associated with inverters with an average efficiency around 77 percent.[145]

8.2.1.5.2 Tracking Systems

Tracking systems are used to optimize the amount of solar energy collected over the course of a day. There are single axis and double axis systems. Sensors are used to align the solar panels or arrays in an optimal (orthogonal) position in relation to the incoming solar radiation.

8.2.1.5.3 Battery Storage Systems

Battery storage systems are used when continued power is required during night and to compensate for cloudy conditions. Special locations are generally required to house battery banks, with their own monitoring system for preventive maintenance. Batteries have lower life expectancies compared to the other components of a PV system, and can account for up to about 30 percent, and sometimes even higher, of the total PV system cost. Charge controllers are used in larger battery systems to avoid overcharging and deep discharging conditions. Figure 63 depicts a typical design configuration for a grid-tied PV system with battery backup. Some regions have implemented net-metering for residential and commercial facilities eliminating the need for battery systems.

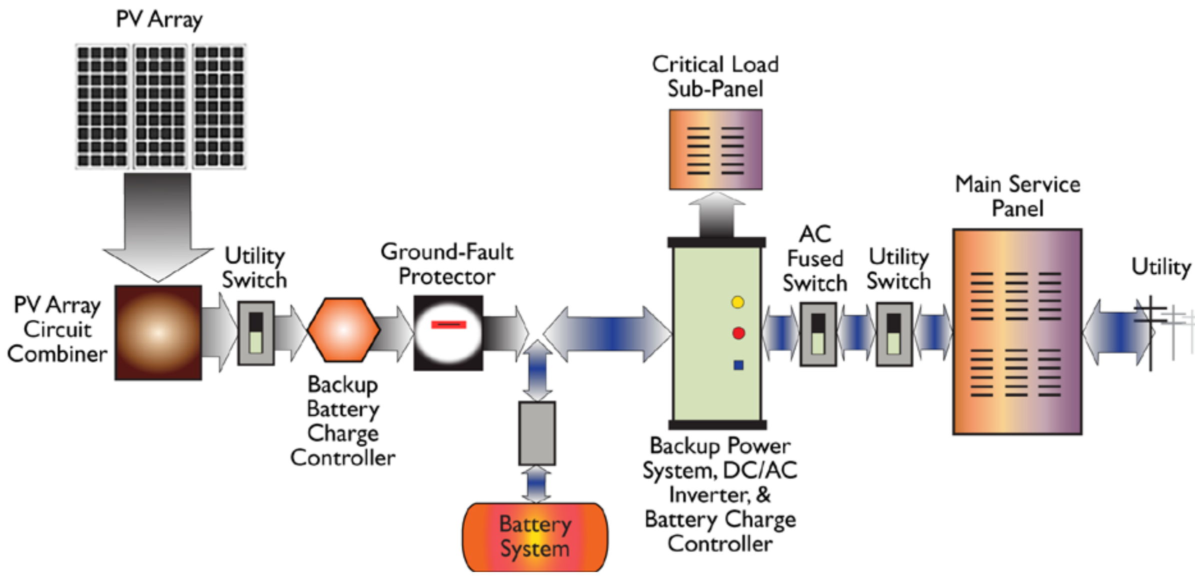


Figure 63. Grid-interactive PV system with battery backup.[144]

8.2.2 Solar Thermal

Solar thermal applications can be defined by their respective temperature range of operation.[146] Less than 100°C water heating is used for building heat, domestic hot water, swimming pools, and evaporative systems, such as distillation and dryers. Less than 150°C is applicable to air conditioning and cooling, and for heating water, oil, or air for industrial use. Temperatures from 200 to 2000°C may be used for generation of electrical and mechanical power. To obtain temperatures greater than 100°C, concentrators in the form of lenses or mirrors must be used to focus the sun's energy. Concentration ratios[lii] range from one for flat plate collectors to more than 1,000 for concentrators. Table 33 provides the temperature range and concentration ratio of various solar thermal collectors. Table 34 lists the performance ratings of thermal solar collectors.

Table 33. Solar thermal collectors.[146]

Collector Type	Temperature Range (°C)	Concentration Ratio
Flat Plate	30 – 80	1
Evacuated Tube	50 – 200	1
Parabolic Trough	60 – 250	15 – 45
Dish/engine	100 – 500	100 – 1000
Heliostat	150 – 2000	100 – 1500

[lii] Concentration ratio is the ratio of the area of the receiver to the aperture of the focused light.

Table 34. Average thermal performance rating of solar thermal collectors in 2008.[liii, 147]

Low-Temperature	Medium-Temperature					High-Temperature
Liquid/Air	Air	Liquid				Parabolic Trough
Metallic and Nonmetallic		ICS/ Thermosiphon	Flat-Plate (Pumped)	Evacuated Tube	Concentrator	
1,196	864	894	988	958	1,173	828

8.2.2.1 Flat Plate Collectors

Flat plate collectors are generally fixed, mounted units that absorb the sun's energy primarily to heat water for facilities. Piping or flow tubes are made from high thermal conductivity materials and hold the water or air to be circulated into a building or residence. The flow tubes are contained in a waterproof box with insulation beneath the tubes and a transparent glass window on top to transmit the sun's energy, as depicted in Figure 64 and Figure 65. Low iron glass is commonly used due to its good transmittance. Flat plate collectors can be used with unpumped systems, which rely on natural convection, or with pumped distribution to hot water holding tanks. Flat plate collectors have been successful for use in residential systems and for pool heating systems, but have not had the same success for commercial and industrial applications. This is attributed to the high initial investment along with a general lack of knowledge particularly on expected benefits.

Figure 64. Photograph of a flat plate collector.[148]

[liii] BTUs/ft^2/day

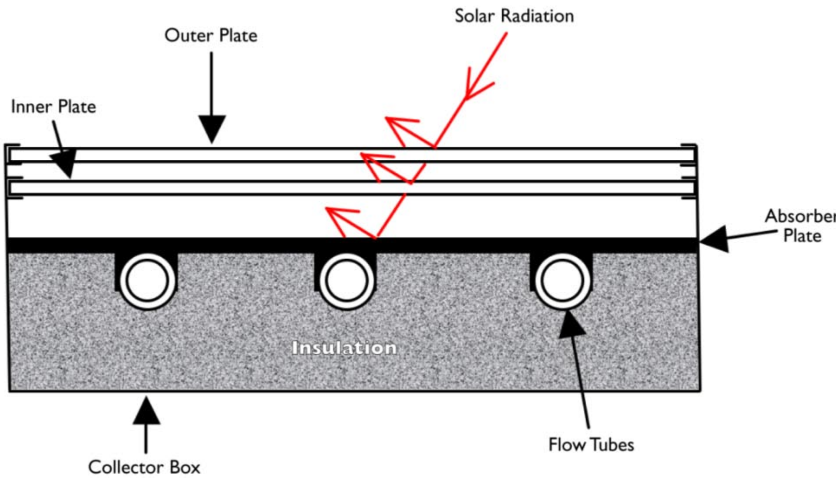


Figure 65. Illustration of a flat plate collector.[148]

8.2.2.1.1 Integrated Collector Storage and Thermosiphon Hot Water Systems

The integrated collector storage (ICS) and thermosiphon rely on natural convection for fluid circulation, and thus no pumping is required. They are small systems used for residential applications. There are several configurations of heat transport between the solar collector and the storage tank. There may also be a need for freeze protection in very cold environments. The ICS system is typically used for 30 to 40 gallon systems. They are limited to regions with less than twenty freezes per year, and only provide hot water during daylight hours and thus are used in conjunction with a conventional hot water system. However, they have few maintenance requirements.

The thermosiphon system can be used for 40 to 120 gallon systems. These have a higher performance than ICS but are vulnerable to damage in areas of multiple freeze cycles. The storage tanks are located directly above the solar collectors, either on the roof or inside an attic. Thermosiphon systems are also used in conjunction with a conventional hot water system.

8.2.2.1.2 Pumped Solar Heating Systems

Pumped solar thermal collector hot water systems can be used for large systems, providing hot water for residential, commercial and industrial applications. Temperature requirements can range from 60 to 260°C, depending on the application. For systems with temperature requirements higher than 100°C, a pressurized system is used. Higher temperature systems always result in less efficiency as more heat loss occurs. Similar to the unpumped systems, the lack of a continuous energy source requires the solar heating system to be tied in with a conventional system.

8.2.2.2 Evacuated Tube Collectors

Evacuated tube collectors are designed for higher temperature use than flat plate collectors. They are used for industrial and commercial use and have been used for residential heating in cloudy regions. Glass tubes in which pressures reach 10^{-3} mbar are connected to a header pipe which distributes the heated gas or fluid. The evacuated glass tubes create high insulation conditions creating higher temperature capabilities than flat plate collectors. Low conductivity gases, such as xenon (Xe), may be used to further optimize performance. There are a few different evacuated tube collector designs, which have been categorized as direct flow or indirect flow collectors.

Direct flow collectors are configured such that the working fluid flows through the absorber. They consist of metallic fins located inside the evacuated glass tubes and are attached to a copper or glass absorber pipe. Glass-glass tubes have also been developed for direct flow, whereby two concentric tubes are fused together at one end. The glass-metal system offers high efficiency, but the use of different thermal expansion materials has caused problems, such as loss of vacuum. Glass-glass tubes can become more efficient at high temperatures.

Indirect flow tubes copper pipes, under vacuum pressure, are placed within a U-shaped evacuated glass tube. A small amount of water is placed within the copper tube which repeatedly changes to vapor, rises to the top transferring heat, then condenses and falls back down to the bottom. The vacuum pressure reduces the boiling point of the water, although the freezing point remains unchanged. Thus, in cold environments, an additive is included to prevent freezing. Figure 66 shows the various evacuated tube types, while Figure 67 depicts a flat plate design.

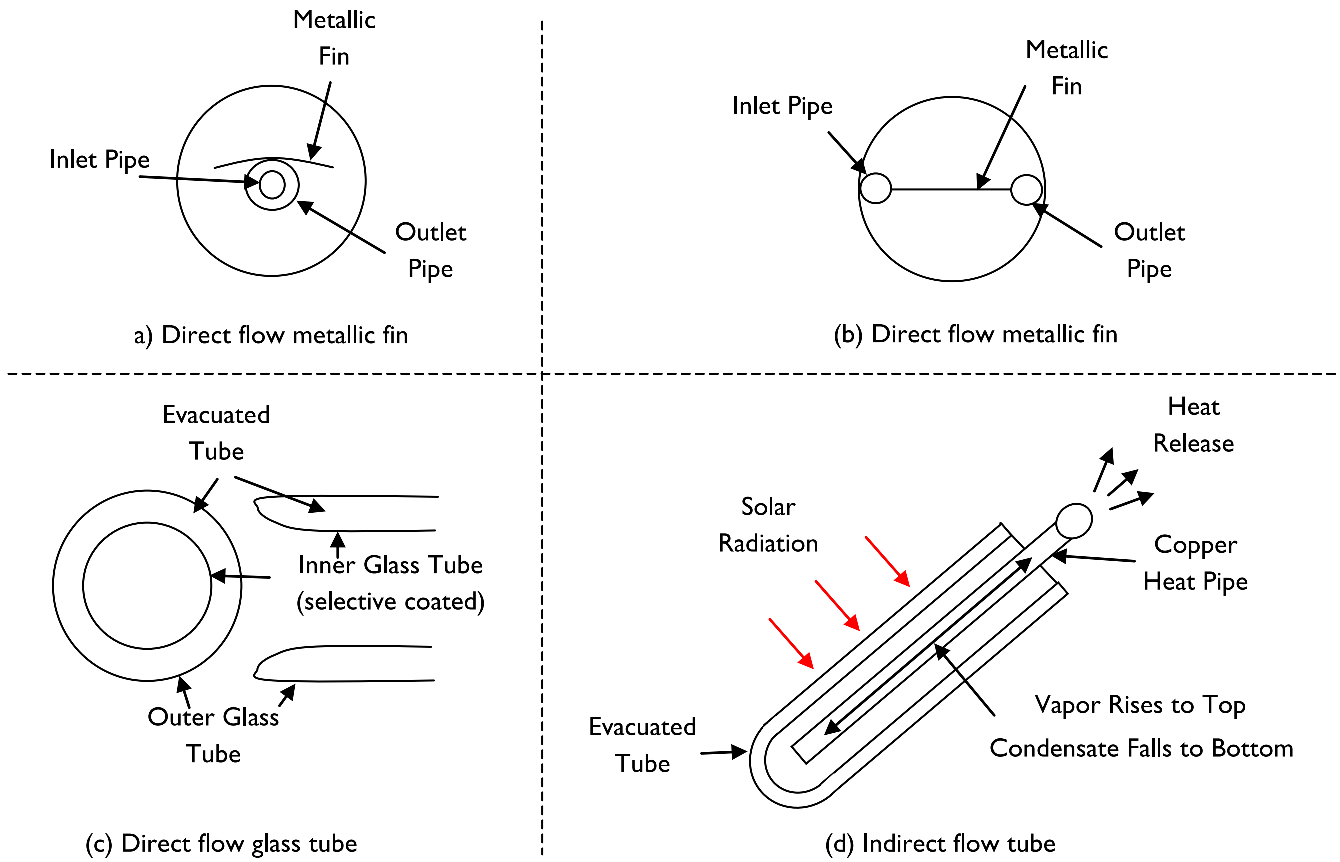


Figure 66. Evacuated tube collector designs.[149]

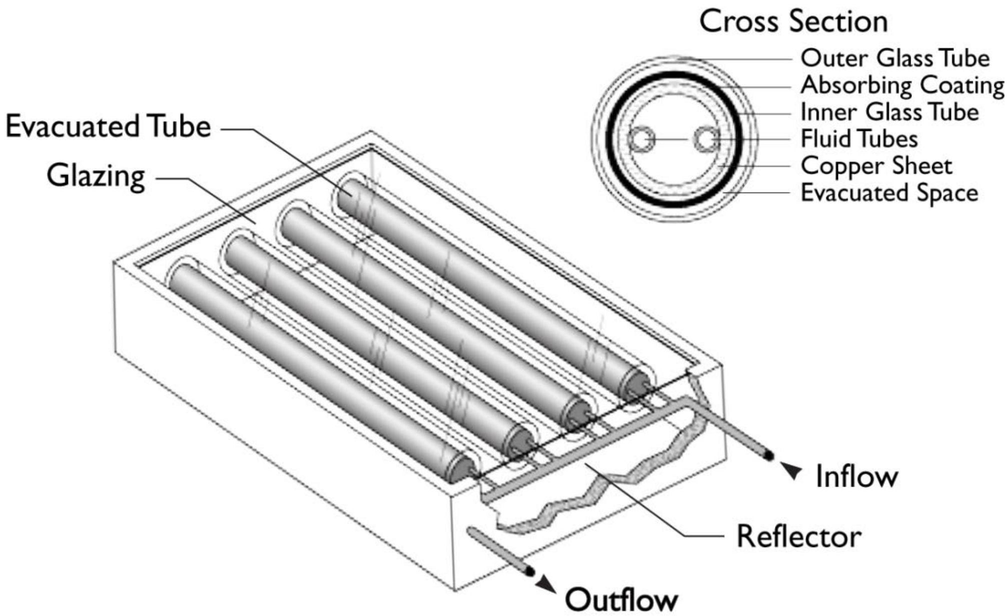


Figure 67. Flat plate evacuated tube collector.[143]

8.2.2.3 Transpired Solar Collectors

Transpired solar collectors are used to heat outside air, which is then distributed to a building's heating system. The collector contains a porous absorber plate, which is heated by the sun's radiation. Outside air is pulled through the plate and collected in the plenum for distribution to the building's heating system. Thus the air is preheated, effectively reducing the amount of fossil fuels used to attain a set temperature. A typical transpired solar collector is depicted in Figure 68.

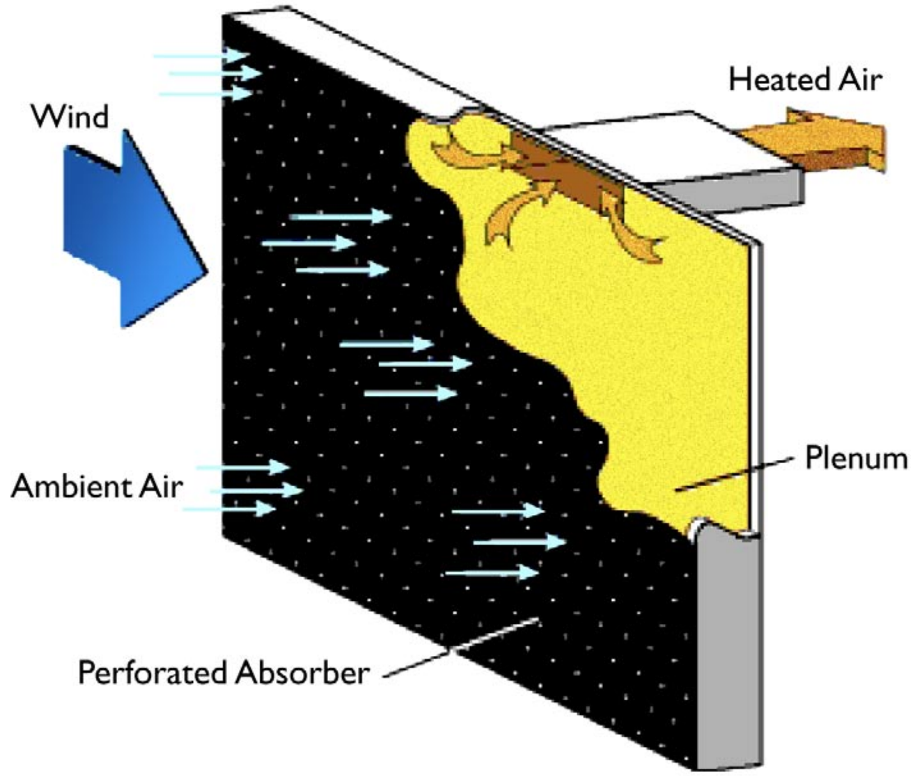


Figure 68. Transpired solar collector.[150]

The cost of transpired solar collectors depends upon the building load, solar resource, installation, and life of the system. Analyses have determined that greater than 50 percent efficiency can be obtained with proper design. Many installations have been add-on collectors on the south facing walls of buildings. This type of installation does not maximize energy collection, but has reduced impact on used space, and is easy to connect to the building's system.

New construction can optimize the efficiency of solar collectors by designing the building to allow adequate space and optimal positioning of collectors. Transpired solar collectors can also prevent some heating of the building during summers by collecting the solar energy rather than entering the building, and venting the heated air at the top of the building. Transpired solar collectors can be constructed with modular designs for installation flexibility, and may be placed at an angle or on a tracking system to optimize energy capture. They have long lives of more than 30 years since there are no dynamic components. Table 35 lists military facilities that have installed transpired solar collectors.

Table 35. Military installations with transpired solar collectors.[151]

Installation	Number of Buildings (Number of Solar Collectors)	Year of Initial Installation	Type of Building
Buckley AFB	1 (1)	2007	Material Handling Facility
Buckley Annex (Army)	1 (2)	2004	Aviation Hangar
Edwards AFB	1 (1)	2001	Aircraft Support Facility
Elmendorf AFB	1 (2)	2008	Warehouse Shop
Peterson AFB	1 (1)	2007	Defueling Hangar
Fort Carson	2 (3)	2006	Aviation and Vehicle Maintenance Facilities
Fort Drum	27 (50)	2005	Various
Fort Huachuca	2 (2)	2001	Aviation Hangars
Fort Lewis	1 (1)	2006	Maintenance Facility
Norfolk Naval Station	2 (2)	1997	Maintenance Facility / Training Gymnasium
TOTAL	39 (65)		

8.2.3 Concentrating Solar Power

Concentrating solar power technologies use the sun's energy to superheat fluids and ultimately produce steam to drive a steam turbine generator. The sun's energy is captured using flat plate mirrors, parabolic mirrors, or concave dish collectors. This technology has been in existence for a couple of decades and was first demonstrated in the US in California using parabolic mirrors. Power towers have since been built using flat mirrors (heliostats) to focus the sun's energy on a tower containing long pipes filled with a heat transfer fluid. CSP technology has the advantage of lower energy cost compared to photovoltaic systems. They are generally large systems tied into power grids for utility scale operations. Solar thermal electric technology may be built as a retrofit to complement existing fossil fuel plants where feasible. Table 36 provides a general summary of concentrating solar power types.

Table 36. Characteristics of solar concentrating power systems.[152]

	Parabolic Trough	Power Tower	Dish/Engine
Size	30 – 320 MW*	10 – 200 MW*	5 – 25 kW*
Operating Temperature (°C)	390	565	750
Annual Capacity Factor	23 – 50%*	20 – 77%*	25%
Peak Efficiency	20% (d)	23% (p)	29.4% (d)
Net Annual Efficiency	11 (d') – 16%*	7 (d') – 20%*	12 – 25%* (p)
Commercial Status	Commercially available	Scale-up Demonstration	Prototype Demonstration
Technology Development Risk	Low	Medium	High
Storage Available	Limited	Yes	Battery
Hybrid Designs	Yes	Yes	Yes
Cost			
$/m^2$	630 – 275*	475 – 200*	3100 – 320*
$/W	4.0 – 2.7*	4.4 – 2.5*	12.6 – 1.3*
$/W_p$^	4.0 – 1.3*	2.4 – 0.9*	12.6 – 1.1*

* Values indicate changes over the 1997 – 2030 timeframe.
^ $/W_p$ removes the effect of thermal storage (or hybridization for dish/engine).
(d) = demonstrated, (p) = predicted, (d') = has been demonstrated, out years are predicted values.

8.2.3.1 Parabolic Troughs

Parabolic troughs, also known as linear concentrator systems, are the most proven solar thermal electric technology with several commercial scale power plants dating back to the first Solar Electric Generating System (SEGS) plant in 1984. They consist of large mirrors which concentrate the sun's energy onto a linear receiver tube. They usually consist of multiple rows of solar collectors on a single axis tracking system and are oriented on a north-south horizontal axis (see Figure 69).

Figure 69. Parabolic trough solar collector.[153]

Parabolic troughs consist of four basic elements, the support structure, the mirrors or reflectors, the linear receiver, and the collector balance. There have been a few different support structure designs, based upon established structural frame designs, providing support to the array of mirrors or reflectors, the linear receiver, and mounted on a single axis tracking system. Parabolic shaped mirrors, composed of high transmittance glass with a silver layer on the back (back surface mirrors), are the current standard for all parabolic troughs. Front surface mirrors may achieve higher reflectivity, but they suffer from low durability. The glass is typically low iron or white glass for high transmittance with a thickness of 4 mm. The silver layer reflects the sun's radiation onto the linear receiver. The receiver, also called the heat collection element, is a stainless steel tube containing a heat transfer fluid. The stainless steel tube is coated with a solar absorber surface, and surrounded by an evacuated glass tube. The receiver contains special seals and metal bellows to account for the differing thermal expansions of the glass and stainless steel (see Figure 70). The collector balance consists of all the control equipment for the parabolic trough.

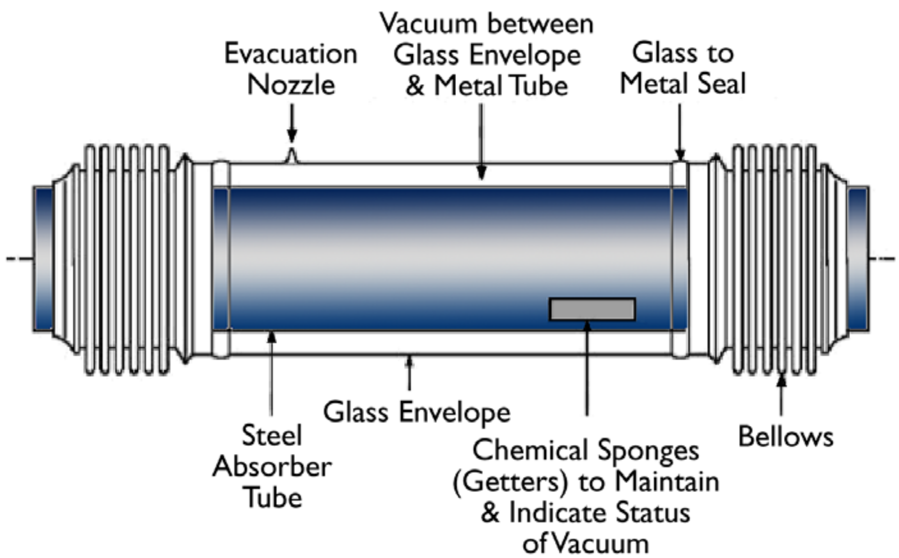


Figure 70. Linear receiver tube.[154]

A number of SEGS plants were constructed in California through the 1980s into 1990, and these are listed in Table 37. A diagram of the SEGS I plant design is shown in Figure 71. Since then, there have been a number of parabolic trough plants built around the world with several more under construction.

Table 37. Parabolic trough plants in the US.[155]

Plant	Year built	Location	Net Turbine Capacity (MW)	Field Area (m^2)	Oil Temperature (°C)	Average Gross Solar Production of Electricity 1998–2002 (MWh)
SEGS I	1984	Daggett	14	82,960	307	16,500
SEGS II	1985	Daggett	30	165,376	316	32,500
SEGS III	1986	Kramer Jct.	30	230,300	349	68,555
SEGS IV	1986	Kramer Jct.	30	230,300	349	68,278
SEGS V	1987	Kramer Jct.	30	233,120	349	72,879
SEGS VI	1988	Kramer Jct.	30	188,000	391	67,758
SEGS VII	1988	Kramer Jct.	30	194,280	391	65,048
SEGS VIII	1989	Harper Lake	80	464,340	391	137,990
SEGS IX	1990	Harper Lake	80	483,960	391	125,036

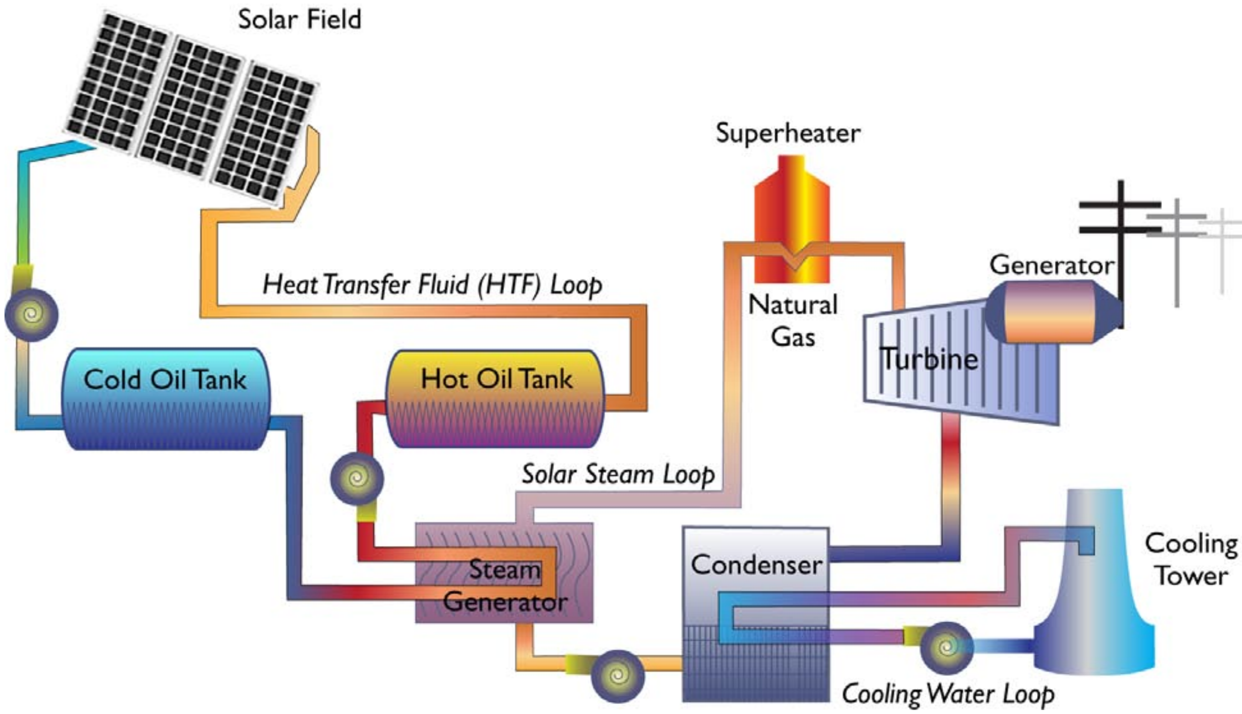


Figure 71. Illustration of the SEGS I plant design.[156]

Broken glass mirrors due to high winds, especially at the ends of the solar arrays, as well as the glass tubes on the linear receivers has led to newer materials and designs to increase reliability and decrease costs. The rate of mirror breakage has been low, but the replacement costs are high. The glass surfaces must also be able to withstand repeated washing. Higher durability reflector surfaces should significantly reduce costs. Alternate materials for thermal energy storage have also been studied to increase efficiency.

Table 38 provides a listing of the various heat transfer fluids researched. Molten salts provide good thermal storage, although special materials must be used due to compatibility and corrosion problems. Thermal storage is also used with the power tower technology, *Section 8.2.3.3*, where plants that use molten salts have been built. The availability of water is a factor as parabolic trough plants are best constructed in hot arid environments. Dry cooling technology can be used, but this significantly decreases the plant efficiency. Due to the high costs associated with installation, the trend has been to build larger size plants, which reduce the time for a return on investment.

Table 38. Candidate heat transfer media.[157]

Storage Medium	Temperature		Average Density	Average Heat Conductivity	Average Heat Capacity	Volume Specific Heat Capacity	Media Costs per kg	Media Costs per kWh
	Cold (°C)	Hot (°C)	(kg/m³)	(W/mK)	(kJ/kgK)	(kWh/m³)	($/kg)	($/kWh)
Solid Media								
Sand-rock-mineral oil	200	300	1,700	1.0	1.30	60	0.15	4.2
Reinforced concrete	200	400	2,200	1.5	0.85	100	0.05	1.0
NaCl (solid)	200	500	2,160	7.0	0.85	150	0.15	1.5
Cast iron	200	400	7,200	37.0	0.56	160	1.00	32.0
Cast steel	200	700	7,800	40.0	0.60	450	5.00	60.0
Silica fire bricks	200	700	1,820	1.5	1.00	150	1.00	7.0
Magnesia fire bricks	200	1200	3,000	5.0	1.15	600	2.00	6.0
Liquid Media								
Mineral oil	200	300	770	0.12	2.6	55	0.30	4.2
Synthetic oil	250	350	900	0.11	2.3	57	3.00	43.0
Silicone oil	300	400	900	0.10	2.1	52	5.00	80.0
Nitrite salts	250	450	1,825	0.57	1.5	152	1.00	12.0
Nitrate salts	265	565	1,870	0.52	1.6	250	0.70	5.2
Carbonate salts	450	850	2,100	2.0	1.8	430	2.40	11.0
Liquid sodium	270	530	850	71.0	1.3	80	2.00	21.0
Phase Change Media								
$NaNO_3$	308		2,257	0.5	200	125	0.20	3.6
KNO_3	333		2,110	0.5	267	156	0.30	4.1
KOH	380		2,044	0.5	150	85	1.00	24.0
Salt ceramics ($NaCO_3$-$BaCO_3$/MgO)	500 – 850		2,600	5.0	420	300	2.00	17.0
NaCl	802		2,160	5.0	520	280	0.15	1.2
Na_2CO_3	854		2,533	2.0	276	194	0.20	2.6
K_2CO_3	897		2,290	2.0	236	150	0.60	9.1

A newer design that has been developed is the integrated solar combined cycle system (ISCCS), which combines parabolic trough technology with a gas turbine generator. The advantage of this design is that it uses a waste heat recovery system as shown in Figure 72. This design offers an improvement in plant efficiency and lower costs.

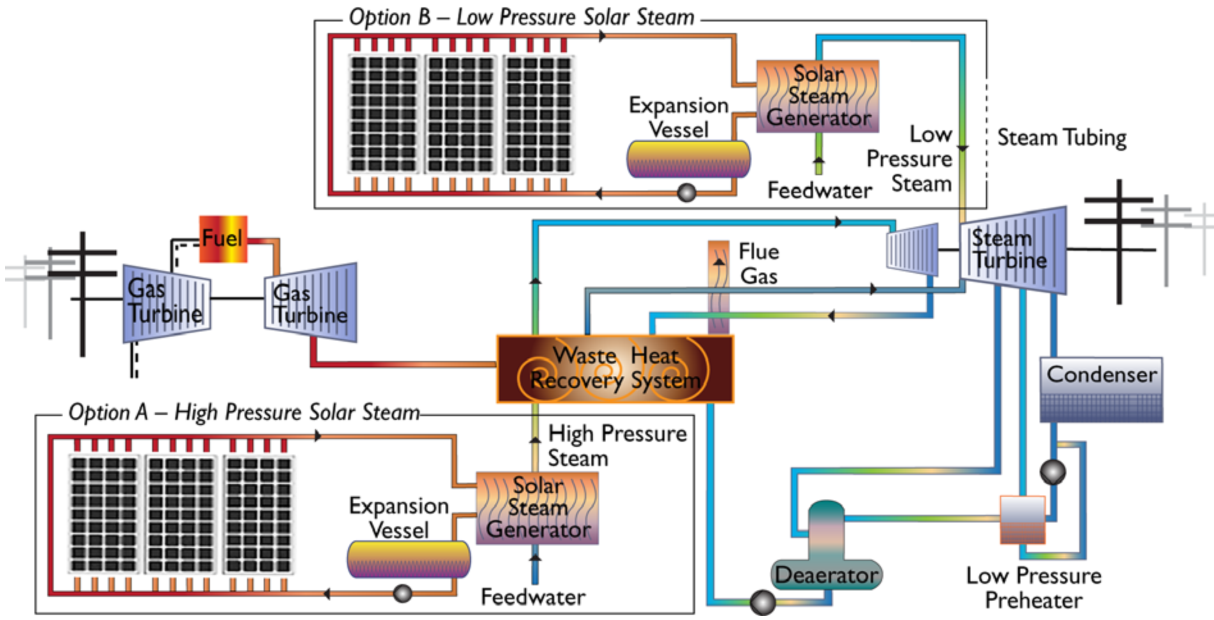


Figure 72. Integrated solar combined cycle system.[158]

8.2.3.2 Dish/Engine

Dish/engine systems are a relatively new technology that has been demonstrated to achieve higher efficiencies (i.e., 29.4 percent) than other solar-to-electric technologies. The dish/engine technology, unlike parabolic trough and power towers, are applicable to smaller loads with individual units ranging in size from 9 to 25 kilowatts (see Figure 73). Due to their smaller size, dish/engines can be used in remote locations, interconnected to construct a large array of units, and connected to a power grid. Two axis tracking systems must be used to concentrate the energy required by the system.

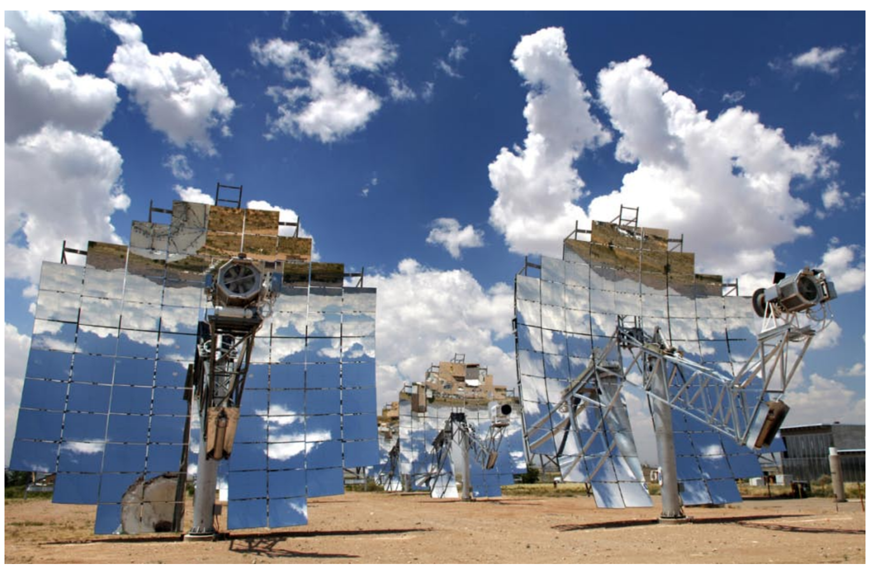


Figure 73. Photograph of dish/engine systems.[159]

The dish is a collection of mirrors used to concentrate the sun's rays onto a thermal receiver. The mirrors are constructed using the same materials used for parabolic trough mirrors. The power conversion unit includes the thermal receiver and an engine generator. The thermal receiver typically consists of tubes containing a heat transfer fluid. The most common engine used in dish/engine units is the Stirling engine, which has obtained a 31.25 percent net efficiency.[160] The Stirling engine is a sealed system containing hydrogen. The change in hydrogen temperature causes respective changes in pressure that drives a piston engine. Research is being conducted on microturbines which may be used in place of the Stirling engine.

8.2.3.3 Power Towers

Power towers generate electricity from sunlight by concentrating the sun's energy, using numerous tracking mirrors called heliostats, onto a heat exchanger within a tower, where heat transfer fluids are heated and distributed to power a conventional steam generator (see Figure 74). Power towers are suited for utility scale applications generally from 30 to 400 MW.

Figure 74. Power tower.[161]

The mirrors are constructed using similar technologies as the parabolic trough mirrors. Power tower technologies also use thermal storage systems and general plant designs similar to parabolic trough systems, and have potential use in an integrated solar combined cycle system. A typical power tower plant design is depicted in Figure 75.

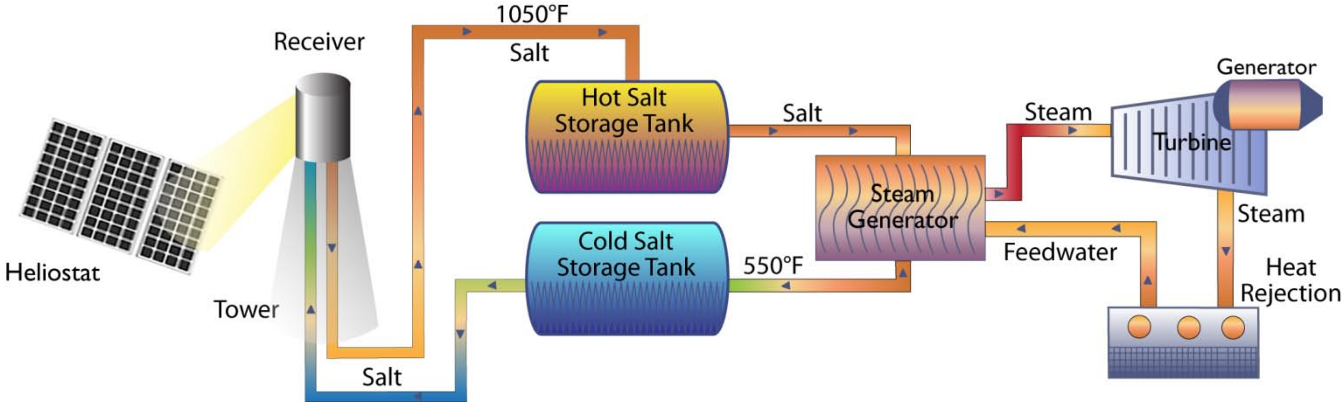


Figure 75. Power tower plant design.[162]

Although power towers are a newer form of solar thermal electric generation than parabolic troughs, much of the same materials and designs are used which have been demonstrated over the past two decades, including two pilot power tower plants, Solar One and Solar Two, built in southern California. There are now a number of power tower plants around the world and several under construction.

8.3 Solar Cooling

Solar cooling has been used for decades, primarily in the southern US, for residential and commercial buildings. In residential housing, the sun's rays are used to evaporate water, which produces cool air that is captured and distributed to the home's cooling system. It may be a standalone system or integrated into an air conditioning system. For industrial cooling, solar thermal collectors are used to provide heat, which is then used in conjunction with an absorption chiller to produce cool air.

8.4 Daylighting

Daylighting is the use of windows and skylights to bring natural lighting into a building or home to reduce the use of electrical lighting. Daylighting is primarily used in new construction. However, some retrofit windows, doors and skylights can be added to an existing building, but are limited by the existing building design. Daylighting in new buildings may be implemented in conjunction with building integrated photovoltaics technology, as shown in Figure 76.

Figure 76. BIPV daylighting.[163]

8.5 Testing Standards and Specifications

There are hundreds of test standards from various organizations relative to solar PV and thermal collectors to evaluate collector performance and reliability. Photovoltaic performance is typically measured in terms maximum power, W_p, under standard reporting conditions. The term reporting is used to reflect that test conditions other than SRC may have been used in testing and then corrected to SRC. Factors involved in testing are the temperature, spectral irradiance, and total irradiance. Efficiency is the maximum power output divided by the total irradiance. Solar thermal collectors are similarly rated by maximum thermal performance under standard conditions.

The Solar Rating and Certification Corporation (SRCC) is a nonprofit organization established in 1980 to develop and implement certification programs. It sets up operating guidelines, testing requirements and standards, and rating methods that test laboratories use to achieve SRCC certification. The International Organization for Standardization (ISO) and the Institute of Electrical and Electronics Engineers (IEEE) also have developed solar technology standards for industry. ASTM International has numerous test standards relative to solar energy. Links to these resources are listed in *Appendix E: Resources*.

8.6 Economics

There are ample tools available to aid energy managers in performing a cost analysis of solar projects. The cost of solar energy is dependent upon a location's solar resources, the load, installation, operation, maintenance and repair costs, and the lifetime of the system. Government organizations have made numerous energy data and resource maps available via the internet, (see *Appendix E: Resources*). In addition to all the tools made available, there are also organizations which can help in the decision making process. The DoD Renewable Energy Assessment Team has conducted a general study on the development of solar projects on major military installations.[164] The National Renewable Energy Laboratory offers operations assistance for renewable energy projects.

The major hurdle to implementing solar projects is the high cost of solar energy. The price of PV solar energy is generally in the range of $0.20 to $0.40 per kWh, and parabolic troughs are generally in the range of $0.12 to $0.14 per kWh. Methods to performing a lifecycle cost analysis are covered in *Chapter 15*. In most cases the high cost of solar energy results in higher lifecycle costs, and as such, incentives are needed to build solar projects, and in turn decrease the cost of solar power in the future. Incentives are available for the various renewable energy resources from local, state, and federal organizations.

8.6.1 Photovoltaic Technology Trends

Installation of PV systems has grown dramatically over the past decade. This growth has been fueled by federal, state, and local incentives to reduce the use of fossil fuels, thereby reducing some dependency on foreign resources, increasing energy security in the US, and reducing energy production's adverse impact on health, safety, and the environment. Figure 77 shows the increase in solar modules produced in the US during the period from 1999 to 2008. Table 39 and Table 40 show the shipments of PV cells and modules between 2006 and 2008, by type and by market sector respectively.

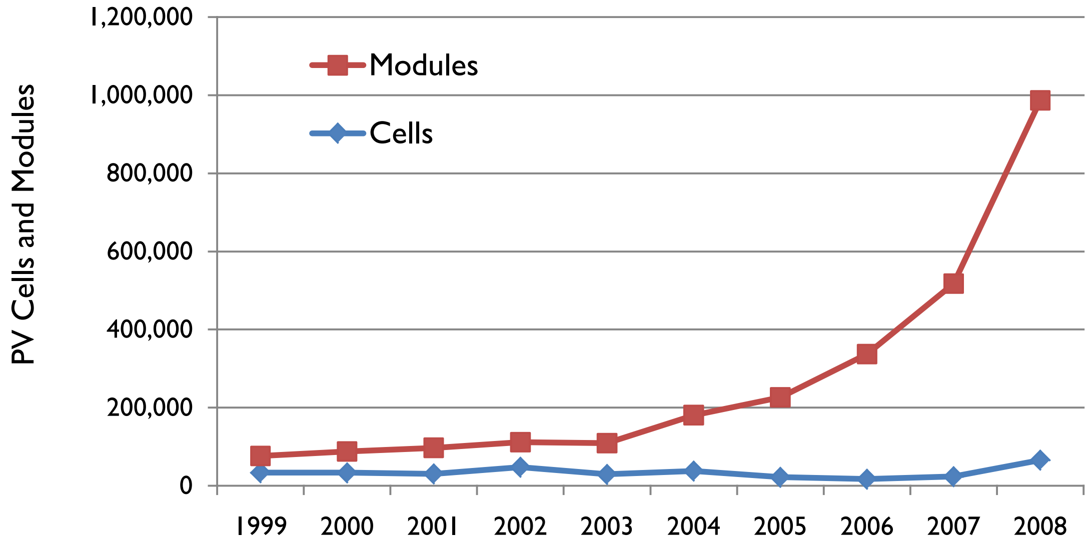


Figure 77. Annual photovoltaic cells and modules produced in the US.[165]

Table 39. Photovoltaic cell and module shipments by type.[165]

Type	Shipments (kW_p)				Percent of Total			
	2006	2007	2008	2009	2006	2007	2008	2009
Crystalline Silicon								
Single-Crystal	85,627	128,542	359,259	580,629	25	25	36	45
Cast and Ribbon	147,892	181,788	306,537	403,531	44	35	31	31
Subtotal	233,518	310,330	665,795	984,161	69	60	67	77
Thin-Film	101,766	202,519	293,182	266,547	30	39	30	21
Concentrator	1,984	4,835	27,527	31,852	1	1	3	2
US Total	**337,268**	**517,684**	**986,504**	**1,282,560**	**100**	**100**	**100**	**100**

Table 40. Domestic shipments of photovoltaic cells and modules by market sector.[165]

Sector and End Use	Crystalline Silicon	Thin-Film Silicon	Concentrator Silicon	2008 Total	2007 Total
			Market Sector		
Residential	152,057	21,932	-	173,989	68,417
Commercial	217,446	36,396	10	253,852	140,434
Industrial	37,702	13,701	90	51,493	32,702
Electric Power	8,601	17,158	10,060	35,819	35,294
Transportation	9,100	-	-	9,100	3,627
US Total	**424,906**	**89,186**	**10,160**	**524,252**	**280,475**
			End Use		
Electricity Generation					
Grid-Interactive	403,283	87,418	10,153	500,854	253,101
Remote	14,738	789	-	15,527	10,867
Communication	2,546	69	8	2,622	2,836
Consumer Goods	160	152	-	312	589
Transportation	914	2	-	916	4,018
Water Pumping	1,050	95	-	1,145	3,852
Cells/Modules to OEM	1,998	661	-	2,659	4,802
Health	217	-	-	217	410
US Total	**424,906**	**89,186**	**10,160**	**524,252**	**280,475**

The average installed costs of PV systems have decreased up until 2005, where they have leveled off through 2007, as shown in Figure 78.[166] This data represents a conglomeration of all systems designs and materials. The trend shows an average decrease in installed costs of 4.8% per year over the period of 1998 to 2005. Thereafter, the increased demand for solar modules created a shortage in the supply of silicon resulting in increased silicon costs, which served to level off the costs of installed systems. Figure 79 shows the average installed costs per watt for different sizes of PV systems. There has also been a steady increasing trend in the size of PV systems installed.

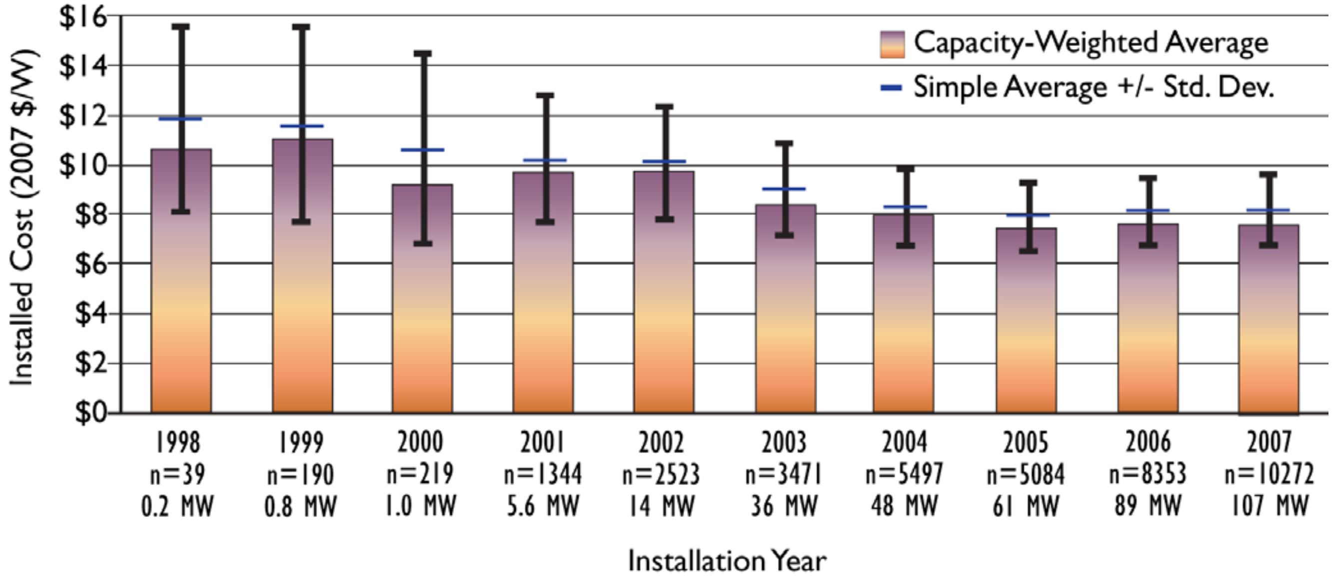


Figure 78. Installed costs of PV systems.[166]

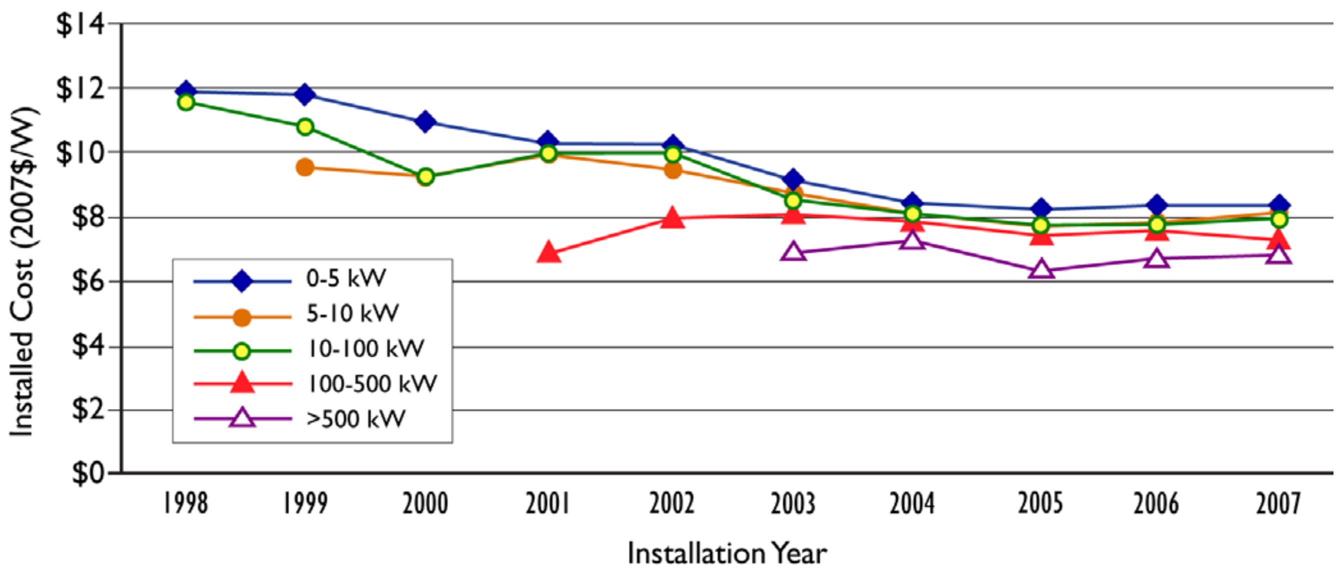


Figure 79. Installed PV costs by system size.[166]

8.6.2 Solar Thermal Technology Trends

There has been an overall trend in solar thermal collectors that is similar to the trend for PV modules as shown in Figure 80. In the period from 2006 to 2008, a decrease in low temperature collectors was offset by increases in medium and high temperature units. Average prices for the different technologies for 2007 and 2008 are listed in Table 41.

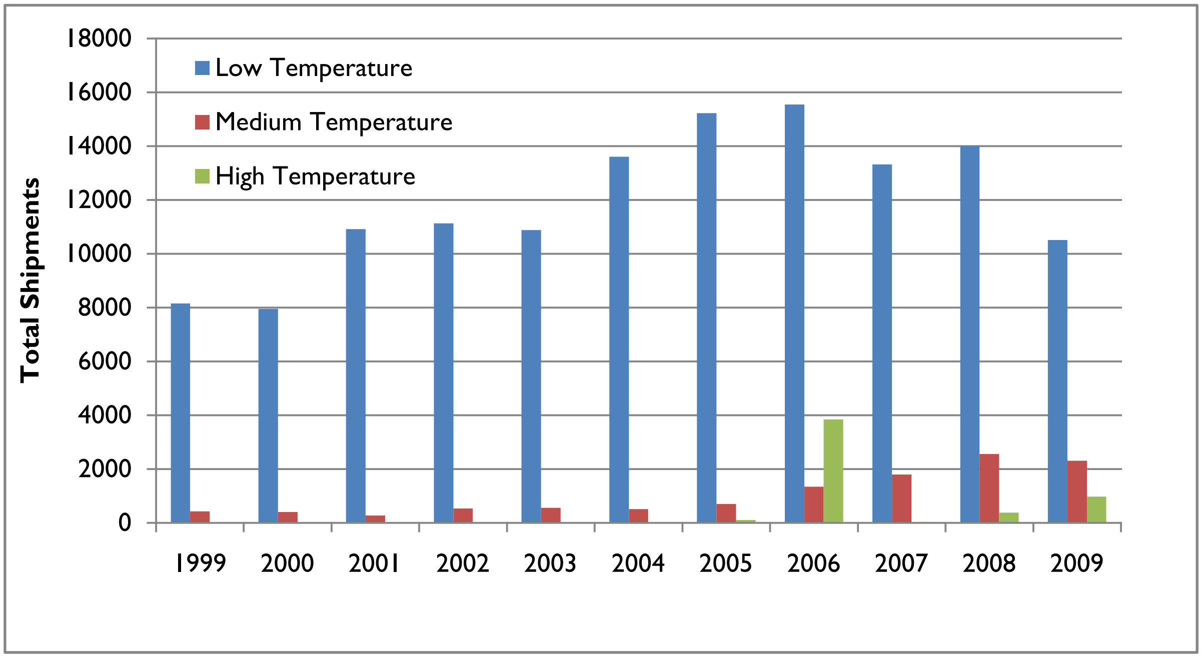


Figure 80. Annual solar thermal collector shipments.[167]

Table 41. Solar thermal collector shipments by type.[167]

Type	2008			2009		
	Quantity (Thousand ft^2)	Revenue (Thousand $)	Average Price ($/ft^2)	Quantity (Thousand ft^2)	Revenue (Thousand $)	Average Price ($/ft^2)
Low-Temperature						
Liquid/Air	14,015	26,518	1.89	10,511	20,411	1.94
Medium-Temperature						
Air	28	P	P	22	P	P
Liquid						
ICS/Thermosiphon	321	6,631	20.66	147	4,830	32.80
Flat Plate	1,842	32,043	17.40	1,783	34,642	19.43
Evacuated Tube	351	9,009	25.69	328	8,481	25.88
Concentrator	19	P	P	27	P	P
High-Temperature						
Parabolic Dish/Trough	388	4,640	11.96	980	24,814	25.32
US Total						
	16,963	**81,348**	**4.80**	**13,798**	**96,708**	**7.01**

P Proprietary data

8.6.3 Solar Resources

The amount of solar radiation per day per location is crucial in determining the cost effectiveness of solar systems. The National Renewable Energy Laboratory has conducted a program to capture solar radiation statistics across the US and to update statistics regularly, which are available via the internet. Figure 81, Figure 82, and Figure 83 are annual solar radiation resource maps for tilted flat plate, direct normal concentrator, and two-axis concentrator collectors, respectively.

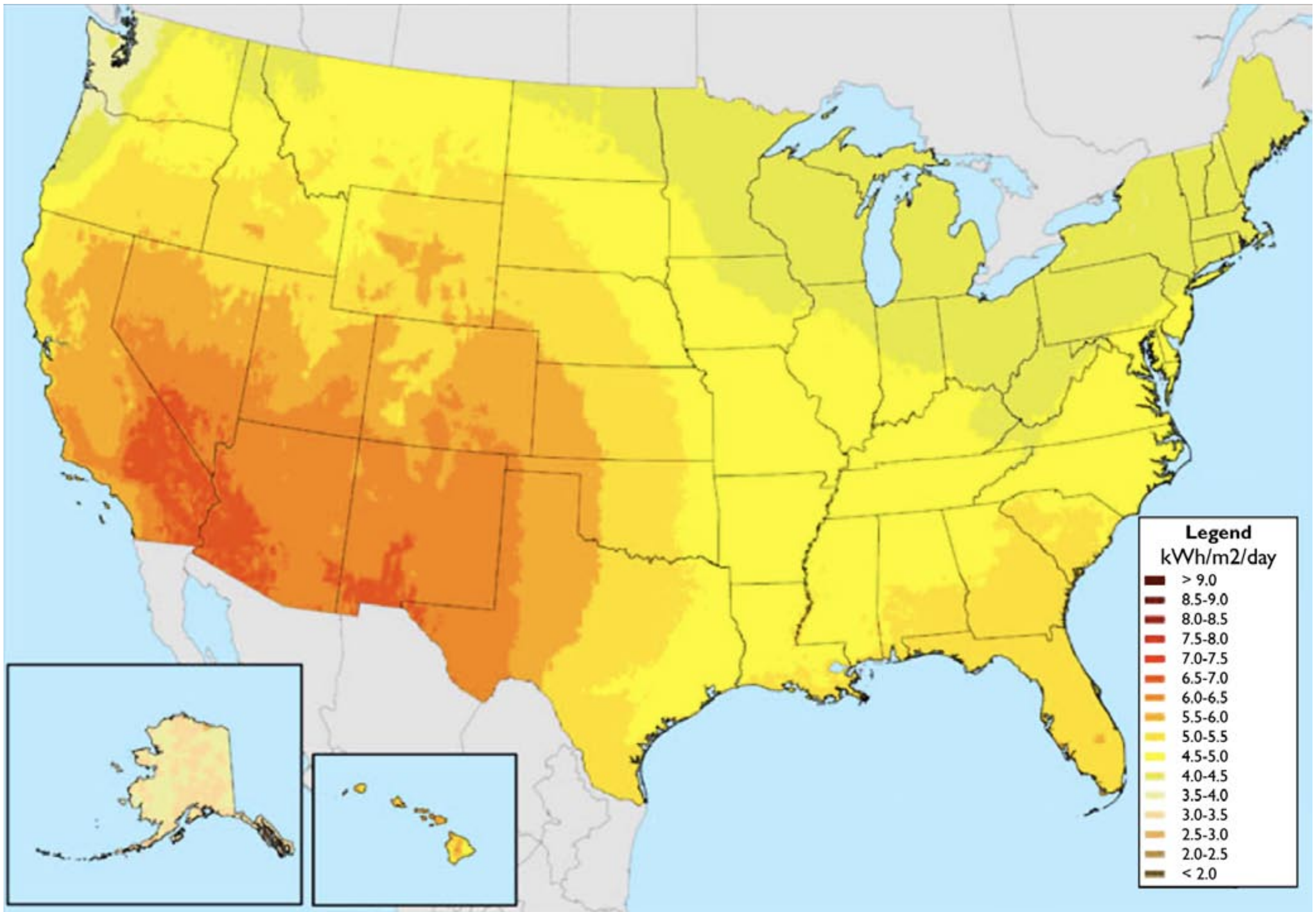


Figure 81. US photovoltaic flat-plate solar resource.[168]

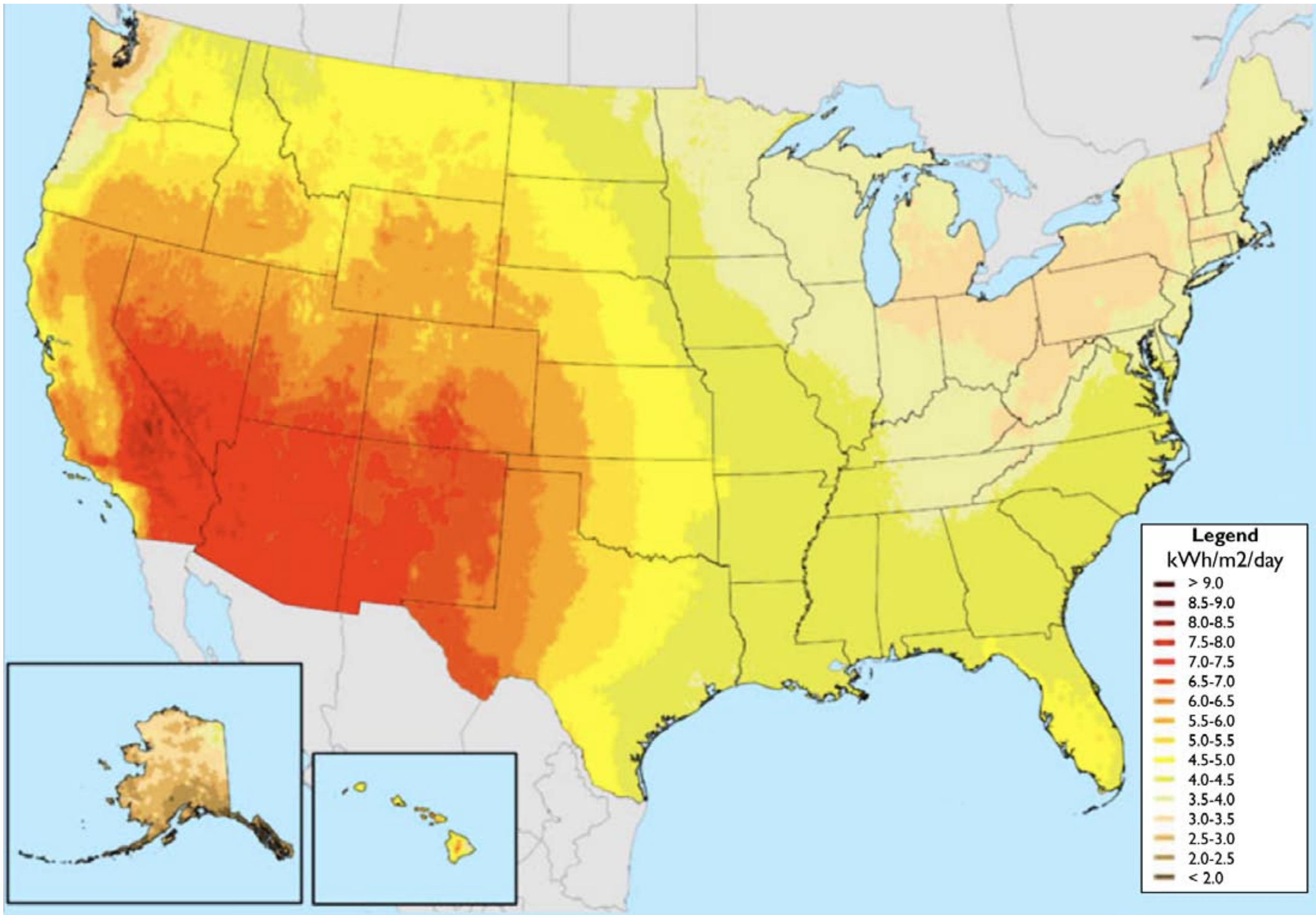


Figure 82. US concentrating solar resource.[168]

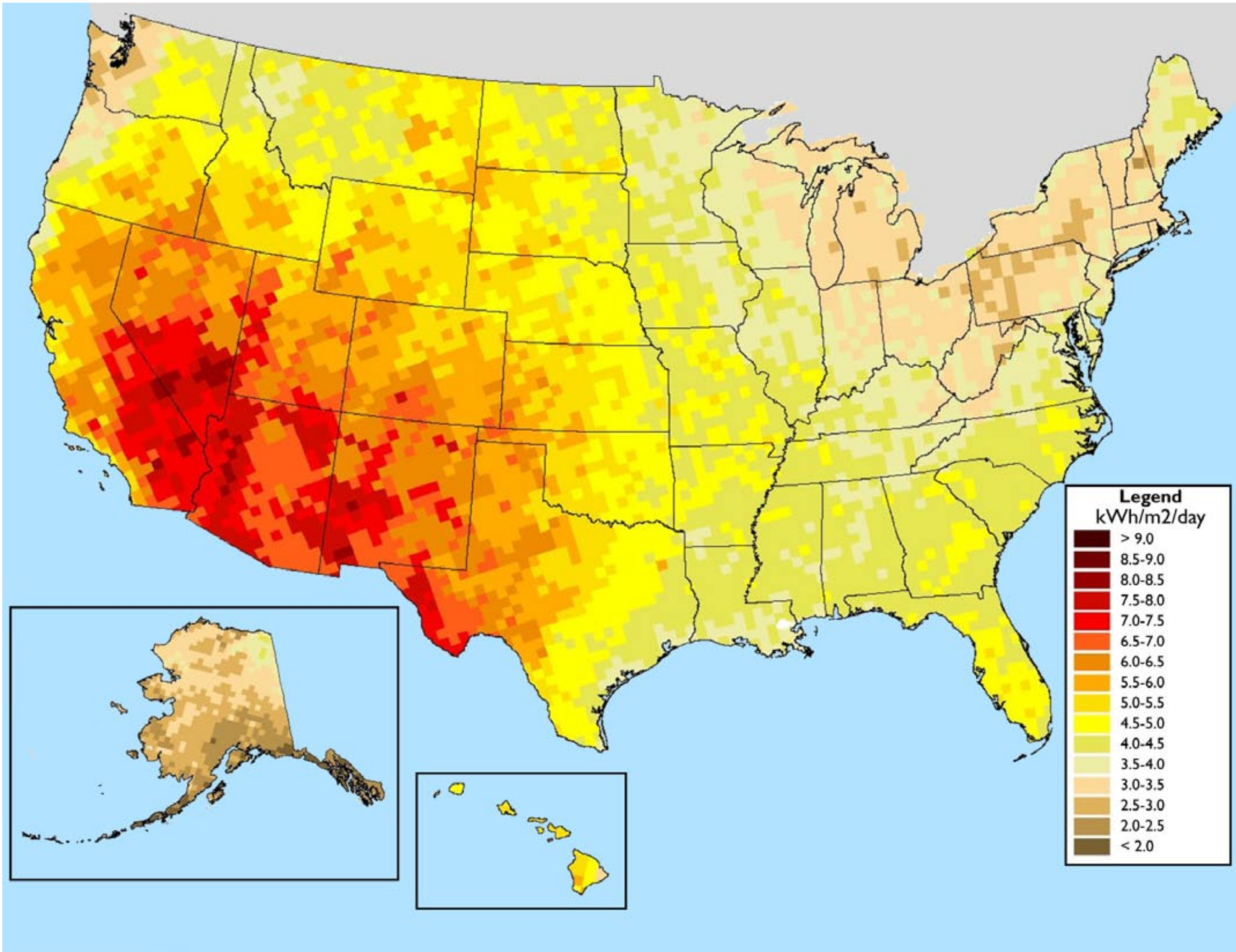


Figure 83 US two-axis concentrating solar resource.[168]

8.6.4 Land and Building Space

Land and building space is an important issue when considering renewable energy resources. Smaller systems take advantage of incorporating solar systems on rooftops and in conjunction with other functions, such as car ports and awnings, resulting in zero additional footprint. Large systems require land use, which will most likely compete with the use of those lands for other functions or preservation. One strategy has been to make use of land unsuitable for other purposes, such as former landfills. There have been a few studies conducted on the area needed to harness solar energy to power the entire US and the average power consumed per person in the US.

One study determined the percentage of power required in the US that could be supplied from rooftop systems.[145] The study assumed 22 percent available roof space from residential housing, and 65 percent roof space on commercial buildings. Using averages for electricity demand per person and solar panel efficiencies per area, it was determined that approximately 65 m^2 is required for solar systems to supply the energy consumed per person in the US. Thus, available rooftop space was calculated as capable of supplying 67 percent of the nation's electricity needs. This estimate is impractical however, since a number of considerations were excluded. All available space was assumed to be usable to produce solar power. In reality, not all existing buildings were constructed with roof areas suitable for solar energy capture nor in ideal locations, as shade from trees or other buildings will reduce usable space. Furthermore, space must be made available for maintenance procedures. Despite this under estimation, rooftop systems can provide a significant amount of solar power, limiting the impact of land use. Newly constructed buildings in which solar power will be used have the advantage of designing the building to optimize solar energy capture. Retrofit systems often encounter situations where the solar systems cannot be optimized, resulting in longer payback periods and a lower return on investment (ROI).

Another study involved an assessment of the various PV system designs and performance versus land impact. It was found that under current solar cell efficiencies, tracking systems actually delivered less power per land area due to increased area required to prevent self shading. Horizontal flat plate designs currently have the highest energy density as shown in Figure 84. Fixed tilt and tracking systems significantly increase the system's efficiency and power yield up to as much as a 50 percent improvement, but considerably more land is needed for these designs. A horizontal PV system requires approximately 100 m^2 to produce enough power for the average person's electricity needs in the US, while twice the area is required for a one axis tracking system to produce the same amount of electricity (see Figure 85).

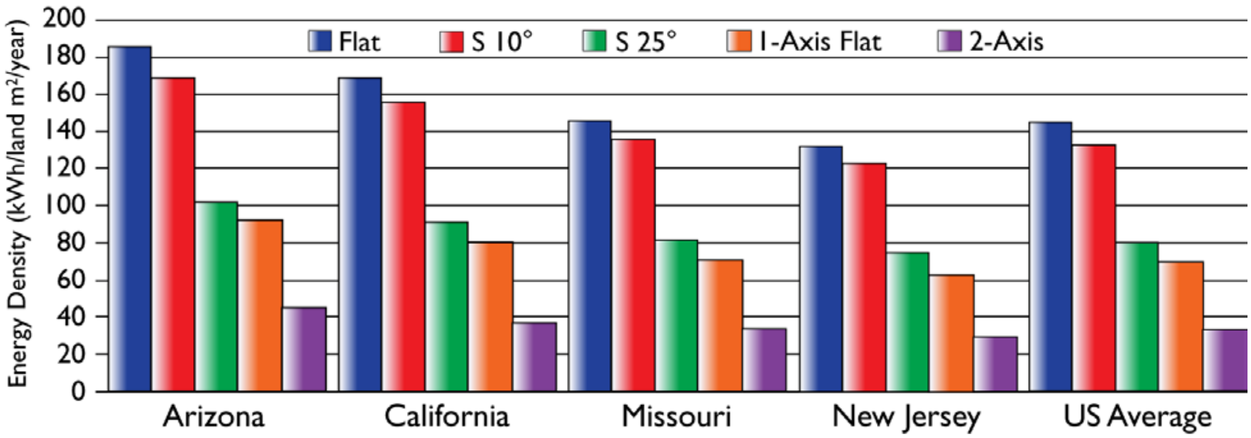


Figure 84. Energy density for different PV system designs.[145]

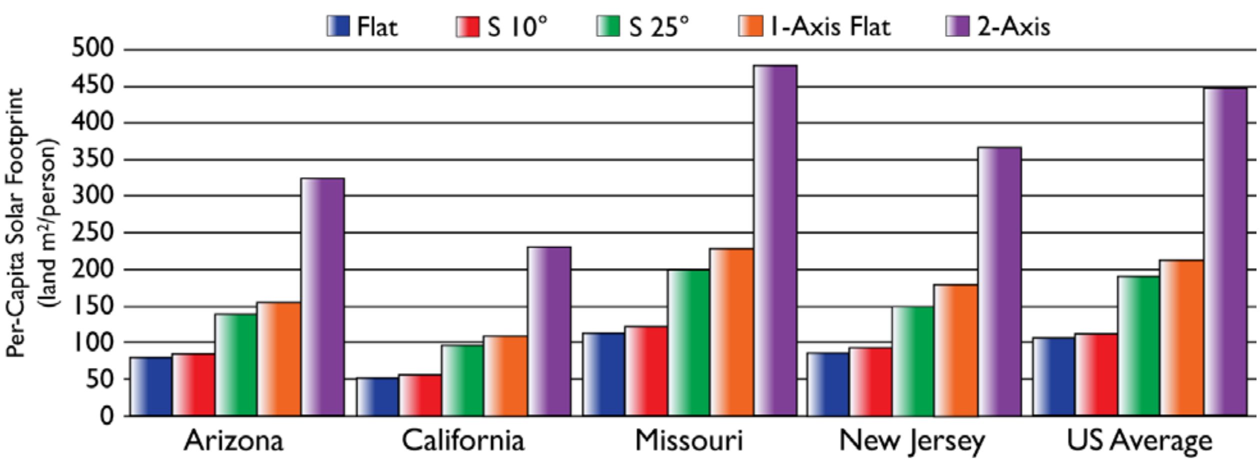


Figure 85. Solar footprint for different PV system designs.[145]

8.6.5 Software Programs

There have been many software programs (too many to be included in this context) developed to aid in designing solar systems and to perform life cycle costs analyses. These include tools for assessing thermal transfer through numerous media, daylighting, air flow, shading, climate analysis, HVAC systems, energy evaluation, and economics. A list of these programs and tools can be found on the NREL website (http://apps1.eere.energy.gov/buildings/tools_directory/about.cfm).

8.7 Solar Project Case Studies

There are numerous solar projects that have been implemented on DoD facilities and bases. They include rooftop designs, carports, and land-based systems. This section provides information on solar projects at two bases, Fort Carson and Nellis Air Force Base. Table 42 provides a listing of some of the solar PV and solar thermal systems on military bases. There are many more in development including a 500 MW system at Fort Irwin.

Table 42. Solar systems on military bases.

Location	Type	Size	Facility or Area	Annual Energy Output	Notes	Projected Annual Savings
Naval Base Coronado	Photovoltaic	750 kW	Carport (446 vehicles)	1.2 GWh	3% base energy - peak summer load	$228,000
Naval Base Coronado	Photovoltaic	30 kW	Roof (HQ Building)	50 MWh		$9,600
Naval Base Coronado	Photovoltaic	21.6 kW	Roof (Command Staff Building)	35 MWh		
Naval Base San Diego	Photovoltaic	14.4 kW	Roof (Medical Clinic)	26 MWh		
Naval Base Santa Cruz Island	Photovoltaic	150 kW	Land with battery backup (power for radar/communications)			
Naval Base Santa Cruz Island	Photovoltaic		Land (power for water pumping station)			
Naval Base Santa Cruz Island	Photovoltaic	30 kW	Portable with battery backup			
Naval Base San Clemente Island	Photovoltaic	80 kW	Land with battery backup (power for radar/communications)			
NAF El Centro	Photovoltaic	30.4 kW	Carport			
NAF El Centro	Photovoltaic	20 kW			Thin-film	
Naval Air Station North Island	Photovoltaic	160 w	Stand alone with battery (8 units)		Pier E - LED night lighting on pier	
Naval Base Point Loma	Photovoltaic	29.5 kW	Roof (Building 564)	48.9 MWh		
NAWS China Lake	Photovoltaic	192 kW	Carport			
Naval Base Ventura County	Photovoltaic	135 kW	Roof (Building 806)			
NWS Seal Beach	Photovoltaic	30 kW	Roof			

Location	Type	Size	Facility or Area	Annual Energy Output	Notes	Projected Annual Savings
Naval Base Ventura County	Photovoltaic	34 kW	Building 1000			
Naval Base Ventura County - Port Hueneme	Photovoltaic	15 kW	Addition to existing roof system (Building PH-850 31 kW)			
NAWS China Lake	Photovoltaic	71 kW				
Naval Support Activity Monterey	Photovoltaic	10 kW	Roof (Hermann Hall)			
Naval Base San Diego	Solar heating		Roof (Building 3279)	700 MWh	60% annual pool heating	$17,000
Naval Base Ventura County - Port Hueneme	Solar heating		Roof (Building PH-850)		Hot water and space heating	
Buckley AFB	Solar walls - UTC		Material Handling Facility		1 Building, 1 wall	
Buckley Annex (Army)	Solar walls - UTC		Aviation Hangar		1 Building, 2 walls	
Edwards AFB	Solar walls - UTC		Aircraft Support Facility		1 Building, 1 wall	
Elmendorf AFB	Solar walls - UTC		Warehouse Shop		1 Building, 2 walls	
Peterson AFB	Solar walls - UTC		Defueling Hangar		1 Building, 1 wall	
Fort Carson	Solar walls - UTC		Aviation and Vehicle Maintenance Facilities		2 Buildings, 3 walls	
Fort Drum	Solar walls - UTC		Various		27 Buildings, 50 walls	
Fort Huachuca	Solar walls - UTC		Aviation Hangars		2 bldgs - 2 walls	

Location	Type	Size	Facility or Area	Annual Energy Output	Notes	Projected Annual Savings
Fort Lewis	Solar walls - UTC		Maintenance Facility		1 Building, 1 wall	
Norfolk Naval Station	Solar walls - UTC		Maintenance Facility / Training Gymnasium		2 Buildings, 2 walls	
Fort Carson	Photovoltaic	2 MW	Land		2.5% of Ft. Carson's load = ~540 homes	
Nellis AFB	Photovoltaic	14.2 MW	Land (145 acres)		~ 25 % of base electricity	
Twentynine Palms	Photovoltaic	1.3 MW	Land (> 7 acres)	2.53 GWh	Tracking system, ~5% of base electricity	
Fort Sam Houston	Photovoltaic	180 kW	Roof (Building 1350)			$72,000
Fort Bliss	Solar heating		Aquatic center			
Fort Dix	Photovoltaic		Roof (99th Regional Support Command Headquarters)	310 MWh	~ 10% of base electricity	$160,000
McGuire AFB	Photovoltaic	14 kW	Roof (Library)		~ 7% of the total annual electricity	$10,000
McGuire AFB	Photovoltaic	75 kW	Roof (Medical Clinic)		~ 3% of the total annual electricity	$43,000

8.7.1 Fort Carson

Fort Carson has a 2 MW PV array that generates approximately 3.2 GWh of energy per year.[169] It is a ground mounted fixed tilt system covering approximately 12 acres of a former landfill (see Figure 86). The system became fully operational on January 9, 2008, and serves 2.5 percent of Fort Carson's load, or the equivalent of about 540 homes.

Figure 86. Fort Carson solar array.[170]

The solar array consists of 27,876 thin film CdTe modules. The manufacturer has a no cost recycling program to prevent cadmium contamination in landfills. The system produces 72.5 W per panel at SRC resulting in approximately ten percent efficiency. The system includes fuse boxes mounted on the back of structural cross members, which combine up to ten strings of six panels; combiner boxes mounted on the end of some rows, which combine up to 12 fuse boxes; and master combiner boxes mounted on inverter pads, which combine up to 10 combiner boxes (see Figure 87). There are four 500 kVA inverters and four 500 kVA transformers along with all support structures and distribution cables. The power output of the system is shown in Figure 88, for the estimated output versus 2008 and 2009.

Figure 87. Fort Carson solar array system components.[169]

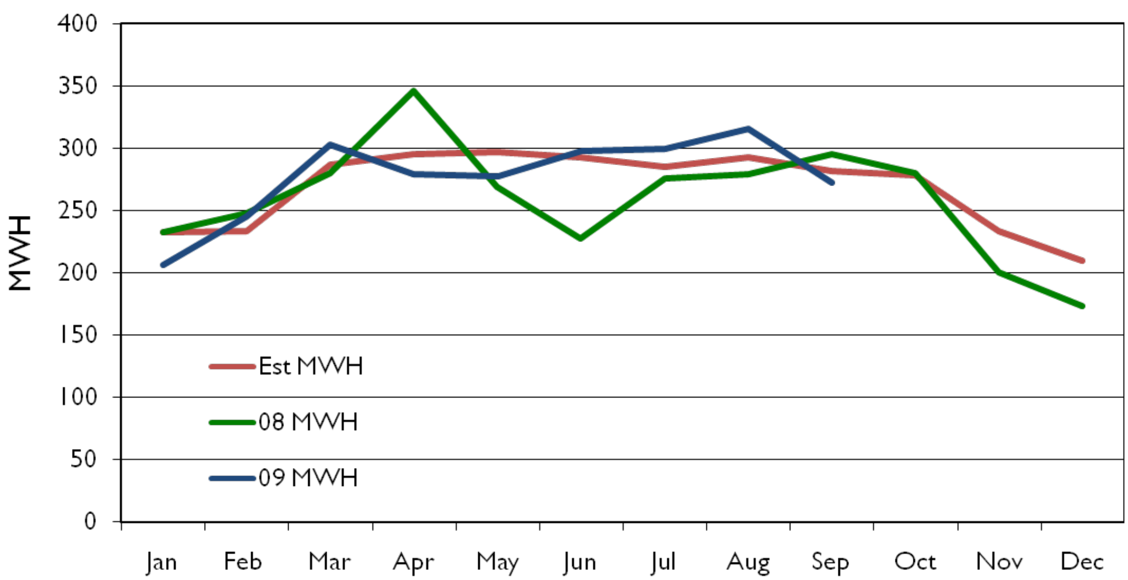


Figure 88. Fort Carson solar array power output.[169]

The majority of the project was built on a former landfill, and as such, special design, engineering, permit, O&M considerations had to be considered. Site preparations for the solar array involved cooperation of the local department of health and environment, public community, the Army Corps of Engineers, the Army Environmental Command, and contractors. The Army Environmental Command provided $645K in funding to prepare the site. A summary flowchart of the process is shown in Figure 89.

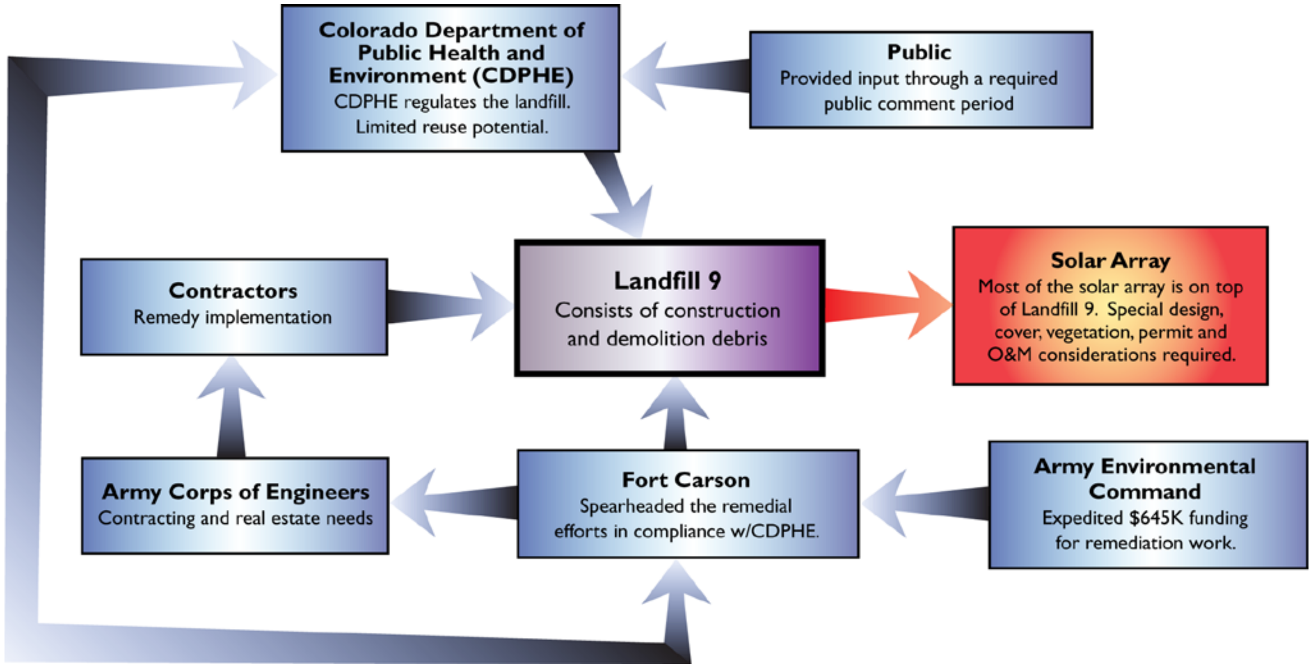


Figure 89. Site preparations for the Fort Carson solar system.[169]

The DoD provided a no lease agreement for the land with a local contractor, which owns and operates the solar PV system. The Colorado Springs Utility provided the interconnection of the system to the main power grid. The Western Area Power Administration (WAPA), a federal power marketing agent under the DOE, provided a power purchase contract with the supplier. The DoD purchases the electricity through a fixed price PPA. This model has the advantage that the DoD does not provide any initial funding and the local contractor that operates and maintains the system is eligible for tax incentives, for which the government is not eligible. The project took approximately 18 months from conception to completion with three months of that to construct the PV system.

Fort Carson also has additional solar projects on base. They have used a solar thermal system for more than 20 years for heating indoor pool water. They were also the first federal facility to install a transpired solar collector in 1997. A second transpired solar collector was installed in 2007 using the Energy Conservation Investment Program (see Figure 90). The solar thermal collection system warms outside air up to as much as 54°F. The estimated reduction of heating cost was $3 to $5 per year/ft^2 resulting in a projected yearly savings of $36K to $60K. A lesson learned from this project was that retrofit applications are not optimal. The solar collectors were placed on southern facing walls, but not entirely in an optimal position, and the layout of the system limited intake capabilities. The collectors are most effective with intakes every 50 feet on center (or 100 feet between intakes).

Figure 90. Fort Carson solar walls.[171]

8.7.2 Nellis Air Force Base

Nellis Air Force has a 14 MW PV array that generates approximately 30 GWh of energy per year, which provides one fourth of the total power needed for the 12,000 person base (see Figure 91).[172] The array consists of 72,416 solar panels on a two-axis tracking system, saves approximately $1,000,000 per year in electricity costs, and reduces carbon emissions by 24,000 tons. The Air Force established a twenty year fixed price PPA with MMA Renewable Ventures LLC. MMA operates and maintains the solar array and sells the renewable energy certificates (RECs) to the Nevada Power Authority (NPA) to meet its state requirements for renewable energy, specifically solar energy.

Figure 91. Solar array on Nellis Air Force Base.[141]

The state of Nevada instituted a more stringent requirement on power companies to produce a certain percentage of PV solar renewable energy compared to other renewables.[173] This has driven the price of PV solar RECs up to approximately three times that of the other renewable energies. Thus, buyers are willing to pay more for PV solar power to obtain the PV RECs. Nellis AFB had ample land available, including a 33 acre former landfill which is unusable for most applications. The combination of good solar resources, available land, and financial incentives led to the creation of the Nellis PV solar plant. The Air Force leased 140 acres, including the former landfill, to MMA for $10 over 20 years. USAF government property is managed by Air Force staff, and leasing agreements requires approval by the Secretary of the Air force or an authorized representative. SunPower Corp. built the array, costing approximately $100M and created a subsidiary, SolarStar Nellis AFB LLC. to operate and maintain the array, which was then sold to MMA. Nellis AFB buys the power from MMA at a 20 year fixed price, which is cheaper than buying power from NPA. MMA sells the RECs to NPA to meet its state requirements.

9 WIND ENERGY

Wind energy is the fastest growing renewable energy technology in both the US and the world. There are many reasons why the wind energy market has experienced such a large growth. Two significant factors include the vast development potential and unlimited domestic supply. State renewable portfolio standards (RPS), which were created out of concerns about the future pollution control costs and liabilities of coal and natural gas facilities, have also been a large driving force. Wind power is also among the most competitive forms of renewable energy technologies available today and costs $0.04 to $0.06 per kilowatt-hour. It offers one of the cleanest forms of energy production, with minimal environmental impact and no emissions to the atmosphere. It also has significant potential even for military sites (see Figure 92).

Figure 92. Four of six wind turbines in operation at Ascension Auxiliary Airfield.[174]

Wind power, however, is not versatile in where it can be located and a significant amount of planning is required to deploy this technology. It also cannot exist as a sole source of energy production since wind power output is variable and can only be captured when the wind blows. Using wind as a baseload energy source is not currently possible without a proven, cost effective method of mass energy storage. Energy produced from wind typically serves as a supplement to baseload energy production. Since wind is widely available domestically, it has the ability to help decrease the US dependence on foreign countries to fulfill energy needs. A shift toward producing energy from wind will help to reduce the environmental impacts generated by conventional energy production methods. By the end of 2009, wind power was approaching two percent of the total power production, and trends suggest that this number will continue to grow relatively rapidly. The Department of Energy reported that wind power could provide 20 percent of US electricity by 2030.[liv, 175] Several of the important advantages and disadvantages of wind power are presented in Table 43.

[liv] 20% Wind by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply http://www.20percentwind.org/20percent_wind_energy_report_revOct08.pdf

Table 43. Advantages and disadvantages of wind power.

Advantages	Disadvantages
• Lower cost than most many resources	• Output is intermittent
• Mature technology that is continuing to improve	• Forecasting generation schedules a challenge
• Lower financial risk than other renewable	• Not baseload production
• Large development potential	• Visually disruptive
• No emissions	• Transmission costly when not readily available
• Small land footprint	• Long term reliability is a challenge
• Low costs	• Transportation and installation difficult due to size
• Requires no water resources to operate	

The major challenge of implementing wind power is that wind is intermittent, and thus it must be used in conjunction with other power resources. Without energy storage it is only a method of reducing the use of conventional fossil fuels. Wind energy cannot be stored economically and not all locations have adequate wind to meet particular demands. This section discusses the current technology of wind energy production, as well as the requirements and considerations for siting a wind farm. It will also provide an economic analysis of wind farm development.

9.1 History

Wind energy is one of the oldest forms of energy to be harnessed by mankind, and the use of wind power has taken on many different forms over the course of time. Prior to generating electricity, wind farms were used for activities such as grinding grains, cutting lumber, and pumping or gathering water from its source. A brief, progressive history of wind power generation follows:

- As early as 5000 B.C. wind energy propelled boats along the Nile River.
- Wind mills were built in Persia as early as 200 B.C.
- 14th century, Dutch windmills were in use to drain areas of the Rhine River delta.
- The first windmill for electricity production in the United States was built in Cleveland, Ohio by Charles F. Brush in 1888.
- In the fall of 1941, the first megawatt-class wind turbine was synchronized to a utility grid in Vermont. The Smith-Putnam wind turbine ran for 1,100 hours.
- The first utility grid-connected wind turbine operated in the UK was built by John Brown & Company in 1954 in the Orkney Islands. It had an 18 meter diameter, three-blade rotor with a rated output of 100 kW.

A graphical representation of the evolution of the US wind industry is presented in Figure 93.

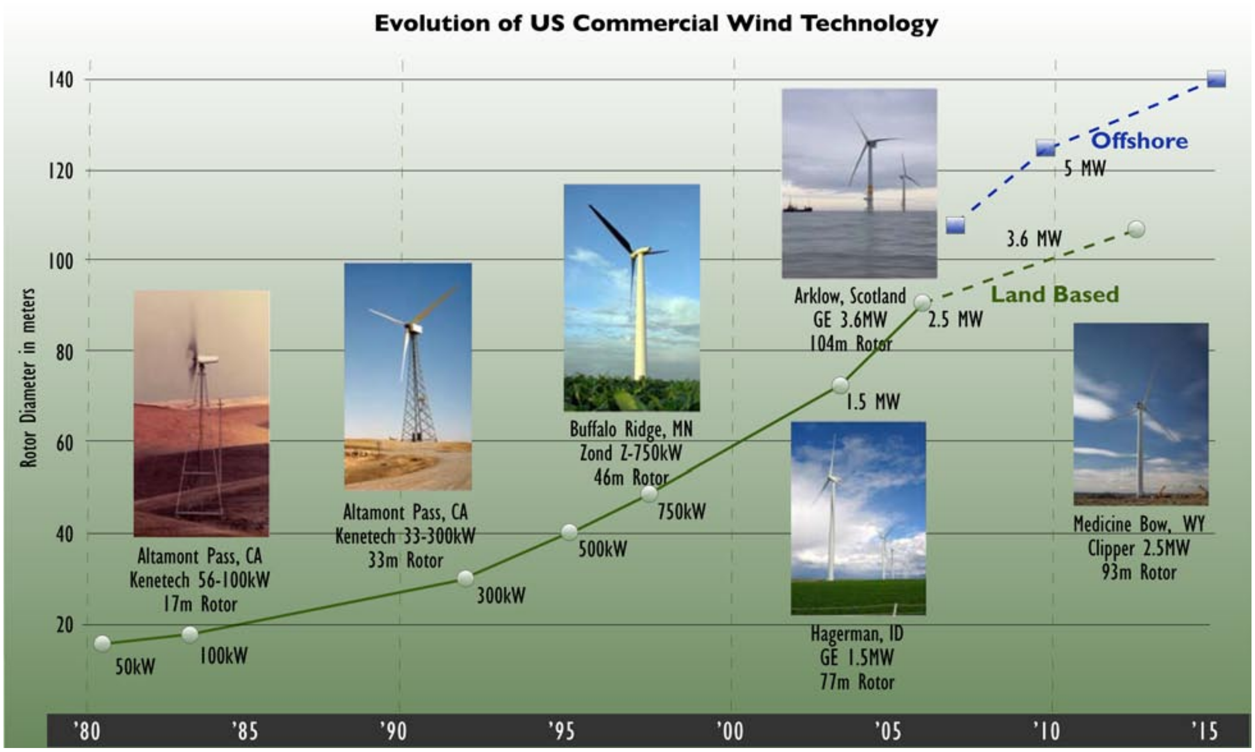


Figure 93. The evolution of wind turbines dimensions.[176]

Wind is plentiful throughout the world, yet the challenge still exists to figure out new ways for this age old energy source to be useful and more competitive in modern civilization. In the current era, wind power technology has adapted and survived in a competitive energy market. The methods used today to harness wind for large scale production are relatively new, although have been proven to be a viable source of energy with competitive life cycle costs. Given modern technology and infrastructure, most wind turbines now operate to run generators, which feed electricity to an electric battery for small scale or remote systems, or directly into a grid for large scale production.

The fluctuation in the price of fossil fuels has generally been the sole factor for creating interest for wind power. However, a more forward-thinking, long-term approach to power production and security is beginning to emerge. This approach considers long-term effects of pollution and destruction of natural resources. Mandates set forth by state and federal authorities are now requiring a percentage of power to be produced from renewable sources. Deadlines for compliance are providing a secondary, but important driver for the wind industry. Energy security is also a factor, which drives the decrease in dependency on foreign resources and design of smart grids.

9.2 Modern Advancements

Wind energy production has become both feasible and economical through new engineering materials and processes. Modern advancements in science have led to increased efficiency and reliability for wind turbines. Through improved reliability and new technological advancements, wind energy has been building momentum as a viable form of clean energy. Researchers have been able to refine wind turbine designs to determine best practices, which enable designers to maximize both efficiency and reliability. Using wind farms to help power the grid, however, is a relatively new technology and there exists room for further advancements using new materials, principles of mechanics, and improved weather forecasting and sensing. Existing facilities are now providing clean, renewable, and cost effective power to energy grids, as well as valuable data for continuing research on future technology improvements.

Future generations will continue to improve upon efficiency with an even greater return on investment. Many manufacturers and developers in the wind industry have set and adopted a 20 year life cycle design goal on wind power production equipment. Some indicate that this goal can be met with current equipment, yet real time operations and maintenance data for certain critical components indicate that more improvements are required to meet this goal.

9.2.1 Engineering Materials

A greater understanding of facture mechanics and fatigue stresses has allowed wind turbine technology to become far more reliable. Many early design attempts suffered from very short run times before fatigue stresses ultimately led to catastrophic failures. Because of these early failures, wind generated electricity was not considered as being economically competitive or reliable enough for large scale development. As a result of research of catastrophic failures in the aerospace industry, the understanding of fatigue and cyclic failures has become far more advanced. This understanding has been transitioned to modern turbines, which are now being built to have much longer operational lives than early attempts at utility scale wind production. This has led to wind energy being validated as a viable way to produce electricity for utilities.

Along with the understanding of how materials behave, new materials with novel properties are constantly being developed which greatly enhance the ability to harness wind energy. Early attempts failed because engineering materials in the past could not provide the required properties needed to accomplish an efficient design. Today advanced composite manufacturing and engineering is required to produce solid, one-piece turbine blades. Fiber composites and aluminum alloys have become the most popular materials used for structural components because they possess excellent strength-to-weight ratios and high stiffness.

9.2.2 Weather Forecasting

The predictability of wind plant output remains low for short-term (hourly or daily) operation even with modern forecasting capabilities. With wind power being used to supplement power utilities they must be able to integrate with the current electrical grids and cooperate with existing power sources. Supply and demand is a major issue since the supply of wind energy is intermittent making the remaining energy needed difficult to manage. Power utilities have to manage their portfolio of power sources and certain facilities, such as nuclear or fossil fuels, need advanced notice to operate an optimally efficient electrical grid. Rather than operating below the demand, often more power is produced than is needed which results in waste without having the current ability for large capacity storage of wind energy. More accurate forecasting allows for energy managers to produce power at greater efficiency and allows for wind energy to be more effectively utilized.

Location of a wind farm is important when determining how accurate the available weather forecast is. In the US Midwest, some of the most advanced weather forecasting is conducted to provide residents with timely tornado warnings. The weather forecasting in these areas, demands a staff of knowledgeable forecasters, and state-of-the-art technology in weather forecasting. This same level of weather prediction might not necessarily be available in all areas of the country. Project planners must consider this variability. Wind sensors provide information for both wind turbine operation as well as the complementary energy production. Although more advanced notice in wind changes can help to manage the secondary energy production more efficiently.

9.2.3 Blade Design

New blade designs have greatly increased wind turbine performance throughout history. In the 1980's improved blade designs led to a 30 percent increase in efficiency.[177] In recent years there has been more progress not only with lighter and stronger materials, but also with new and improved mechanical design concepts. Collaboration between government agencies, such as NASA and the DOE, with industry has allowed for new designs to be researched and tested in state-of-the-art wind facilities. NREL has testing facilities that are accredited by the American Association of Laboratory Accreditation (A2LA). The suite of tests conducted on both small and large turbines includes acoustic noise emissions, duration, power performance, power quality, safety and function. These tests are performed according to appropriate standards.[lv] For instance, a rear spoiler concept is being tested to reduce peak stresses on the blade and increase long term reliability. Although a spoiler design might rob a turbine blade of efficiency as it adds drag and weight, it might have a greater payoff by extending the life of the turbine components.

To increase overall efficiency, the trend is toward building larger and taller turbines. Modern blades can span more than 120 m in length. It has been determined that it is more cost effective to build fewer large turbines, than to build a greater number of smaller turbines when constructing a wind farm. There is a savings per kWh of electricity, which results from a combination of reduced installation and equipment costs and increased power output from taller, higher efficiency turbines. Assembly and manufacture play a big role in overall product costs. Equipment generally becomes cheaper per kWh as size increases, since assembly and manufacturing costs increase only slightly, and thus the primary additional costs are for the extra materials.

Blades are typically made from aluminum and composite materials. Large scale structural composite fabrication is a relatively new achievement for industry. The limited number of applications for these enormous composite structures makes this a relatively niche industry with a requirement for a very large dedicated manufacturing floor space. While the industry continues to grow to meet the demands of a rapid global growth, initially there were very few producers of these state-of-the-art turbine blades. Lightweight materials have reduced the mass and thus the force required to spin the blade. This allows for an increased efficiency since wind turbines can generate more electricity from short gusts by operating at optimal tip speed ratios for longer durations.

9.2.4 Computer Modeling and Simulation

Modeling and simulation is a valuable tool for planners and designers of wind power projects because validation testing of new designs or layouts requires a large capital investment. Modeling provides a way to test a new design or layout at a reduced cost and often in a short amount of time. Modeling is used for several aspects of wind farm design from weather forecasting, to the design of new mechanical components and drive train concepts.

Although physical models are sometimes necessary, computer modeling and simulation can help engineers and planners increase overall wind farm efficiency. Developers can test new system designs by simulating each component to predict the efficiency of a new design, which enables the evaluation of multiple layout configurations based upon location and component selection. It is a way to conduct multiple tests over a range of scenarios, which is much less expensive than physical testing. When validation tests are required, modeling and simulation can be used prior to testing to ensure that such validation tests yield more relevant information and data. The use of models may be able to completely eliminate the need for expensive prototypes and thereby reduces developmental costs.

9.3 Scenic Impact

Wind farms generally have a high public acceptance despite their significant scenic impact. According to a 2010 survey 89 percent of Americans strongly agree that increasing the amount of energy America gets from wind is a good idea.[178] Since wind farms can often be seen from a significant distance, there are many who object to the visual disruption caused to the landscape. However, through public surveys,

[lv] National Renewable Energy Laboratory - Wind Research - Accredited Testing. http://www.nrel.gov/wind/accredited_testing.html

developers have found that a majority of people rank energy independence and air quality as more important to the quality of life than the disruption of scenery. The state of Wyoming is becoming substantially vested in wind power production. It has conducted research regarding wind development and how it affects the residents.[179] Valuable information and data has resulted from these studies which suggest that compromises can help minimize negative societal impacts. For instance, in scenic landscapes, turbines can be positioned, such that they are less visually obvious. One method is to position an array of turbines atop a ridgeline with mountains as the backdrop. Future wind farm planning can use this research to develop more appeasable siting of turbines, which results in a broader public acceptance. Deep sea, offshore wind farms are another solution for minimizing the effect wind power has on existing landscape. In some instances, offshore floating winds farms can eliminate scenic impact altogether.

9.4 Environmental Concerns

There are drawbacks to nearly every energy source. Wind turbines can have negative impacts on ornithology. Bird and bat strikes can create a threat to bird populations in proximity to wind farms or when located in migratory paths. In comparison, however, pollution from fossil fuels is the number one culprit of bird deaths. Thus, as an alternative to fossil fuel, wind farms are a good option for wildlife conservation. Several manmade objects contribute more bird fatalities each year than wind turbines, as shown in Figure 94.[180]

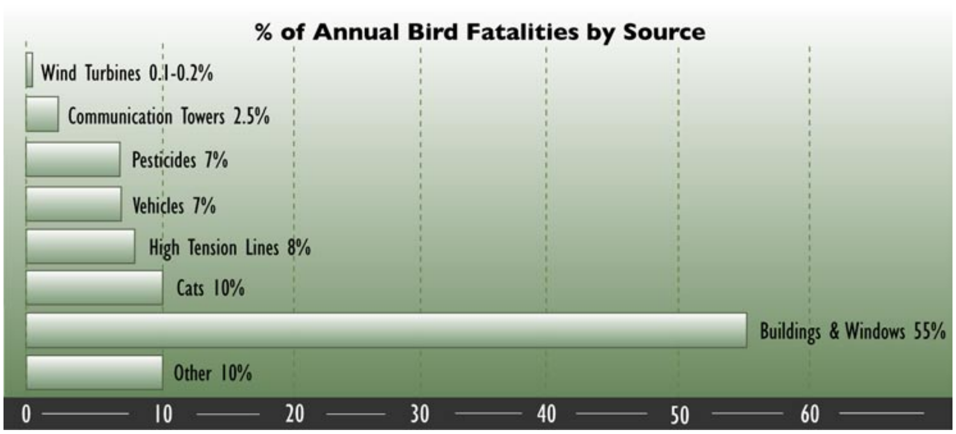


Figure 94. An estimated percentage of bird fatalities from respective sources each year.[180]

Many migratory birds are quite good at detecting and avoiding wind turbines, however the ability to avoid manmade structures appears vary with specie. Still as development continues, the increased threat to bird populations also rises. The extent of the threat is under debate. Remote islands may have to be more sensitive to this issue since they often harbor endangered or rare species. Risk to bird populations could create a reason why potential wind farm sites might fail to meet environmental qualifications.

The US Fish and Wildlife Service offers the Environmental Conservation Online System which is designed to aid wind farm siting activities.[lvi] In April, 2010, the Wind Turbine Advisory Guidelines Committee sent recommendations through the US Fish and Wildlife Service to the Secretary of the Interior on how to handle wildlife around wind farm developments.[181] The committee recommended the following 5 tier approach:

[lvi] Environmental Conservation Online System (ECOS) http://ecos.fws.gov/ecos/indexPublic.do

- **Tier 1:** Preliminary evaluation or screening of sites
  - Landscape-level screening of possible project sites
- **Tier 2:** Site characterization
  - Broad characterization of one or more potential project sites
- **Tier 3:** Field studies to document site wildlife conditions and predict project impacts
  - Site-specific assessments at the proposed project site
- **Tier 4:** Post-construction fatality studies
  - To evaluate direct fatality impacts
- **Tier 5:** Other post-construction studies
  - To evaluate direct and indirect effects of adverse habitat impacts, and assess how they may be addressed

In addition to reducing emissions, wind energy reduces the need for water in energy production which is a significant environmental benefit. Many competing technologies use large amounts of water, mainly in cooling operations. Having no requirement for adequate water supply, wind energy can provide a generation source in areas where water in scarce.

While generating power from wind energy using turbines is completely clean in terms of chemical pollution and air emissions, it does contribute to noise pollution. However, in most cases turbines are placed at a sufficient distance from any inhabitants of the area, the noise is minimal. The contribution of noise and the dependence on distance from the source is presented in Figure 95.

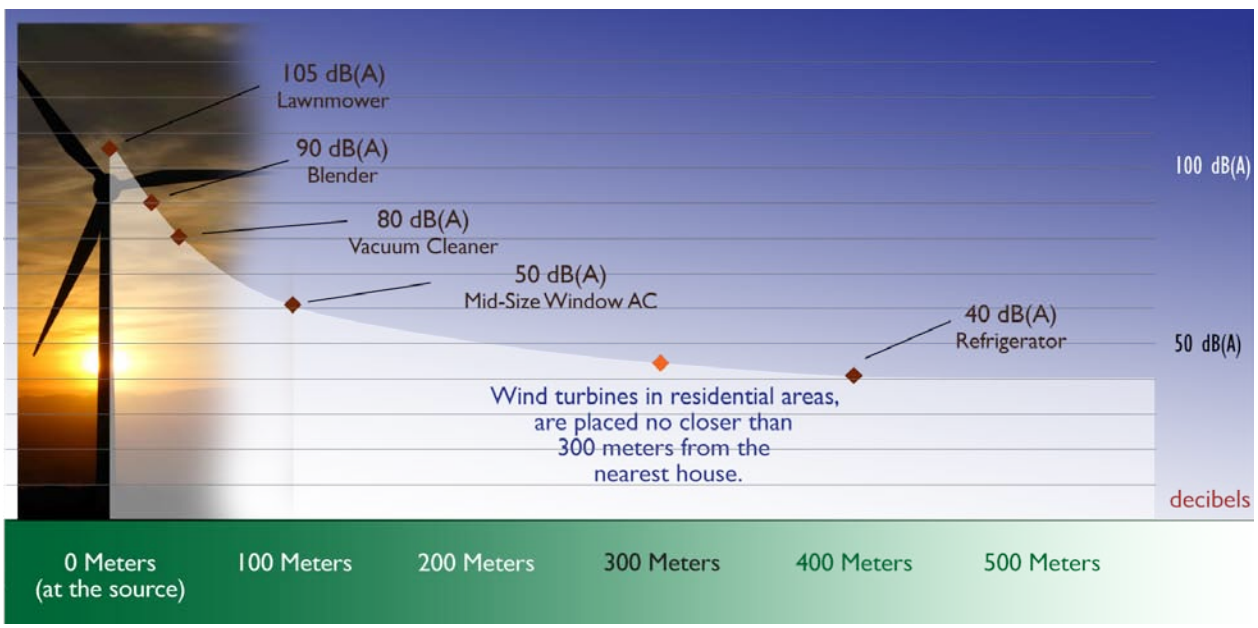


Figure 95. Noise contribution of wind turbines at various distances.[182]

9.5 Wind Turbines and Turbine Technology

Two main turbine designs are recognized by the industry and are categorized based upon the orientation of their rotational axis: vertical and horizontal. Horizontal axis turbines are considered the most efficient design and therefore are at the forefront of all commercial wind power developments. It is worth noting that vertical axis turbines do maintain several key advantages over horizontal designs. While development of vertical axis turbines is mostly limited to smaller residential class turbines, research on new designs is ongoing.

Design philosophies for wind turbines are in continual debate as advances in technology are made. A few notable topics include vertical versus horizontal, upwind versus downwind facing, tube versus lattice towers, onshore versus offshore, and number of blades. While many of these design facets may be able to coexist, some have clear advantages and others remain just one key breakthrough short from becoming the accepted norm.

9.5.1 Large Wind Turbines

Turbines are available in a wide variety of sizes. Large wind turbines are considered to be those used for utility scale production and are classified as turbines which produce greater than 80 kW of power. Figure 96 illustrates the progression of large wind turbines.

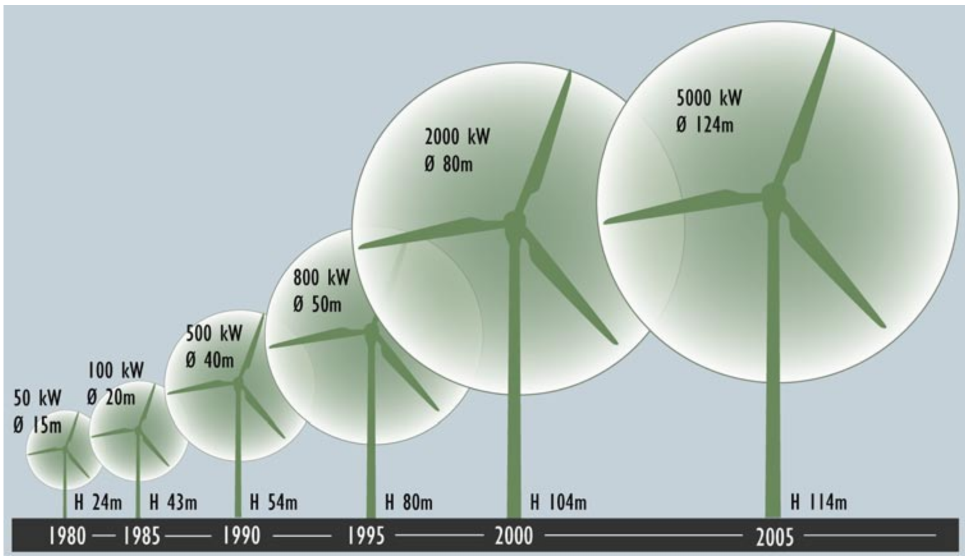


Figure 96. Large wind turbine height and capacity progression.[183]

9.5.2 Small Wind Turbines

Residential scale turbines are available in the energy market, however, they are not typically considered for large scale production as efficiency suffers at smaller turbine sizes. The federal regulations (specifically, the Public Utility Regulatory Policies Act of 1978, or PURPA) require utilities to connect with and purchase power from small (less than 80 kW) wind energy systems.[184] Additional benefits vary by state. Many states offer net metering on wind turbines. Net metering allows electricity meters to run in both directions, or in effect, the power utility must purchase excess electricity back from the end user at the same price it offers electricity. Many small wind systems serve as a distributed generation power source for remote locations. Capital required to install a DG wind system can be far less than the capital required to run transmission lines to an existing grid. In addition to fiscal sensibility, DG wind turbines can provide an affordable second option when right of way for transmissions lines cannot be obtained.

9.5.3 Vertical Axis Wind Turbines

The vertical axis wind turbine (VAWT) design offers one key advantage: it can operate unbiased to wind direction. This provides up front capital savings to the opposing designs as it eliminates the necessity to have additional mechanisms for tracking wind direction and keeping the turbine in yaw (facing the optimal direction). Another similar advantage of this orientation is that mechanical components and generators can be located on the ground. This reduces the bulk and structural strength needed for the tower since it does not have to support the turbine components at the top. Some of the main advantages and disadvantages are presented in Table 44.

Table 44. Advantages and disadvantages of vertical axis orientation.

Advantages	Disadvantages
• Operates unbiased to wind direction	• Difficult to mount blades on tall shaft (limits height)
• Gearbox can be located on the ground	• Low wind speeds close to ground level
• Operates well with upward sloping wind direction	• Guy wires needed to stabilize create large footprint
• Blade design less susceptible to turbulence	• Bearing replacement requires more maintenance
	• Cannot generally self start
	• Overall efficiency is poor

Early vertical axis designs were subject to high pulsating torques. This was especially so with designs such Savonius, Darrieus, giromill and cycloturbine. Designs with helical twists in the blades have been able to solve this issue surrounding the large fluctuations of torque. Turbines with helical blades are generally designed with three blades having a 60° twist. They perform well with upward slanting airflow. This makes them ideal for rooftops or mountaintops. Figure 97 shows how a lift based Darrieus wind turbine works.

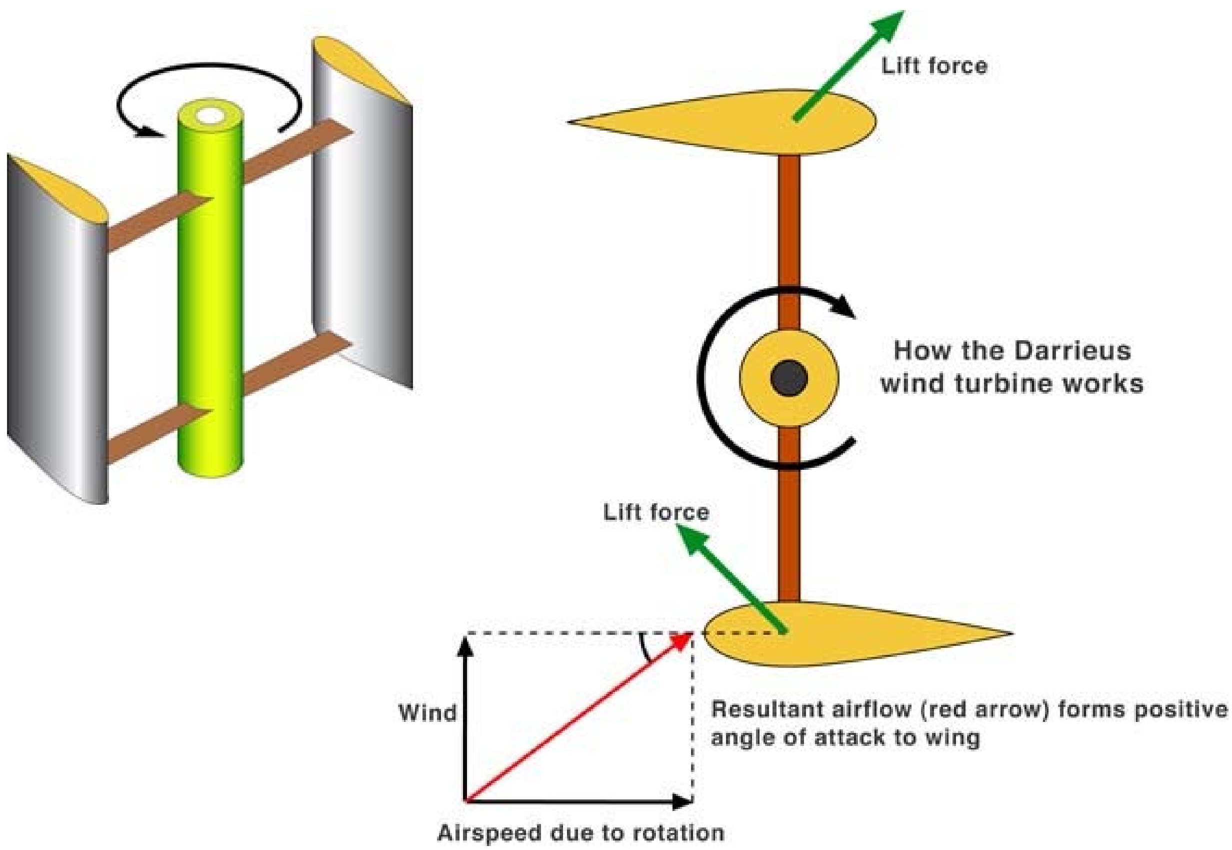


Figure 97. Basic mechanics of a Darrieus wind turbine.

There are many different blade styles found on VAWTs. The two main types of turbines are drag and lift. A common drag design is the Savonius design. Its blades form an S shape when viewed from above.

A Savonius turbine typically operates a low rotational speed. While it is good for milling grain or performing direct mechanical power, it is not ideal for generating electricity.

VAWTs do lack in efficiency when compared to horizontal axis turbines as a result of many factors. Installation cost is also a major issue for vertical axis turbines. Mounting the blade on the tower requires very large cranes. Due to the challenges associated with mounting a vertical axis turbine on tall towers, they are limited to lower heights. As a consequence, VAWT's are not able to gain the same advantages that taller heights offer such as, greater wind speeds with less turbulence. Additionally, VAWT turbine bearings, as in almost any wind turbine, are subject to large amounts of stress and potentially failure. Replacing a bearing is a very large cost with VAWT designs since the turbine blade must be completely removed in order. This procedure is costly since it involves removing the blade with a large crane and causes lengthy downtimes.

An advantage of the vertical axis orientation is that it may be designed to be very space efficient. All turbines leave a wake of slower moving air in their downwind path which disrupts the efficiency and creates turbulence for surrounding turbines. To mitigate this, they must be spaced at an appropriate distance apart. In comparison to horizontal axis designs, vertical axis designs can be located closer together since they do not slow down the air as much.

Certain smaller vertical axis designs can be considered for remote systems, or even mobile systems, as their more compact design translates into easier transportation and installation. Except for small residential sized turbines, large scale Darrieus turbines ceased to be built after the late 1990's.

9.5.4 Horizontal Axis Wind Turbines

The face of a horizontal axis wind turbine (HAWT) blade is struck by the wind at a consistent angle regardless of the position in its rotation. The result is a consistent lateral wind loading over the course of a rotation, reducing vibration and audible noise coupled to the tower or mount. This design has proven more cost effective and reliable. For this reason HAWTs dominate large-scale wind power production. HAWTs commonly face upwind, and the upwind facing design is accepted as the most reliable design. Although a downwind design can allow for a turbine to position itself in the direction of the wind without a need for a yaw control device, downwind variants suffer from fatigue and structural failure as a result of the turbulence generated when a blade passes through the tower's wind shadow. Some downwind designs have attempted to correct for and mitigate the effects of the wind shadow. Some of the advantages and disadvantages of HAWTs are presented in Table 45.

Table 45. Advantages and disadvantages of horizontal axis turbines compared to vertical axis turbines.

Advantages	Disadvantages
• Can access higher wind speeds (taller designs)	• Requires a yaw mechanism to face toward wind
• Superior overall efficiency	• Must support an elevated generator and gearbox
• Fewer costly maintenance procedures	• Larger components difficult to transport
• Higher reliability	
• Small land footprint	
• Easier to install blades	
• Variable blade pitch allows optimal angle of attack	
• Exposed to less turbulence at greater heights	

Standard HAWT components can be divided into 4 basic subsystems:

1) Rotor and hub
2) Drivetrain
3) Tower and foundation
4) Controls and electrical equipment

Many of the components are illustrated in Figure 98.

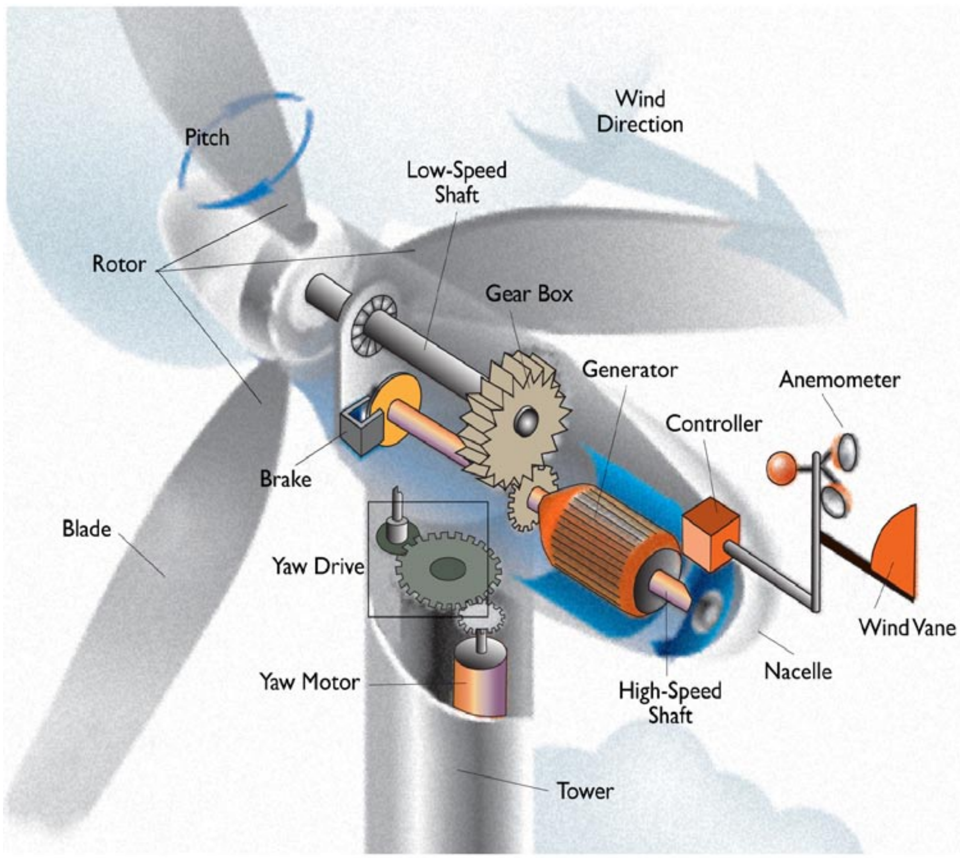


Figure 98. Common components of a horizontal axis wind turbine.[185]

9.5.4.1 Rotor, Hub, and Blades

Rotors with two or three blades are most common. Three blades are generally favored because they produce the lower cyclical stresses and are the accepted standard for efficiency and reliability. A two-blade design does feature many notable advantages over a three-blade design, such as easier installation and cheaper material costs.

9.5.4.1.1 Pitch mechanism

The pitch mechanism is located within the hub to control the angle of attack of the turbine blades. A variable blade pitch allows the turbine blade angle of attack to be adjusted in order to collect the maximum amount of wind energy for the time of day and the season. This is typically done remotely.

9.5.4.2 Drive Train

There are several different drive train designs which include planetary, direct drive, and hybrid. Drive trains are made of up several individual components which vary depending on design, but generally include: gear box, generator, shafts, nacelle, and brakes. These are described briefly in the following sections.

9.5.4.2.1 Nacelle

The nacelle sits on top of the tower and contains components such as the gearbox, generator, shafts, brakes, and controller. Its primary function is to protect components from the environment but it also adds to the aesthetic appearance of a turbine.

9.5.4.2.2 Gear Box

A gear box is used to connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to approximately 1000 to 1800 rpm. Most generators require the higher rotational speed to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring direct-drive generators, which do not require gearboxes and are capable of operating at lower rotational speeds.

9.5.4.2.3 Generator

The generator is typically an off-the-shelf induction design that produces 60-cycle AC electricity. Newer direct drive designs are not found commercially and instead are being designed specifically for wind turbine applications.

9.5.4.2.4 Shafts

In general, two shafts are required. A low-speed-shaft is turned by the rotor and a high-speed-shaft powers the generator. Direct drive systems are able to use only one.

9.5.4.2.5 Brakes

Brakes can be applied to the rotor during emergencies. They typically are in the form of a mechanical, hydraulic, or electronically controlled disc break.

9.5.4.3 Tower, Foundation, and Controls

Other important components include the tower, foundation, and various controls, such as yaw control, anemometer, and wind vane. These are discussed briefly in the following sections. Various types of electrical equipment are also needed to transmit electricity to the ground and eventually to the grid.

9.5.4.3.1 Tower and Foundation

The tower supports and suspends the nacelle and turbine components off the ground. They can be made from tubular steel, concrete, or steel lattice. The height of the tower has a direct impact on wind power capacity. The foundation supports the tower and is a major installation cost.

9.5.4.3.2 Anemometer

An anemometer is a device used to measure wind speed. It transmits wind speed data to the controller.

9.5.4.3.3 Controller

A controller starts and stops the turbine at set wind speeds. It starts the turbine when the wind is 8 to 16 mph and stops the turbine at speeds greater than 55 mph to protect it from damaging high winds.

9.5.4.3.4 Wind Vane

The wind vane determines the direction of the wind and communicates this information to the yaw drive for proper rotor orientation. Wind farms are also beginning to incorporate upwind sensors to communicate wind speed and direction information for faster yaw response times.

9.5.4.3.5 Yaw Control

The yaw control consists of a yaw drive and a yaw motor and is used to keep an upwind turbine facing into the wind. Downwind turbines do not require a yaw control because the wind automatically aligns the nacelle with the direction of the wind. The blade is dragging behind the pivot point of the nacelle on the tower, which acts to align the turbine (e.g., instead of being in front of the pivot point).

9.5.5 Emerging Designs

There are many forms of new equipment that are being used and implemented in an effort to increase efficiency. New designs that have a rotorless hub are also beginning to emerge. Wind speed and direction sensors and devices are being installed upwind of wind farms in order to predict changes in wind direction and coordinate that information to the yaw control of the wind turbines to improve reaction time and increase efficiency. Other systems are being researched and considered, such as the use of a pump to transfer kinetic energy to a ground generator. The advantages of this design are to reduce the weight in the nacelle thereby reducing the size and cost of the structural support as well as reduce operations and maintenance costs. Moving power equipment to the ground is safer and more efficient for maintenance operations. However, commercial-off-the-shelf components are not suitable or ideal for this application, and therefore further research and development is needed, which will require investment of time and capital. Proving a valid cost efficient model is difficult when so many components are custom built and not available commercial-off-the-shelf.

9.5.5.1 Direct Drive Power Trains

Direct drive power trains differ from conventional power trains (see Figure 99) in that they implement a generator capable of producing power at a much lower rotational speed. They do not require gearing and an additional shaft. In order to accomplish this, the generator must be larger in diameter. The design typically requires an advanced fluid cooling system as well as the use of permanent magnets, both of which make the generator more expensive and heavy.

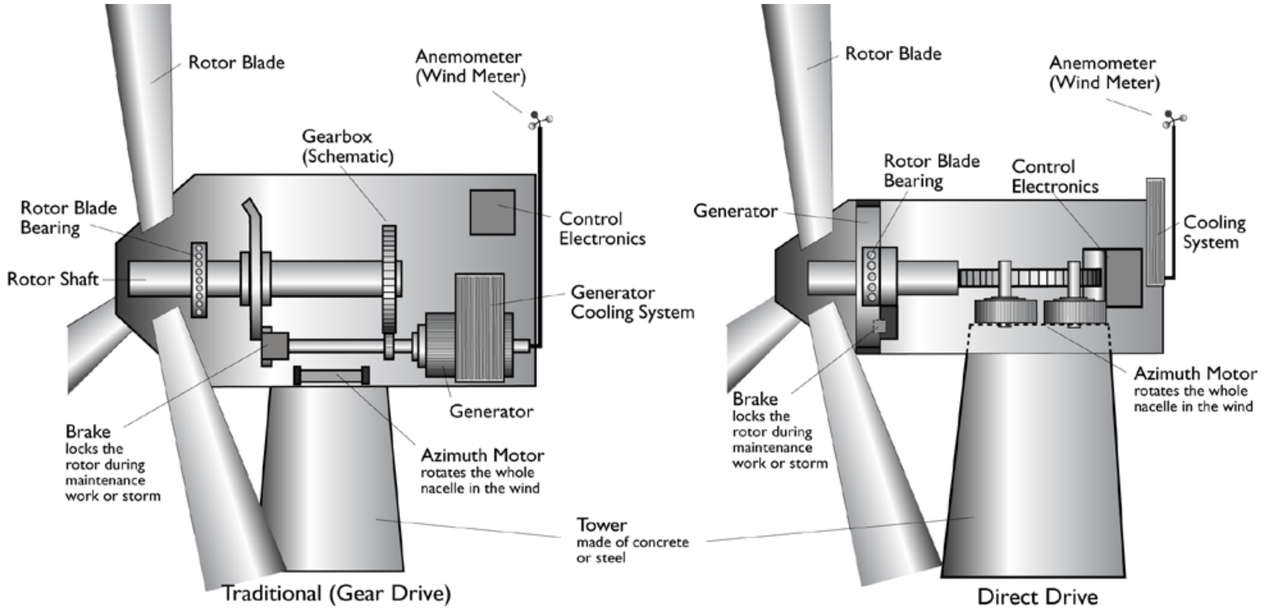


Figure 99. Wind turbine direct drive power train versus traditional gear drive.

Direct drive systems are costly not only for the increased size of the generator, but also because the generator must be custom built. In addition, unlike typical drive trains, it is not an off-the-shelf component. Direct drive power trains dominate operation and maintenance costs due to greater reliability. The current challenge with direct drive systems is to reduce both weight and equipment cost. These systems are an available option from some manufacturers, but are not yet as proven in the industry as the more traditional drive train systems. As more reliability data and lessons learned are produced for the direct drive system they can potentially become the most commonly accepted design for new installations.

9.6 Offshore Wind

Offshore wind once served as one of the world's most valuable energy sources and enabled global exploration, transportation, and the shipment of goods. Following the invention of the steam engine, offshore wind has provided little energy contribution to modern society. The currently untapped energy potential of offshore wind has generated interest from many entrepreneurs and developers to find a way for civilization to once again benefit from clean energy provided by the coastlines.

With the current growth and advancements in onshore wind turbine technology researchers are now looking for ways transition these technologies to offshore wind farms. Offshore wind production is an attractive development idea due to the high wind penetration found along the coast and at sea. Achieving a greater wind power potential is perhaps the simplest way to improve efficiency in wind power production. An increase in average wind speed can have an exponential effect on power production. The vast coastlines of the US are second only to China for offshore wind development potential.

Thus far, deployed offshore wind production is limited to Europe. The offshore wind farm sites built to date have been secured into the bedrock of the ocean floor at depths up to 20 m. Floating concepts are also being developed, which provide a large potential for growth in wind development. The technology for floating structures is adapted from the offshore oil industry which has been proven reliable. The advantages of floating designs are that they can be located at much greater ocean depths and have minimal visibility from shore. From a power production standpoint, wind power potential generally increases at greater depths. As with onshore systems, tower cost and transmission costs decrease per kilowatt-hour as turbine size increases. However, there are increased installation costs associated with offshore wind, which is partly because installation equipment, such as ships and cranes, specifically for installing offshore wind turbines do not currently exist. Installations to date have used makeshift barges, cranes, and ships which have been modified or retrofitted to transport and install turbines at sea. As the market matures, and specialized equipment becomes available, the installation costs for offshore wind will likely decrease.

An aqueous environment introduces many new and unknown mechanical forces on wind turbines such as tides, currents, and surface turbulence or waves. In addition, corrosive marine environments increase O&M costs and ultimately lead to reduced energy production efficiency. Greater maintenance costs can be attributed to protecting from and repairing corrosion, as well as the added costs of working in a harsher marine environment.

As a relatively new concept, offshore wind production does face many challenges. There several different anchoring concepts, many of which have minimal experimental or operational data to support a proven offshore wind farm design. In particular, floating structures have significant design variability, as illustrated in Figure 100. Since designs have been adapted from the oil industry it is likely that there will be more than one viable solution. The ease of installation and overall costs will likely determine which design(s) will become the optimal solution for offshore wind.

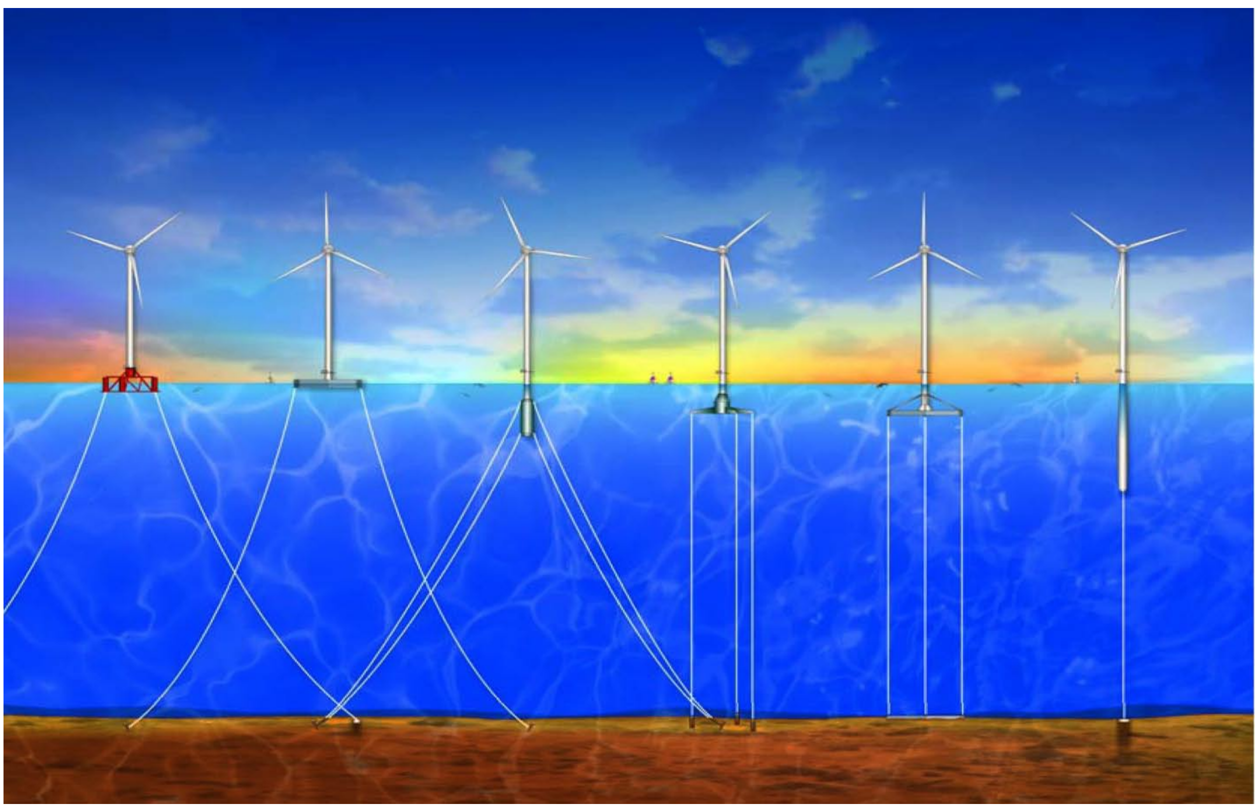


Figure 100. An example of different anchoring concepts for floating offshore designs.[186]

Ocean depth plays a significant role in the design of anchoring systems. Floating systems which are tethered to the ocean floor are one way of implementing wind turbines in deep or shallow waters. Shallow waters allow for towers to be inserted directly into the ocean floor. This technique has been implemented successfully for wind farms in Europe. A major challenge during installation can be determining the integrity of the ocean floor.

Much of the technology for harnessing wind at greater depths is currently in the R&D stages. Two floating wind projects are StatoilHydro's HyWind project in Norway and a two-turbine pilot project operated by SeaEnergy Renewables, which is located off the east coast of Scotland.[187] The HyWind project is the first demonstration of concept for a floating turbine. It has been equipped with more than 200 sensors to collect data for future offshore wind turbine projects.[188] In its early stages, the floating turbine experienced just three degrees of motion as a result of the ocean environment.

Much of the added costs can be offset by the increase in site efficiency when comparing offshore to land based sites. As more test data is collected for offshore wind, the design and maintenance procedures can be modified to increase overall efficiency of offshore turbine systems. Offshore wind technology could reach very competitive efficiencies and provide a very viable alternative energy source.

9.7 Peak vs. Off-Peak

Wind power, like many other renewable energy sources, is used for peak power production due to inconsistent and unpredictable wind speeds. It is important for power authorities to be able to accurately predict future contributions from renewable energy sources, since they must be balanced with baseload production to meet a dynamic demand. Increased accuracy in the prediction of wind energy production can effectively minimize the amount of energy wasted or overproduced.

9.7.1 Wind Power Potential

Wind power potential (WPP), also known as wind power density, is a fundamental figure of merit used in wind farm development. While more complicated calculations exist, wind power potential is commonly used for its simplicity. A simple calculation for wind power potential, a measure of the speed of the wind through a cylindrical volume of air, is provided in Equation 9.

$$WPP = \frac{Power}{Area} = \frac{1}{2}\rho v^3 \qquad \text{Equation 9}$$

Where

ρ – air density

v – wind velocity

A WPP value of 40 is on the low side, while 600 would be on the high side. A value of approximately 170 is suitable for development. WPP is generally an average number and can fluctuate with the season and from year to year. An accurate WPP is generally dependent on collecting data from at least two years. The longer the data collection period, the more accurate the WPP will be for that location.

9.7.2 Wind Capacity Factor

Since wind speed is not constant, a wind farm's annual energy production is never as much as the sum of the generator nameplate ratings multiplied by the total hours in a year. The ratio of actual productivity in a year to this theoretical maximum is called the capacity factor. Wind turbines have reached a capacity factor of 36 percent in some locations. Most fall within a range of 20 to 40 percent. The capacity factor can differ greatly for various types of power generation, and wind power is no exception. The wind power capacity factor is unique because it is not influenced by variations in fuel cost as other power sources may be, instead relying on the inherent properties of the wind.

9.7.3 Wind Penetration

A value which refers to the fraction of energy produced by wind compared with the total available generation capacity is known as wind penetration. It is a dynamic value and high recorded values occur when availability of wind is high and electrical demand is low. Large wind penetrations are difficult to incorporate due to technological restraints with current generation. A 20 percent penetration is feasible with most systems. Most electrical systems operate below five percent penetration, yet some systems with higher installed wind capacity frequently exhibit values closer to 20 percent. There is no set theoretical maximum for wind penetration. In November 2009, wind penetration in Spain reached 50 percent meaning that half of the electricity requirements were being supplied by wind power. This occurrence took place at off peak hours.

9.7.4 Wind Capacity Credit

Although wind generators typically have a very high mechanical availability, exceeding 95 percent, their rate for producing power at maximum capacity is much lower. Mechanical reliability alone gives a forced outage rate of below five percent in most instances; however, the variability of wind can produce an effective forced outage rate of 50 to 80 percent. In addition, the ability of wind generators to supply capacity when it is most needed, directly affects the value a wind plant has to an electric system. Higher or lower capacity credit is dependent upon the wind farm's ability to correlate with an electric system. The correlation of wind generation with system load, along with the wind generator's outage rate, are the primary determinants of wind capacity credit.[189] In essence, wind capacity credit has become a figure of merit as it provides a synthetic indicator of the potential value of wind to a system. Wind capacity credit (WCC) is essentially the amount of conventional generation that can be replaced by wind generation.

9.7.5 Power Coefficient

The power coefficient is a parameter that is used to optimize the power generation of a wind turbine at a given wind speed. It is essentially a ratio of the power extracted from the wind by the turbine to the power available in the wind. Equation 10 is the formula for the power coefficient, where the denominator represents the power available from the wind.

$$C_p = \frac{P}{\frac{1}{2}\rho_a A v^3}$$ **Equation 10**

Where

C_p – power coefficient

P – power generated

ρ_a – density of air

A – area swept by turbine blades, $A = \pi R^2$, where R is the radius or the length of a blade

v – wind velocity

The turbine tip speed ratio is used to characterize specific turbine designs. It is presented in Equation 11 and is dependent on the rotor tip speed, rotor diameter, and wind speed.

$$\lambda = \frac{\Omega R}{v}$$ **Equation 11**

Where

λ – turbine tip speed ratio

Ω – rotor tip speed

Figure 101 shows a diagram of power coefficients for various turbine designs. The ideal efficiency is reached at the top of the curve. This is the speed at which a turbine can balance maximum power output while minimizing damage and wear from higher speeds. Increased tip speed beyond the ideal efficiency produces an insignificant amount of increased power and can greatly reduce the life of turbine components.

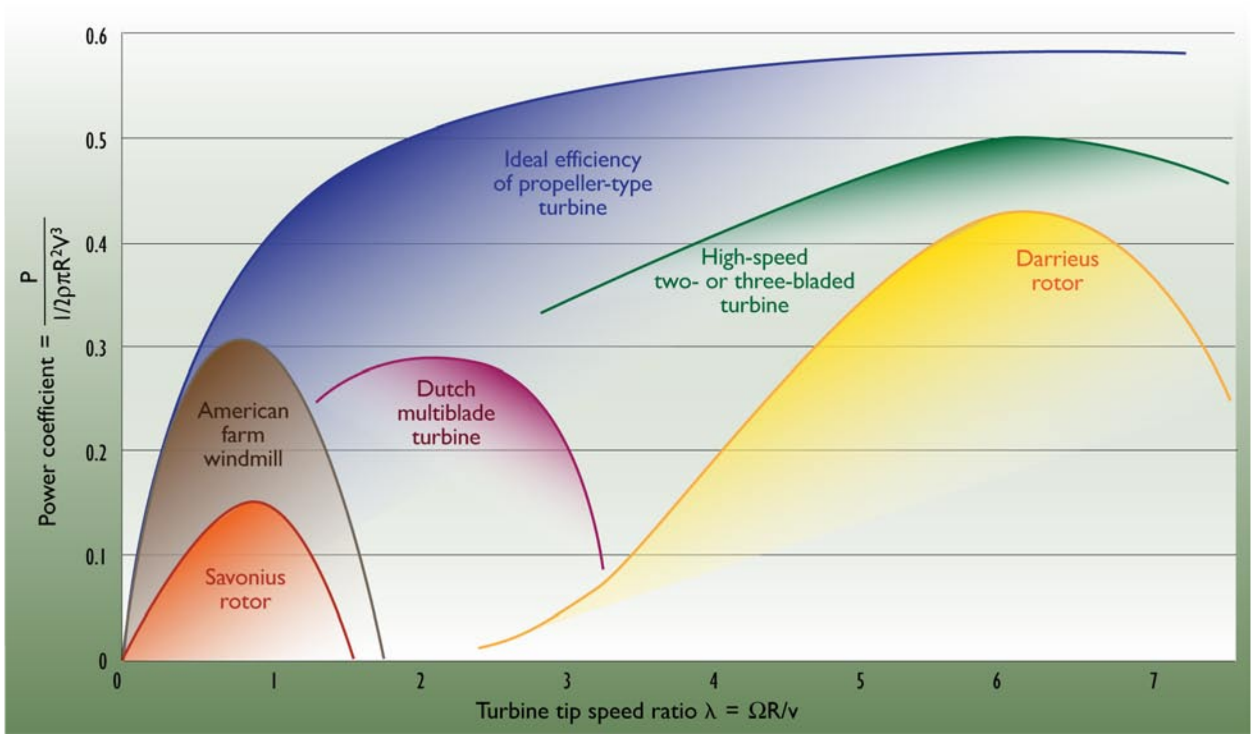


Figure 101. Plot of turbine power coefficient vs. tip speed.[190]

9.7.6 Reliability

A major challenge for the wind industry is to meet the expected design life of turbine components. Many existing systems have had to face unexpected operations and maintenance costs. Wind turbine manufacturers must now account for this risk and lower design life in future systems. The reduced reliability and increased O&M costs of the gearboxes have been affecting the cost of wind turbine sales in recent years. There are many factors which are currently being investigated as a means to identify and solve such reliability issues. Computer modeling and simulation helps researchers to understand the nature of the stress loading, which causes these failures. Fatigue failures in both bearings and gear teeth are major failures contributing to the poor reliability.

Turbines have already proven they are reliable enough to generate a return on investment. The next goal, which has been adopted by the industry, is to design turbine systems to last 20 years without any major maintenance or part failures. For some components this goal is being met. However, the quest for lighter weight, higher efficiency parts generally has an adverse effect on reliability and certain components still need to prove they are able meet this goal. Sacrificing power output for long term reliability can often have a beneficial effect when evaluating life cycle costs.

In the event of a catastrophic failure, such as a complete bearing failure, long downtimes and high maintenance costs occur since cranes must be used to remove and replace large heavy equipment from atop of the turbine towers. One method for reducing O&M costs related to failures is to perform frequent scheduled maintenance. A faulty bearing is a detectible and inexpensive fix when caught in time. Budgeting and planning for greater preventative maintenance costs up front eliminates the risks of having far greater O&M costs down the road. There are efforts to reduce maintenance costs through the use of structural health monitoring systems which can detect failures without the need to send a technician all the way to the top of a turbine for routine checks.

One method of reducing gear and bearing raceway fretting fatigue is a process known as superfinishing. Superfinishing is a vibrational process which reduces material surface roughness thereby greatly reducing fretting corrosion and pitting in contacting metal surfaces. It has been effectively applied to gear surfaces and bearing raceways. Superfinishing has been used to improve reliability and efficiency in high performance engines. It is one example of a cost effective and sustainable solution which is being evaluated to increase turbine reliability in future designs.

Underperformance compared to preconstruction estimates is an issue with wind farm development.[191] It has been difficult to explain exactly why this occurs, but is likely the effect of a number of factors. Inaccurate or incomplete data, as well as less than optimal turbine performance are just two factors that may be contributing to this shortfall. However, new data and new understandings of the performance of wind turbines is allowing for more accurate predictions. A more conservative approach can be taken using uncertainty factors in the model. Factors which can contribute to underestimation of wind power output include:

- Periods of low/high wind
- Shutdowns for maintenance
- Premature part failures
- Incomplete or inaccurate weather data
- Manufacturer using ideal or optimal assumptions for turbine rating
- Unforeseen accidents, such as weather damage

9.8 Siting

A wind siting assessment generally includes evaluation of several factors including wind loads (extreme and fatigue), temperature, icing, seismic loads, and grid environment.[192] Wind power density and predicted wind energy production are two of the most important aspects of evaluating the wind resource in a given location.[193] Wind metering devices (Mets) are used in locations that are good prospects for wind energy projects. Mets provide necessary data for important decision making on wind projects. Table 46 provides a wind speed classification system. Data for various wind heights can be extrapolated using vertical extrapolation of wind speed based on the 1/7 power law. The mean wind speed is based on the Rayleigh speed distribution of equivalent wind power density.

Table 46. Wind speed classifications by vertical extrapolation.[194]

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed m/s (mph)	Wind Power Density (W/m^2)	Speed m/s (mph)
0	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

A minimum of two years of data are needed to obtain an estimate for the annual wind power potential, and five years of data are needed to obtain a mean value within six percent of the long-term mean. However, it is generally accepted that two to three years of data combined with regional data is enough to generate an accurate estimate of wind power potential. Where long-term regional data is available, accurate assumptions can be made using only one to two years of data for a specific location.

Wind power potential is generated using wind speed data. There have been many past efforts to create wind maps for aiding in early development efforts. Some of the first maps were generated in the 1990's. This data varied greatly in accuracy from location to location due to inconsistencies in data. Wind speeds were taken at various ground heights, which depended on height of the building or available structures to place metering devices. One of the greatest shortfalls is that much of the wind data used to produce maps in the past was taken at heights lower than modern turbines being designed today (i.e., 30 meters or less), which have been evolving to much greater heights. Also, wind data used in early maps was collected at different intervals and could have been recorded hourly, daily, or even monthly. These variables greatly affect average wind speed calculation and power potential. However, they still provided some insight for researchers and developers in determining beneficial locations. Generally, smaller state and local maps yielded more accurate data since data collection was more consistent.

There have been efforts to modernize wind maps and improve the accuracy of data being used to meet the requirements of current technology. A project by NREL and AWS Truewind called windNavigator has improved wind map accuracies.[lvii] The wind data was collected at a consistent 80 m ground height, (previous maps had a maximum 50 m tower height), and wind speeds were collected at geographic points 200 m apart. Graphical data as presented on a map is shown in Figure 102. Advanced metering combined with modeling and simulation is improving the development timeframe by providing more accurate assessments in less time.

[lvii] AWS Truewind windNavigator. https://www.windnavigator.com

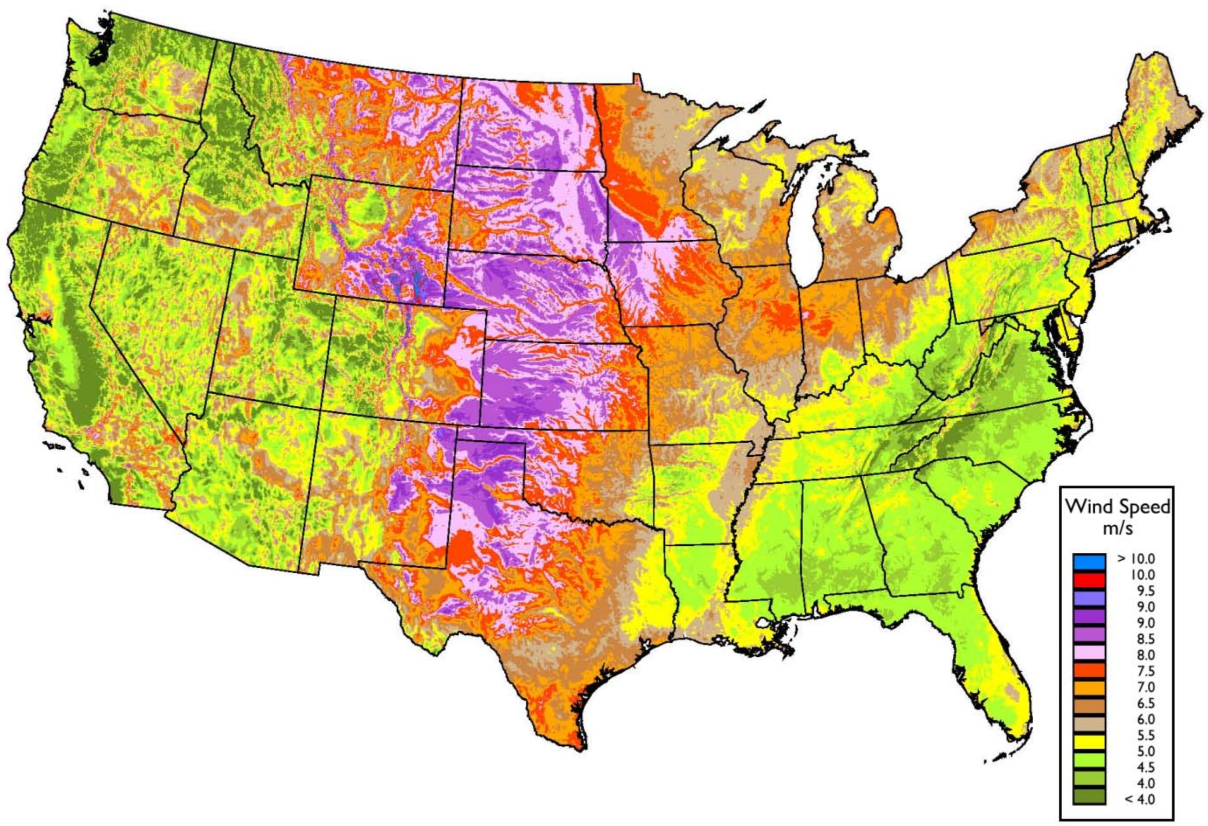


Figure 102. Graphical representation for the transition toward larger and taller wind turbines for propeller style HAWT designs.[195]

For utility power production, wind power depends very heavily on proximity to a power grid and the state of existing power resources. Most wind farms work in cooperation with a power utility to supplement existing energy supply. Access roads and transmission lines are a major cost to consider for new site development. Many commercial development sites to date have been located near available transmission. Developers are currently trying to work with government agencies to find affordable ways to create new transmission lines that will make future wind projects possible.

9.8.1 Radar Interference and Air Traffic Control Issues

Interference with military and weather radar is also an important concern for siting wind projects. This interference has led the Federal Aviation Administration (FAA), the Department of Homeland Security (DHS), and the DoD to contest many proposed wind turbines in the line-of-sight of radar, stalling the development of several thousands of MW capacity of wind energy. A large number of such denials is a serious impediment to the nation's mandated growth of sustainable energy. There is no fundamental physical constraint that prohibits the accurate detection of aircraft and weather patterns around wind farms. However, the nation's aging long range radar infrastructure significantly increases the challenge of distinguishing wind farm signatures from airplanes or weather.

Progress forward requires the development of mitigation measures, and quantitative evaluation tools and metrics to determine when a wind farm poses a sufficient threat to a radar installation for corrective action to be taken. Mitigation measures may include modifications to wind farms, such as methods to reduce radar cross section and telemetry from wind farms to radar, as well as modifications to radar, such as improvements in processing, radar design modifications, radar replacement, and the use of gap fillers in radar coverage.

There is great potential for the mitigation procedures, though there is currently no source of funding to test how proposed mitigations work in practice. In general, the government and industry should cooperate to find methods for funding studies of technical mitigations. The National Oceanic and Atmospheric Administration (NOAA) has a research plan, but no adequate funding to carry it out. Once the potential for different mitigations are understood, there is no scientific hurdle for constructing regulations that are technically based and simple to understand and implement, with a single government entity taking responsibility for overseeing the process. In individual cases, the best solution might be to replace the aging radar station with modern and flexible equipment that has the capability to distinguish wind farm clutter from aircraft signatures.

Wind turbines visible to air traffic control (ATC) radar, long-range radar, airborne radar, and weather radar can cause a loss of detection, false indications, and corrupt radar data. The effect varies based on type and age of radar, and environment where radar is located. Additionally, wind turbines close to navigational aids, such as a VHF omnidirectional range (VOR) ground station, can result in bearing errors.[196] Wind farms have been operated nearby military installations without having a detrimental effect on military operations. Wind projects are relatively close to long range radar facilities in Mount Laguna, California (25 two MW turbines)and McCamey, Texas (322 turbines totaling 356 MW).

A study from the British Department of Trade and Industry (DTI) concluded that there are hardware and software mitigation efforts that can be implemented to reduce or eliminate the effects of wind turbines on radars.[197] These solutions include adding radars, adding filters to the radar software, or altering the layout of a wind project. They vary in cost based on site-specific situations. While there is potential for mitigation efforts, many have not been evaluated for how they will perform in practice. The effect of wind farms on military readiness has also been evaluated in a 2006 report to the congressional defense committees.[198] Cooperation between radar operators and wind developers is key. In many cases, for-profit developers are willing to pay for a portion or even a complete radar upgrade. Future government legislation might better define who is responsible for the incurred costs for radar improvements around wind farms.

In April 2010, the DoD tasked the Massachusetts Institute of Technology Lincoln Laboratory to conduct a 60-day independent assessment of the impact of wind turbines on long range radar air surveillance capability, with a focus on the proposed wind farm at Shepherds Flat, Oregon and the Air Route Surveillance Radar (ARSR-3) at Fossil, Oregon (QVN). This assessment was to include all currently operating wind turbines within the QVN radar line of sight as well as a prediction of the impact of the proposed Shepherds Flat wind turbines on the QVN radar. In addition, options for mitigating the impact of wind turbines on the QVN radar were to be identified and evaluated.[199]

The Federal Aviation Administration offers a tool for wind developers to assess potential radar conflicts during wind farm siting efforts. The DoD Preliminary Screening Tool[lviii] enables developers to obtain a preliminary review of potential impacts to long-range and weather radar, military training routes and special airspace prior to official obstruction evaluation/airport airspace analysis (OE/AAA) filing. Along with the preliminary screening tool, radar maps can be used to determine potential conflicts with development sites.

Interference with weather radar is a problem for wind farm development. The Next Generation Weather Radar (NEXRAD) Program is a joint effort between the Department of Defense, Department of Commerce, and Department of Transportation. They have produced a Weather Surveillance Radar-1988 Doppler (WSR-88D) radar also known as NEXRADs which can predict the impact a wind turbine will have on neighboring weather radars once turbine height and location have been identified. Figure 103 presents a wind resource map for DoD ranges and space.

[lviii] DoD Preliminary Screening Tool https://oeaaa.faa.gov/oeaaa/external/portal.jsp

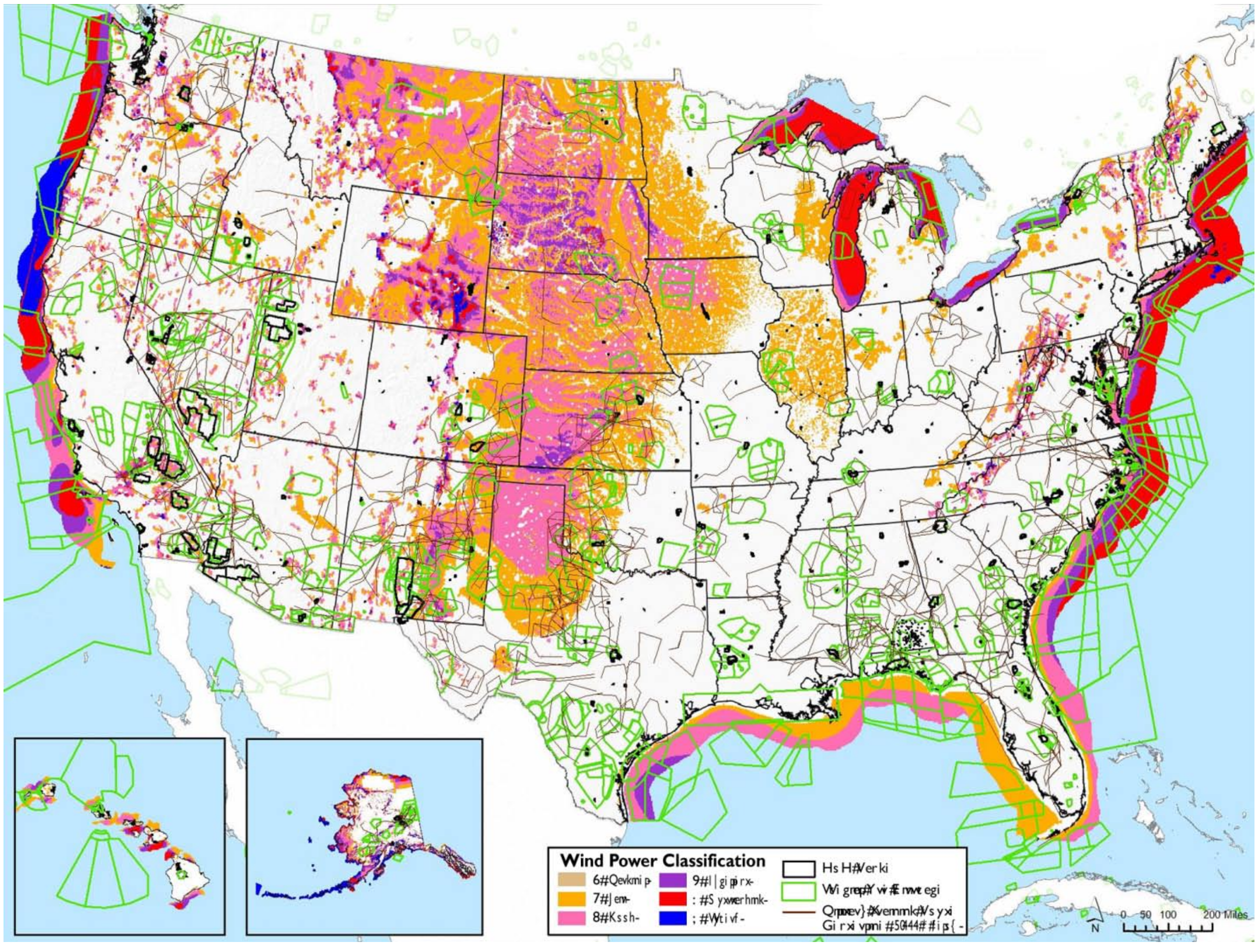


Figure 103. US wind resource and DoD ranges and special use airspace.[200]

9.8.2 Sizing

Higher average wind speeds are typically found as altitude increases. The difference in wind speed can lead to a significant increase in power production. The larger the turbine the more difficult it is to transport and install. To reach greater efficiencies and avoid damaging turbulent flow, it is suggested to site turbines at least 30 ft higher than the highest object within 300 ft.[201] For offshore sites, greater windspeeds are recorded at lower altitudes. This leads to larger, more efficient turbines blades without having to significantly increase tower height and bulk as with land based turbines.

9.8.3 Spacing

Vertical axis turbines have the advantage of allowing a closer spacing. Horizontal axis turbines have a slowing effect on the air and therefore must be spaced further apart to avoid wake losses. This effect is sometimes referred to as a wind shadow. Turbines need to be spaced a minimum of five to ten rotor diameters apart to avoid efficiency losses and damaging turbulence.

9.8.4 Land Usage

Wind farms make an attractive choice for generating power where dual purpose land use is desired. They have a relatively small land footprint when considering their enormous size. A square mile of land can support approximately 10 to 20 MW of development, with the majority of land still available for traditional uses (e.g., farming, ranching, etc.).[202] Flat rural farms lands are often ideal locations for siting wind farms as lack of surrounding shelter promotes steady wind. Farm land can be used with very little impact to existing productivity with benefit to the farmer who is able to subsidize a farming operation through lease agreements. Land footprint is one area where wind power has an advantage over solar power. Solar farms generally require a large amount of dedicated land. In locations with a more varied topography, such as mountainous regions, wind turbines are typically placed along ridge lines or in areas of higher elevation as the wind power potential is greater in these areas. The use of mountainous or uneven land for alternative energy technologies like wind and solar can be a great land management practice as the land is not as universally used for other types of development. This is especially true in locations where high wind speeds are present. However, the remote nature of many potential rural wind site locations often requires costly transmission lines to connect to the electrical grid.

One positive aspect of off-shore wind power production is that it has very little land usage requirements. Building offshore does have some impact on coastlines and harbor activities. It may also prove to have a negative impact on the fishing industry. Since there have been very few offshore wind installations, and none to date in the US, it is difficult to predict the actual impact they will have on their respective development sites. Offshore wind technology is highlighted and discussed in detail in *Section 9.6*.

9.9 Grid Integration and Transmission

Grid integration and transmission has been a major reason for project delays as well as failed projects. Increased operational management and controls must be implemented in wind/conventional combined systems, and adequate transmission lines must be available or constructed.

Wind power is by its nature variable, and as a result, it differs from most types of electrical power generation. Aspects of this variability are often cited as shortcomings, but wind energy can also be viewed as an additional generation source to our national electric grid with its own set of contributing characteristics.[203] For DoD applications, wind generation can be installed to local grids to help reduce the dependence of a particular installation on the national grid.

When managing power sources wind energy is typically used as it becomes available since wind turbines have a relatively low cost to operate. As wind power is harnessed the conventional power source with the highest operational costs is reduced or brought offline. The most expensive operation could be coal or natural gas depending on market prices and local power portfolio.[204] Managing a system with significant wind generation requires conventional resources to potentially operate at a higher capacity during low wind periods. Increased costs are a consequence of the additional duties performed by conventional generators.[205] How wind energy interacts with the grid is important for determining the true cost of wind power.

There is significant variability when it comes to integrating wind power to a grid. Each power authority in the US has different energy schemes and power purchase agreements in their portfolio. Integrating a small percentage of wind in order to decrease baseload energy is a feasible operation for most balancing authorities. At a certain percentage, some baseload energy sources, such as coal, cannot be reduced any further without shutting a plant down completely. A complete shutdown and startup is not economically or logistically feasible. This means, authorities will reach a certain point where adding more renewable energies, such as wind, to the portfolio will not provide additional benefit to the grid. Exceeding this percentage would result in an overproduction of electricity.

Off the grid wind/diesel hybrid systems are a technology receiving significant interest in developing countries as well as for rural and remote areas of developed nations. The hybrid system is being recognized as a more efficient way to operate distributed generation systems when there is no capability or desire to build infrastructure to connect to a grid.[206] This is an excellent option for remote islands, which need to establish their own independent power source in a cost effective manner. The US Air

Force has incorporated this technology at the Ascension Island auxiliary air field (see *Section 9.12.3*) and the Tin City Long Range Radar Range, Alaska (see *Section 9.12.4*).

9.9.1 Transportation and Installation

The transportation of wind turbines and associated components must be considered when choosing a location for a wind farm site. There must be unobstructed roadways which can provide a means of transportation. Often special measures must be taken in order to move large objects, such as turbine blades or towers.

Transportation can now amount to 20 percent of equipment costs. Tall HAWTs are difficult to install, needing very tall and expensive cranes and skilled operators. Specialized trucks and machinery for handling blades and towers, also add to transportation costs.

Offshore construction promises to offer cheaper, less complicated, transportation in the future. However, installations to date have been accomplished using retrofitted equipment leaving room for significant reduction in future installation costs. Faster installation can have a significant impact since large quantities of components are typically stored portside, awaiting installation.

9.10 Economics

Determining the cost of wind farm installations can be a complicated process and is directly related to selecting adequate siting. Once a location has been chosen cost models can be developed to determine a payback period and long term return on investment. Wind power is generally purchased at the current market price of baseline electricity production. This means a return on investment is an estimate and will ultimately depend on fluctuations in the energy market. Estimates can still be useful and fairly accurate.

Wind farms typically come with high fixed costs, but low variable costs.[207] Figure 104 displays the breakdown of costs associated with the initial development and construction of a wind farm.

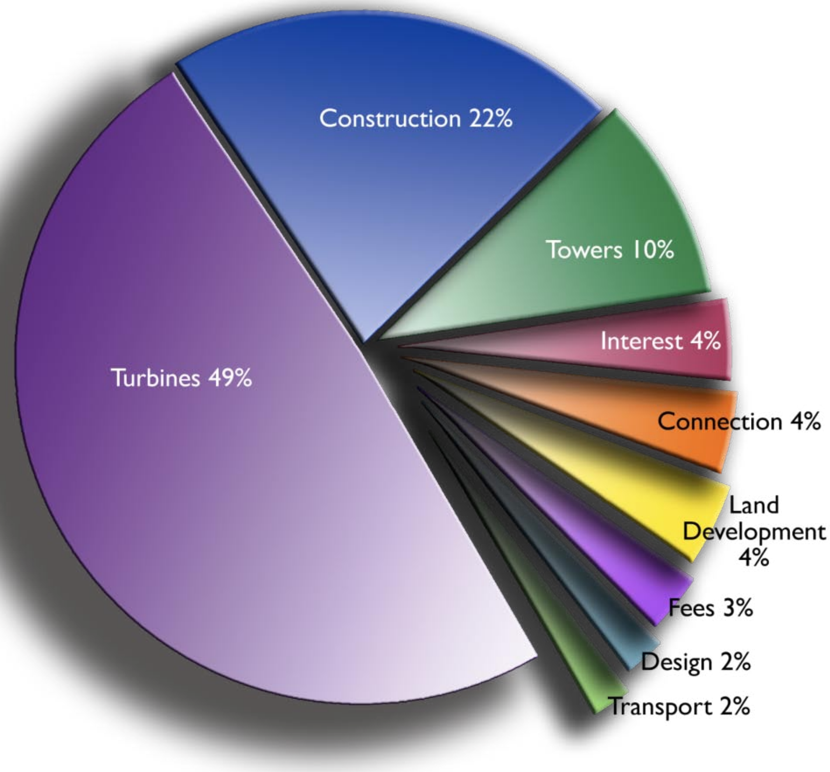


Figure 104. Breakdown of initial costs for developing a wind farm.[207]

Federal and state government subsidies play a significant role in wind farm development. Figure 105 shows how the federal production tax credit has had an enormous effect on growth in this industry.

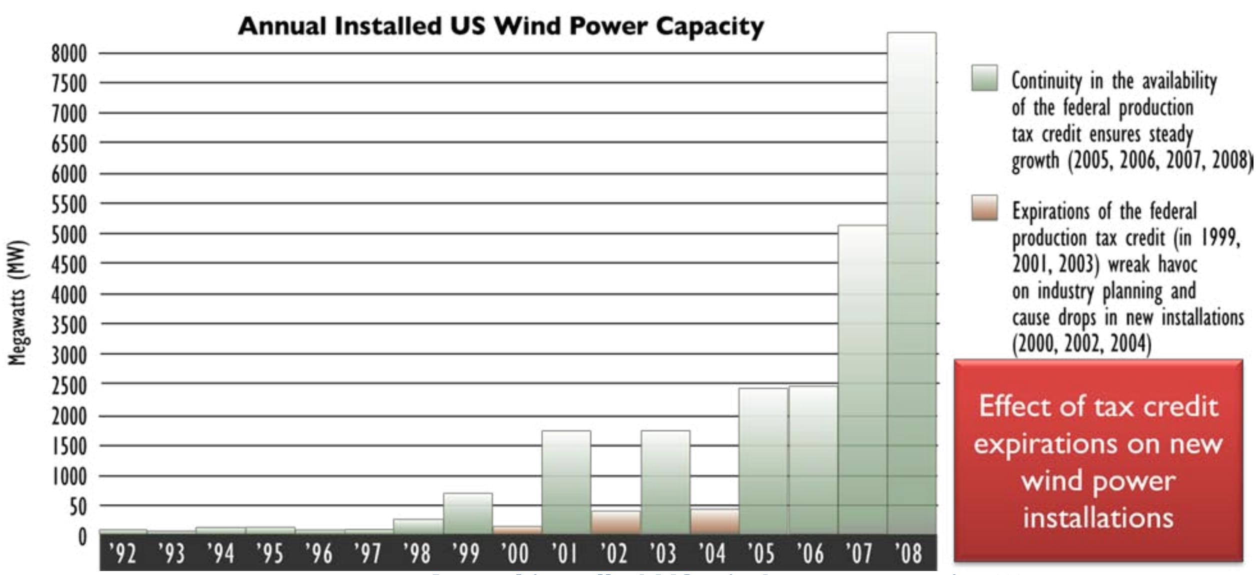


Figure 105. Annual installed US wind power capacity.[208]

An increasing number of unpredicted failures have driven up the cost for wind energy production. Previously, the cost per kilowatt hour for wind energy had been falling, until approximately 2004. Large spikes in growth have also had an effect on the supply and demand mechanics of the industry causing prices to rise (see Figure 106). Manufacturers and developers have not seen steady orders for business in part because much of the industry relies on short-term incentives and government legislature. Therefore more risk must be compensated for in the price.

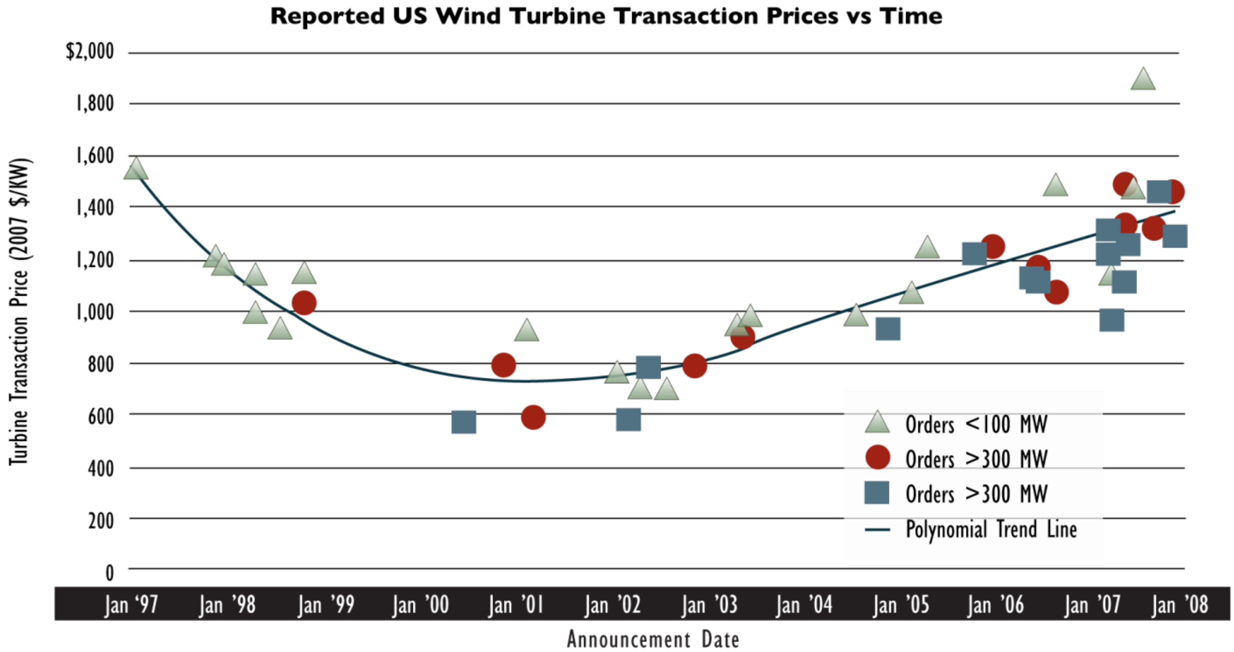


Figure 106. Trending increase in price for wind turbines.[209]

Operations and maintenance is a major economic cost and is dependent upon many factors including scheduled maintenance, unscheduled maintenance, and cost per turbine per year. Ultimately cost per kilowatt-hour is dependent on many factors including site capacity factor, turbine and project size, availability of spare parts and trained personnel, and site accessibility.[210] Relative to other power sources, such as a coal fired or gas fired power plant, wind farms have low operating costs. Table 47 shows a cost model example for a 50 MW wind farm.

Table 47. Cost model example for a 50 MW wind farm (2005).[211]

Project Size	50 MW
Capital Cost	$65,000,000 ($1.3 M per MW)
Annual Production	150 GWh (assuming 35% capacity factor)
Financing	60% Debt, 40% Equity
Annual Gross Revenue	$0.04 per kWh (based on power purchase price)
Expenses	
Debt	60% (15 years at 9.5%)
Distribution	22%
Operation and Maintenance	8%
Land, Property Taxes or Rent	5%
Management Fees, Insurance	5%
Tax Credit and Depreciation	
Depreciation on Wind Equipment	5 year
Tax Credit	$0.021 per kWh (adjusted for inflation during first ten years of operation)

9.11 DoD Specific Issues

Any power utility can be considered a target for terrorists or enemies of the US. Many current generating facilities, such as nuclear and hydro plants, operate under a very high level of security. While a catastrophic event, such as a nuclear meltdown, is not at risk, wind turbines do have a high visibility and their dispersion over a large land area makes them difficult to defend from terrorist activities. Yet at the same time, the dispersion of energy generation over a large land, as opposed to one central location, makes catastrophic attack of power generating facilities and equipment difficult to execute. As development and dependence on wind energy increases, security issues will need to be evaluated closely in order to protect the assets and maintain a strong infrastructure. Moving offshore, particularly into deeper waters, would create an increasingly vulnerable infrastructure toward outside attack.

Wind turbines reaching heights of 200 m or taller for some of the largest operational turbines could pose a threat to low flying aircraft but would be treated similar to any large manmade structure. Military bases or airports which conduct low altitude exercises should make considerations for the proximity of wind farms to airstrips and plan accordingly. Developers often work side by side with nearby air operations to ensure that wind farms will not compromise current or future fight operations.

9.12 DoD Wind Projects

The DoD has a number of ongoing renewable energy projects involving wind power. This section will provide information on past project as well as mention a few projects which are currently being pursued for future development.

9.12.1 F.E Warren Air Force Base

Since 2005, F.E. Warren AFB has operated two 660 kW wind turbines at the base in Wyoming. In 2009, the base added a third, larger wind turbine, which is rated at 2 MW and supplies energy directly to the electrical grid on base. From most points on base the wind turbines can be seen. This facility, like many new installations, has the option to add more turbines to the farm at a later date. Designing smaller systems with the ability to expand at a later date is an ideal approach for DoD wind projects, since it allows for additional renewable energy credits to be generated as funding becomes available.

Figure 107. Turbines located at F.E. Warren Air Force Base.[212]

9.12.2 Camp Williams

The turbines at Camp Williams were built to provide energy to the Utah Army National Guard camp, which is located far from most residences. These turbines were part of a test project to determine the viability of producing energy from wind in the state of Utah. Two turbines installed in 2000 and 2005 have a combined total capacity of 0.89 MW. There have been very few wind farm developments in Utah due to the very inexpensive prices of electricity generated from coal. The turbines at the Utah Army National Guard camp were two of the first turbines installed in state of Utah. New projects are in development in Utah with most of the power being sold through power purchase agreements to other states, such as California.

9.12.3 Ascension Island, US Air Force, South Atlantic

The 45th Operations Group Detachment 2 on Ascension Auxiliary Airfield (AAF), Ascension Island, is a challenging location for energy production. The airmen of the detachment support eastern range space launches by collecting and disseminating radar, telemetry and tracking data. The especially remote nature of Ascension Island means traditional power sources, such as those generated from fossil fuel supply, are either unavailable or costly. The island originally produced all of its power using a diesel generator. The transportation of diesel fuel, combined with the increasing cost for fossil fuels, forced program managers to seek a more sustainable solution and lower operation costs.

In 1995, the USAF installed a wind/diesel hybrid generator. The diesel fuel still functions as the baseload energy source; however it is now supplemented with wind power to decrease energy costs. This reduced the frequency of fuel deliveries needed to keep the observation station operational. The first phase involved the installation of four 225 kW wind turbines. Two additional 900 kW turbines have been added to produce a combined 9.5 GWh of energy per year. As an added benefit, the six turbines lower the load on the three diesel engines to extend the expected operational life of the engines. Now, the wind farm saves 700,000 gallons of fuel per year and $1M dollars, in addition to reducing greenhouse gases by 198,000 pounds.[175] The farm on Ascension Island is currently the largest wind farm development built in support of the Air Force. Figure 92 and Figure 108 show photographs of these wind turbines. Figure 109 shows an operational check of a rotating 900 kW wind turbine brake disk at 45th Operations Group Detachment 2, Ascension Auxiliary Airfield, South Atlantic Ocean. The unit sits atop a 110 foot tower that holds the power generation portion of this 900 kW wind turbine.

Figure 108. Performing maintenance at wind farm on Ascension Island.[213]

Figure 109. A brake disk on a 900 kW wind turbine at Ascension Auxiliary Airfield.[213]

9.12.4 US Air Force Tin City Long Range Radar Range

Wind power becomes more economically viable for locations as distance from major fuel supply or distance from an electricity grids increase. The Tin City Long Range Radar Range has a particularly high cost of electricity due to its extreme cold temperatures and remote location. Similar to the wind/diesel hybrid system at Ascension Island, the US Air Force 611th Civil Engineering Squadron (CES) is currently in the process of installing a wind turbine at a remote radar base in Alaska (see Figure 110). This $1.9M project was funded through the Energy Conservation Investment Program and hopes to reduce fuel consumption by 30 to 35 percent, or approximately 85,000 gallons per year.[214] A potential annual energy savings of $433,000 is estimated. The installed capacity of the turbine is 230 kW. The prevailing winds on the western coast of Alaska put the area in a class seven wind power density zone, the highest possible category.

Figure 110. Turbine to be installed at Tin City Long Range Radar.[214]

Development in this harsh climate has faced many challenges and in particular must address rime ice in the Vestas V27 turbine.[215] In order to combat the extreme cold weather conditions a state-of-the-art cold weather package was implemented. This package includes an electric heating system which directs warm air from the base up to tower and into the blades. In addition to electric heat the cold weather package also incorporates passive solar heating for the blades as well as cold weather lubrication in the nacelle.

The 611th CES is currently pursuing wind turbines at Cape Lisburne, Cape Romonzof and Cape Newenham. Engineering work is also taking place to determine the feasibility of wind power generation at Eareckson Air Station.

9.12.5 Toole Army Depot

A contract was awarded on June 6, 2010 and the project is currently under way to install 1.5 MW wind capacity at Tooele Army Depot, Utah. The turbine will be 225 feet tall with each blade 130 feet long. The system is expected to power one quarter of the Depot's electricity and provide a possible savings on energy costs of up to $125,000 per year.

10 BIOMASS

10.1 Introduction

Biomass is any organic, plant-like material that utilizes carbon dioxide as a part of its growth cycle via photosynthesis. Not only does biomass absorb CO_2, but it also stores solar energy that can be recovered through a series of conversion processes.

Biomass contributes 70% of the non-hydro renewable energy in the US.

The interest in biomass for the production of energy has grown as a result of the global focus on developing renewable fuels and energy resources. With limited, nonrenewable crude oil supplies and increasing demand new and renewable resources are sought as the feedstocks to fuel and energy production. Diversifying the nation's energy portfolio by increasing the use of alternative fuels and renewable energy can have a positive impact on national security and economics, which are two common concerns across the nation. These alternatives to fossil fuels may also reduce greenhouse gas emissions.

Biomass is of great interest in the quest for a new energy supply because not only can it be converted to a fuel, but also used to produce electricity, and heat for thermal utilities. However, because of the numerous available technologies, feedstocks, and continuously developing conversion processes, it is difficult to predict the overall outcome and costs of using biomass for producing power, fuel, or heat. Nevertheless, biomass offers several options that can play a role in current and future energy production.

10.1.1 Advantages

Biomass is an advantageous feedstock for energy production, primarily because of its relatively low feedstock cost, low emissions, and potential sulfur dioxide (SO_2) removal capabilities. In general, compared to fossil fuel sources biomass is a lower cost feedstock. It also generates fewer emissions in its production, specifically greenhouse gas emissions, which makes biomass feedstocks of great interest to countries that have ratified the Kyoto Protocol[lix]. Further, the ash that is contained within the biomass feedstocks contains alkali components that can react with and remove SO_2; SO_2 emissions are currently regulated. This ash also lacks the toxic materials and trace contaminants found in coal ash, thus allowing for its use as a soil additive to help replenish nutrients removed during harvest.[216, 217] In countries that have ratified the Kyoto Protocol, the use of biomass as an energy source as opposed to a traditional fossil fuel can lead to the obtainment of CO_2 credits. Additionally, if plant sources are used for the generation of renewable fuels or energy, they are considered to be CO_2 neutral by the protocol, because it is postulated that any CO_2 released during production is absorbed during the biomass feedstock's growth.[216]

10.1.2 Disadvantages

Biomass does pose some potential drawbacks. Most notable is the heterogeneous nature of biomass with respect to its elemental composition; its variation in mineral content with soil type and harvest timing; moisture content; and energy density. Moisture content is of great importance when determining the heating value of a material as moisture lowers this value. Biomass can be dried using an air dryer to obtain a moisture content between 15 and 20 percent; if an oven dryer is used the moisture content will be near 0 percent. The low physical density or bulk density and energy density of biomass makes the

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[lix] The Kyoto Protocol is a treaty that is designed to mitigate climate change by reducing the emission of greenhouse gases. The United States has not ratified this treaty.

transportation costs expensive and inefficient. Even after densification the bulk density is only about 10 to 40 percent of that for fossil fuels.[216, 217]

10.1.3 Availability and Use

Regardless of the drawbacks associated with biomass it is still a common renewable resource. Of the renewable energy currently produced in the United States, only two percent is from non-hydro sources.[218] Biomass contributes 70 percent of this energy, making it the largest contributor to the production of renewable energy behind hydro sources. Wood wastes and municipal solid wastes are the most used biomass feedstocks in the production of this energy.[218] Additionally, it has been projected that biomass resources have the potential to become the world's largest and most sustainable energy source with an annual bioenergy potential of approximately 2,900 exajoules (EJ, or 8.06×10^5 TWh), where 1 EJ is equal to 10^{18} joules. The current world-wide installed bioenergy capacity is more than 40 GW (or 1.26 EJ/year).[219] The biomass resources available in the US are shown in Figure 111.

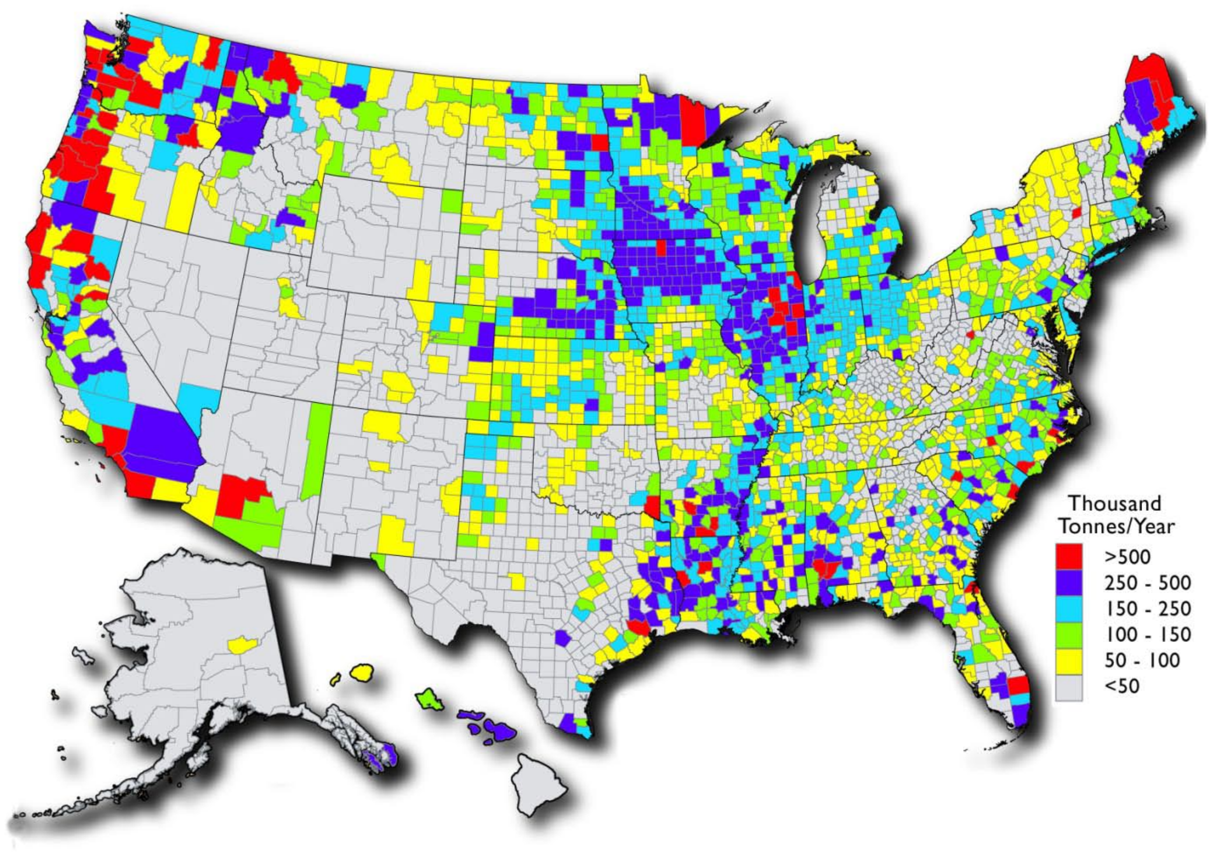

Figure 111. Total available biomass resources in the US including agricultural residues, wood residues, municipal discharges, and dedicated energy crops.[220]

10.2 Feedstocks

Although biomass has commonly been linked to corn ethanol and as a result became synonymous with corn and other agricultural crops, biomass covers a much greater breadth including: agricultural crops and their residues, forestry crops and residues, and waste feedstocks. Consequently, the definition can be expanded to any biological or man-made organic material that can be reduced by a thermal, biological, or chemical process, or a combination thereof, for the production of a usable energy product.

Although biomass feedstocks can be attained from a hodgepodge of sources, the feedstocks are surprisingly uniform in terms of their fuel properties when compared to competing fossil fuel feedstocks, such as coal and petroleum. This is evidenced in the heating values of biomass versus the fossil fuel alternatives. Nearly all biomass feedstocks intended for combustion have a higher heating value (HHV)[lx] in the range of 15 to 19 GJ/tonne[lxi] (6,450 to 8,200 BTU/lb). Agricultural residues have HHVs between 15 and 17 GJ/tonne (6,450 to 7,300 BTU/lb) with woody materials ranging from 18 to 19 GJ/tonne (7,750 to 8,200 BTU/lb). For comparison, traditional fossil fuels, such as coal, have an HHV value that range from 20 to 30 GJ/tonne (8,600 to 12,900 BTU/lb).[216, 217]

10.2.1 Feedstock Type

Biomass feedstocks can be classified based upon their source (i.e., agricultural, forestry, or waste) or based upon their composition (i.e., cellulose-based or sugar-based). Common convention is to classify feedstocks based upon their initial source and therefore this section on feedstock types will be organized accordingly. However, it is of use to know the classification based upon whether or not the material is cellulosic-based or not. Table 48 differentiates the materials within each category based upon classification.

[lx] A fuel's HHV is the measure of the heat released during the complete combustion of the fuel with oxygen (O_2) at a given temperature and pressure. When using the HHV it is assumed that the water vapor formed during the combustion process is condensed, collected, and cooled to the initial temperature. Hence, HHV assumes that the latent heat of evaporation is recovered; whereas, the lower heating value (LHV) does not assume this. In fact, the LHV assumes that the latent heat of evaporation is not recovered. The latent heat of evaporation is typically only recovered if it is cool enough to condense the gas. HHV is the US customary measure of heating value.[216]

[lxi] A tonne is equivalent to one metric ton or 1,000 kg.

Table 48. Grain-based vs. cellulosic-based feedstocks.[221]

Classification	Sugar or Starch-Based Feedstocks	Cellulosic Feedstocks
Agricultural	Corn	Corn Stover
	Sugar Cane	Wheat
	Sugar Beets	Switchgrass
	Wheat	Alfalfa
	Milo	Sugarcane Bagasse
	Sweet Sorghum	Oats
		Barley
		Rye
		Fescue
		Reed Canary Grass
		Miscanthus
		Prairie Cordgrass
		Rice Stover
Forestry		Poplar Trees
		Willow Trees
		Sycamore Trees
		Black Locust Trees
		Eastern Cottonwood
		Eucalyptus
		Pine Trees
		Sweetgum
		Silver Maple Trees
		Tree Branches and Tops
		Saw Dust
		Wood Pellets
Waste		Municipal Solid Waste
		Paper Mill Wastes
		Agricultural Wastes and Manure

10.2.1.1 Agricultural Feedstocks

Agricultural-based biomass feedstocks are conventionally subdivided into two categories: grain-based (i.e., corn, starch, and sugar-based) and cellulose-based. The crops characteristic of the grain-based category are: corn, sugar cane, and sugar beets. These materials consist mainly of simple sugars (i.e., glucose) that can be readily converted by biological organisms through a simple fermentation process. Glucose is a monosaccharide, a simple six carbon sugar compound that is produced by photosynthetic processes and is readily consumed by yeast and other organisms. Since it is a relatively simple compound as opposed to a complex sugar chain or polysaccharide (e.g., cellulose), glucose does not have to be altered prior to its conversion to a more useful form by an organism.

Cellulosic materials consist largely of cellulose, hemicellulose, and lignin; these compounds make up a large fraction of the plant cell wall. Each of these materials can be converted to useful end products; however, the process used for their conversion is much more complex than the conversion of glucose. Cellulosic materials typically contain polysaccharide sugars and starches, and therefore, must undergo pretreatment to break-down the complex sugars to simpler and more digestible compounds. This complicates the process used to convert these materials; although, recently this issue is becoming less and less of an obstacle. This is a direct result of the numerous advancements that are continually being made in this field, especially in the area of feedstock pre-treatment. Agricultural-based, cellulosic feedstocks include wheat straw, switchgrass, and corn stover[lxii]. A more complete list of cellulosic feedstocks is presented in *Section 10.2.2.4*. Oilseed crops are also of importance in the production of renewable energy. Typical oilseed crops are soybeans, cotton, peanuts, and sunflowers.

Figure 112 shows a comparison of the amount of available agricultural feedstocks by source. Currently, only slightly more than one-fifth of the available biomass is being used, and the most available resources are agricultural residues. In fact, corn stover is one of the major, untapped sources of agricultural-derived biomass. Figure 113 shows the potential availability for agricultural feedstocks assuming moderate and high yield increases. The total availability including active, idle, and pastured cropland could grow to between 581 and 998 million dry tons per year (see Figure 114) with crop yield increases between 25 and 50 percent. This availability would require changes in tillage practices, residue to grain and seed ratios, and residue collection technology and equipment.[222]

[lxii] Corn stover is the portion of the corn stalk that remains following harvest

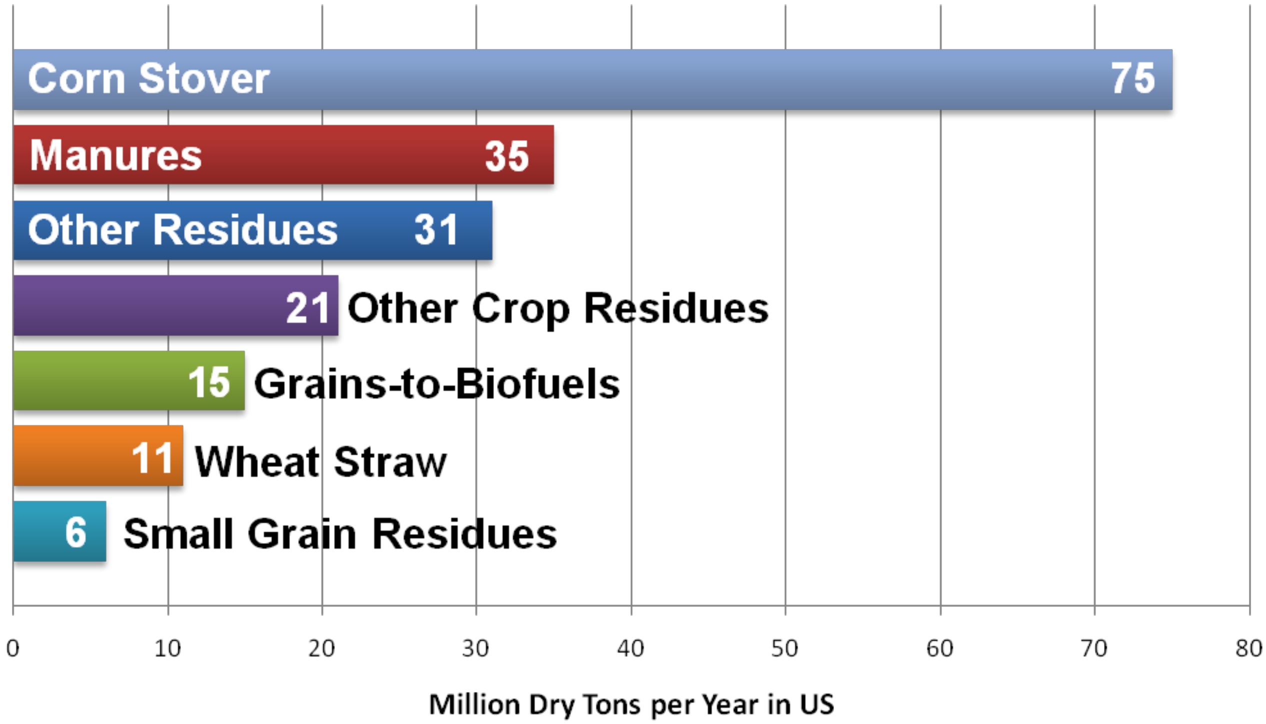

Figure 112. US agricultural feedstock availability.[lxiii, 222]

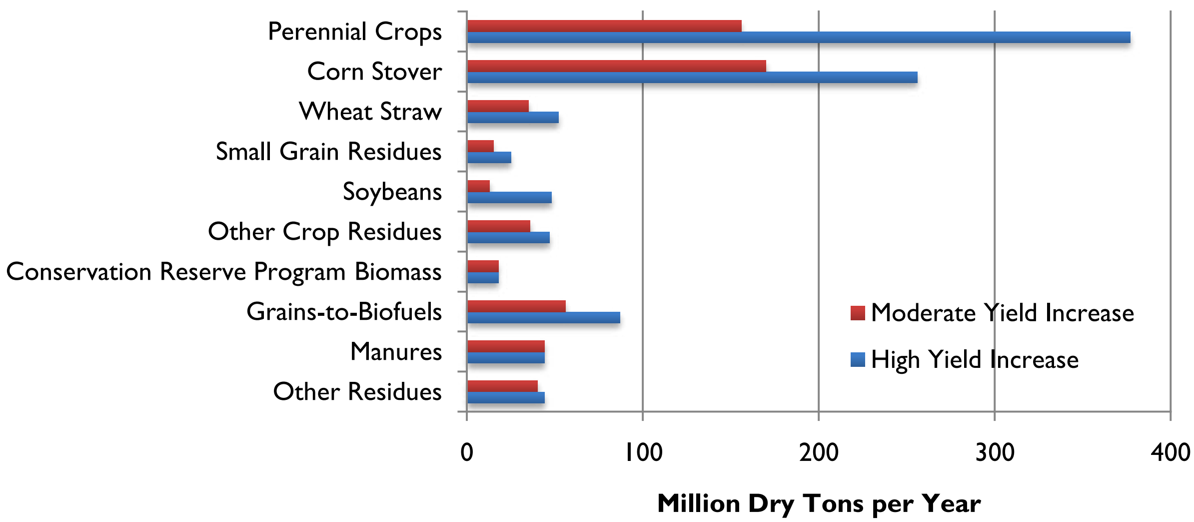

Figure 113. Potential availability of agricultural feedstocks with yield increases due to enhanced farming techniques.[222]

[lxiii] Small grain residues include sorghum, barley, oats, and rice. Other crop residues include cotton, other oil seeds (e.g., sunflower, peanuts, canola), tobacco, sugar crops, potatoes, beans, miscellaneous root crops, and double crops. Other residues include secondary agricultural processing residues, MSW, and fats and greases.

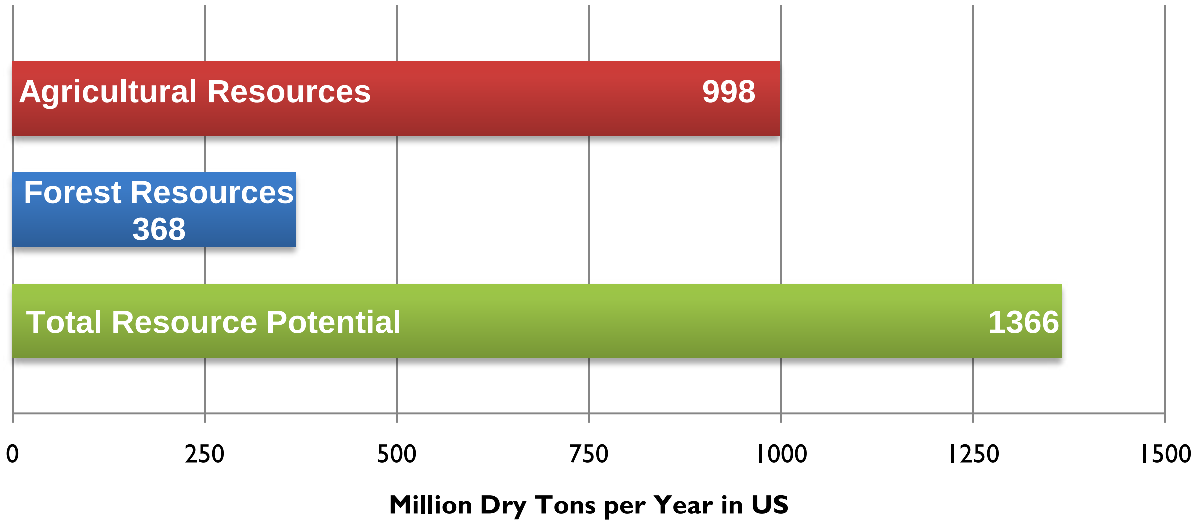

Figure 114. Potential availability for agricultural and forestry feedstocks.[222]

10.2.1.2 Forestry Based Feedstocks

Although strongly considered a sector of agriculture, the forestry industry is very much a vibrant and individualistic biomass resource. The forestry industry as a whole provides a vast majority of cellulosic feedstocks. Whole trees, mill and forest residues, and dedicated wood-based energy crops are all critical cellulosic biomass feedstocks. Dedicated energy crops include fast growing, short rotational woody crops, such as hybrid poplar and willow trees.

Wood and forestry resources have the potential to produce a total of 368 million dry tons of biomass per year in the US (see Figure 114). The removal rates for timber should remain relatively constant, even though the amount of timber used will continue to grow over the next fifty years, since it is expected that the inventory of unutilized timber will continue to grow dramatically as well.[216] When combined, forestry and agricultural resources have the potential to produce 1.366 billion dry tons per year of biomass feedstock.[216] Figure 115 and Figure 116 show the source specific breakdown of the potentially available agricultural and forestry feedstocks.

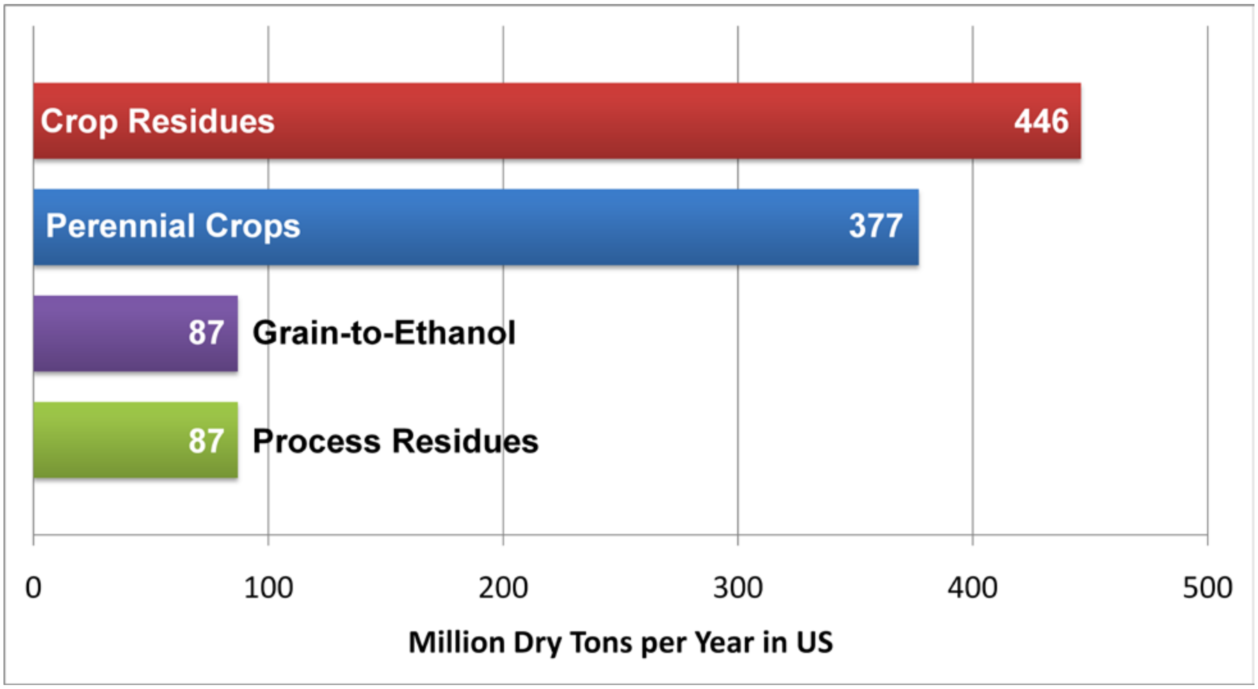

Figure 115. Potential availability of specific agricultural feedstocks.[222]

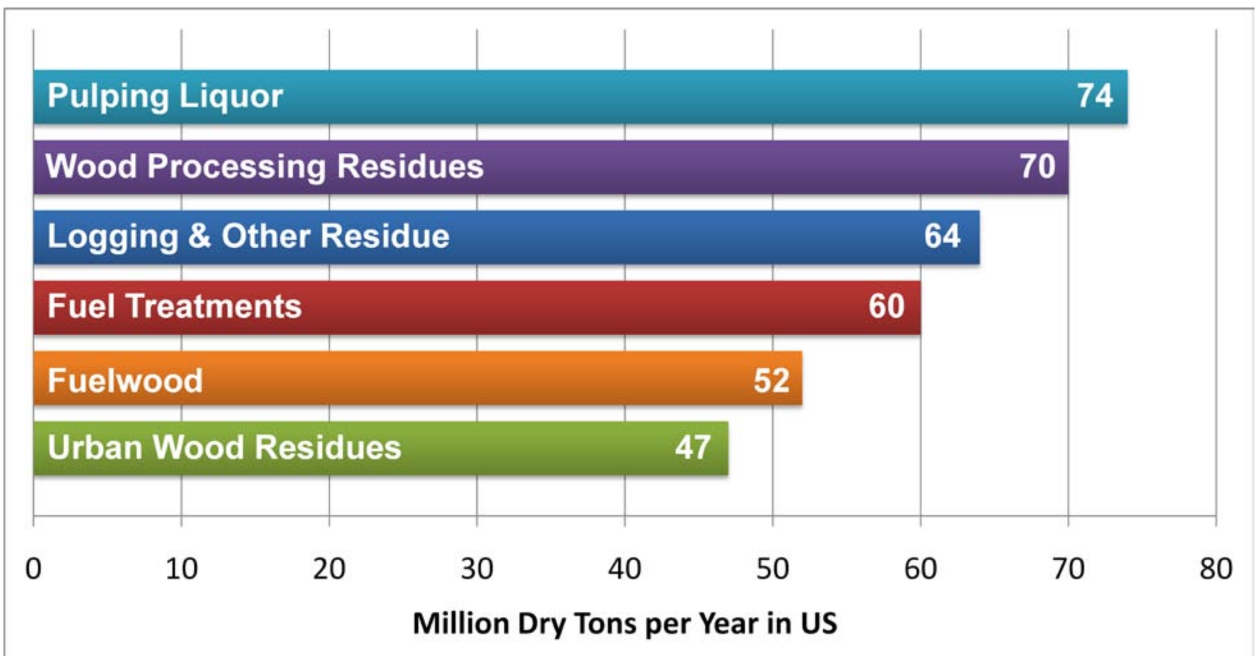

Figure 116. Potential availability of specific forestry feedstocks.[222]

10.2.1.3 Algae

Algae are another biomass feedstock that can be utilized for the production of renewable energy. Algae are an important biomass feedstock because they can be grown in almost any location given that there is an availability of water, CO_2, and sunlight. Algae, which consist of proteins, carbohydrates, fats, and nucleic acids, use a photosynthetic process to convert CO_2 into oil. They are also capable of producing ethanol. These fatty acids or oils can be harvested and refined to produce biodiesel, while the carbohydrate content of the algae can be fermented to produce ethanol.[223]

Algae can be used to produce fuels as an alternative to fossil fuels. They are one of the most productive renewable energy crops, generating approximately 5,000 gallons of biodiesel per acre per year, and their products can be harvested year-round. Algae are advantageous because they do not compete with food crops, are energy positive[lxiv], and use sunlight to convert CO_2 to a fuel.[224] This makes it easy to integrate algae systems into existing systems that expel CO_2 (i.e., coal fired power plants).[225] They can also utilize recycled water.[224]

Conversely, algae prove to be disadvantageous because they grow in extremely low mass concentrations, the harvested end product can vary in oil content from 5 to 40 percent based on time and season, and have variability in the oil quality. The oil produced by algae varies in quality more than that of crop oils, which can be caused by variability in strains, environmental growth conditions, and algae harvesting and oil extraction processes. These factors make it difficult to obtain a consistent production output and quality of algae oil.[225]

To solve many of these issues, discussions have focused on genetically modifying algae. This however could have unwanted repercussions. Many of the algae-environment interactions are not fully understood, and therefore genetic modifications could change the interaction with unknown consequences. These consequences would spread rapidly due to the photosynthetic efficiency of algae.[225]

10.2.1.4 Wastes

This category of biomass feedstock ranges from the gas produced as a result of decaying wastes to the energy that can be recovered from the combustion of waste products, such as garbage and urban wood residues. The most common form of waste used for energy production is municipal solid waste (MSW). MSW includes unwanted by products from consumption, processes, services, and other activities, and range from food wastes to yard debris. Wastes from large production facilities (i.e., manufacturing facilities, chemical production facilities, etc.) can also be collected and used as a source of energy.

Biogas can be harvested and used for energy production.[226] Biogas a mixture of methane gas, CO_2, and other gases produced as a result of wastewater treatment operations, manure degradation and emissions, and the biological degradation of waste materials under the anaerobic[lxv] conditions present within landfills.[216, 227] Biogas can be captured, collected, and combusted to convert the fuel to electricity. Many large farms utilize anaerobic digester technologies. On average, a cow has the potential to produce nearly 2.5 kWh of energy per day from the nearly 120 pounds of manure generated per day per cow.[227] However, for these anaerobic digestion systems that convert manure to electricity to be viable the operation must have more than 500 cows.[227] If swine manure is to be used, the operation must have more than 2,000 pigs to be feasible.[227]

A 2008 study showed that by converting biogas into electricity, via standard microturbines, 88 TWh of electricity could be produced.[227] This is 24 percent of the annual electricity consumption within the US.[227]

10.2.2 Feedstock Selection

The selection of the proper feedstock is one of the most difficult decisions when considering a biomass facility. The difficulty results from numerous limitations in available biomass feedstocks and in the harvest and transportation of these feedstocks. Transportation is a major concern because of the low energy density of biomass in comparison to other fuels which substantially drives up the costs of

[lxiv] Algae are energy positive since they produce more energy than they consume.
[lxv] Anaerobic refers to the absence of oxygen.

producing energy. Therefore, the type of feedstock should be one of the first considerations, and it should be considered simultaneously with the plant location.

If a facility or installation is considering utilizing energy generation from biomass the first step is to perform an assessment of the available feedstocks within the surrounding area. This should take into account any logistical issues (e.g., road type (single or double lane), haul distance, location of feedstock in relation to road) that could potentially arise in the transportation of the biomass from its source location to conversion location, whether it be on-site/ with the source or off-site.

When selecting a biomass feedstock, there are several supplementary points to consider. These include:

- the yield of the feedstock per acre
- the required input to obtain the assumed yield
- the costs that could be avoided by choosing one feedstock as opposed to another
- the environmental impacts associated with using the selected feedstock

For example, if corn stover was selected as the desired feedstock it would be necessary to account for the soil degradation that would result from the removal of this natural fertilizer. This could, in turn, lead to the need for increased purchasing of fertilizers to achieve the desired yield from future crops.

With the consideration of growth rate, yield, processing inputs, and labor, the most suitable crop for conversion depends strongly upon individual situations (i.e., location, available funding, crop cost). Specifically, the costs associated with growing the crop must be compared with those of purchasing the feedstock to determine if it is more cost effective to grow or purchase the feedstock. When considering agricultural crops, such as corn, corn stover, soybeans, perennial grasses (i.e., alfalfa and switchgrass), and others, it is necessary to take into account the labor, time, and energy involved in planting, maintaining, and harvesting the crop, especially if this is to be done on-site. It is also important to consider the costs involved in purchasing the seed, fuel, and fertilizer necessary for obtaining the crop as well.

No matter the choice of feedstock, there should always be a secondary feedstock selected. For instance, if an agricultural or forestry-based crop is selected, there are always risks of droughts and forest fires, respectively, that could lead to decreased or no production. This would cause the plant to shut down unless another alternative could be used during the times of limited feedstock production. Equally as likely are insect infestations or airborne plant diseases that can wipe out an entire crop. All of these possible situations must be considered in order to ensure a complete and functional plant with limited shut down periods.

In addition to these general considerations, basic biomass compositions should be surveyed and evaluated when selecting a biomass feedstock. Considering compositions early in the plant development could limit the number of issues that may arise further in the design cycle. Table 49 lists important feedstock characteristics to consider when selecting feedstocks and notes potential effects they can have on the system as a whole.

Table 49. Biomass characteristics impacting selection.[216]

Feedstock Characteristic	Process Components Impacted	Overall System Effect
Moisture Content	• Predrying equipment[lxvi] • Combustor • Boiler	High moisture content decreases the combustion efficiency and affects the boiler capacity because it takes an added 1,000 BTU to vaporize 1 pound of water
Particle Size	• Combustor • Emission control system	If entering particles are not the same size as those designed for, incomplete combustion will occur and heat energy will be lost to bottom ash and fly ash.
Volatiles, fixed carbon, and probable ash content[lxvii]	• Combustor • Boiler	Directly affects the heating value, flame temperature, and process by which combustion is achieved[lxviii]
Ash Content	• Air pollution control system • Boiler grates • Bottom ash handling equipment	
Fuel Content[lxix]	• Air pollution control system	Allows for the prediction of potential emissions

Furthermore, there are several other factors that affect the availability of biomass feedstock. The risk factors associated with biomass resource supply are:[228]

1. In most cases biomass is a byproduct of human behavior and as a result availability can change as behaviors change
2. The supply of biomass is strongly dependent upon the requirements of other businesses
3. The resource supply can change with political actions
4. The markets for power and energy conversion are immature
5. The suppliers are plentiful
6. The markets are dynamic, and the assessments of the available feedstock quantities are applicable over a short term period
7. The feedstocks themselves are also available for harvest over certain windows
8. Resource competition
9. Contracting challenges

Nevertheless, there are several tools available to determine the feedstock availability within a specific area. One such resource is the DOE's Energy Efficiency and Renewable Energy's Alternative Fuels and

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[lxvi] Predrying equipment is not typically used because it is quite expensive with the cost not being justified. It may be more cost effective to use a green wood fuel with 50-65% moisture content than to utilize pre-drying equipment.

[lxvii] A proximate analysis describes the volatiles, fixed carbon, and ash present in the fuel as a percentage of the dry fuel weight.

[lxviii] Aside from carbon and metals, the volatile components of fuels are burned in the gas phase, while the remaining carbon burns as a solid at the bottom of a furnace or as a fine particulate.

[lxix] An ultimate analysis determines the elemental composition of the fuel as a percentage of the sample's dry weight

Advanced Data Center's State Assessment for Biomass Resources Program. This tool provides information on the available biomass resources and their utilization throughout the US.[229]

The following subsections provide brief overviews of the common (cellulosic) feedstocks used in the production of renewable energy today. These overviews include advantages and disadvantages, as well as general points that should be considered upon selection.

10.2.2.1 Agricultural Residues

Agricultural residues are the portion of the agricultural crop that remains in the field following harvest. These residues have the potential to displace about 12.5 percent of all petroleum imports, or alternatively, they have the potential to offset approximately 5 percent of the electricity consumption in the US. Additionally, the utilization of crop residues increases the economic efficiency of the crop produced by using a greater percentage of the mass for energy generation. However it is important to maintain soil qualities by harvesting the residues in a sustainable fashion, such that they are not overharvested.[230] Sustainability is accomplished by leaving a portion of the crop residue in the field to limit the amount of soil erosion and to help maintain the soil quality. This, however, reduces the potential harvest and cause feedstock shortages if not taken into consideration.

The amount of crop residue that must remain is highly dependent on the pre-existing soil quality, soil type, the previous crop type, tillage method used, and weather conditions.[226, 231] The frequency of crop rotations can also affect the soil quality and in turn the amount of residue harvested. In general, crops, known as legumes (i.e., alfalfa), fix, or put, nutrients into the soil (i.e., nitrogen) whereas other crops take these nutrients out of the soil (i.e., corn). Since these crops have opposite actions, they are often rotated to enhance the soil quality, while minimizing the need for added fertilizers. For corn and alfalfa, the rotation period is typically 3 to 5 years. If planting soy beans, the rotation period is much less, typically 1 to 2 years. However, the rotation schedules depend strongly upon the crops planted and the region in which they are planted. Information on typical crop rotation schedules can be obtained by contacting Cornell Cooperative Extension or the Soil and Water Conservation District. These organizations are county specific and provide information on planting and maintaining agricultural crops.

Under average conditions, 30 to 40 percent of the residues from wheat straw and corn stover can be removed without soil integrity compromises.[226] It can be assumed that 30 percent residue cover is sufficient for protecting the soil integrity, and that if left for grazing, animals generally consume no more than 20 to 25 percent of the stover.[231] However, these values vary by region. In some regions of the country there is limited time following the crop harvest for the residues to be collected. In others only one crop harvest may occur per year due to shorter growing seasons, which reduces the yield of residues compared to locations where more than one harvest can be completed. These factors must be considered to ensure that enough harvestable residues are actually produced to sustain the plant until the next harvest. Likewise, enough storage area must be provided to handle the supply as well, unless alternative arrangements are made (i.e., the producer stores the residues until needed).

It was estimated in 2003 that the cost for agricultural residues, including collection costs, farmer payments[lxx], storage, and transport, were between 35 to 55 dollars per ton.[226] Table 50 provides harvest costs for various residues throughout the US, overall crop production, and a comparison of the residues available versus those that can be utilized.[230] *Section 10.2.2.4* summarizes the heating values and combustibles for common agricultural feedstocks.[232]

[lxx] The payments to the farmer are a form of compensation for the lost nutritional value to their soils.[226]

Table 50. Agricultural crop residue harvest costs for various locations across the US.[230]

County	State	Crop	Crop Yield (bushel/acre)	Gross Residue Yield[lxxi] (lb/acre)	Conservation[lxxi, lxxii] (lb/acre)	Net Residue Yield[lxxi] (lb/acre)	Harvest Cost[lxxiii] ($/ton)
Story	Iowa	Corn	147.0	7,694.2	1,430	6,264.2	12.7
Ford	Kansas	Corn	173.1	9,060.3	2,400	6,660.3	12.4
Riley	Kansas	Winter Wheat	40.7	4,070.0	715	3,355.0	15.7
Ford	Kansas	Wheat / Fallow	28.5	2,849.1	1,500	1,349.1	29.8
Norman	Minnesota	Spring Wheat	31.2	3,119.3	715	2,404.3	19.4
Riley	Kansas	Sorghum	80.9	4,854.0	1,500	3,354.0	16.6
Ford	Kansas	Sorghum	80.2	4,812.0	1,500	3,312.0	16.7
Norman	Minnesota	Barley	54.9	4,392.0	715	3,677.0	17.3
Norman	Minnesota	Oat	67.7	4,062.0	715	3,347.0	18.6
Arkansas	Arkansas	Rice	137.8	5,239.0	0	5,239.0	20.3

In comparison to other crops, agricultural residues are typically dryer than wood, but have a higher ash content and lower density. The lower ash fusion temperature[lxxiv], coupled with a lower moisture content leads to problems such as clogging in the combustor or boiler. These can be alleviated by burning agricultural residues in low concentrations with coal or wood (i.e., co-firing).[216]

Figure 117 shows the agricultural crop residues available in each county and state across the US. The crops included in this map are: corn, wheat, soybeans, sorghum, barley, oats, rice, rye, canola, dry edible beans, dry edible peas, peanuts, potatoes, safflower, sunflower, sugarcane, and flaxseed. The available quantities were estimated from the five year (2003 to 2007) average total grain production, crop-to-residue ratio, moisture content, and the amount of crop residue left in the field. For the purposes of this assessment, it was assumed that 35% of the total residue was available for collection as a feedstock.[231]

[lxxi] Dry weight
[lxxii] Conservation is the amount of crop residue that must be left in the field for land/ animal sustainability.
[lxxiii] Direct costs plus fertilizer costs
[lxxiv] The ash fusion temperature is the temperature at which ash particles fuse together.

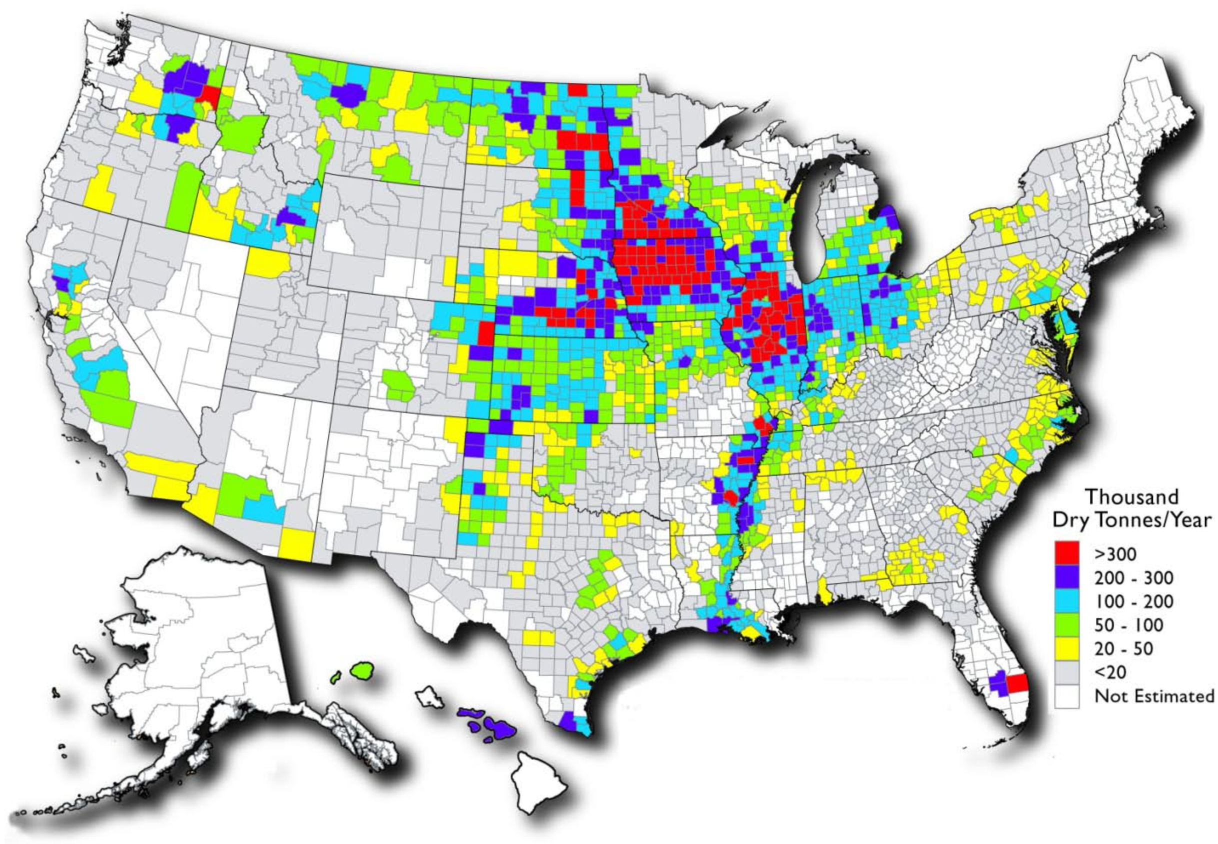

Figure 117. Agricultural crop residue production.[220]

When utilizing agricultural residues, it is important to be aware of the potential for contamination by dirt and rocks. These contaminants contribute more than 2.5 percent of the weight of corn stover on average and lead to increased operations and maintenance costs for the boiler equipment and power system components. In terms of other residues such as oat hulls, the contaminants often originate in the processing plant rather than the field.[233]

10.2.2.2 Dedicated Forestry Energy Crops

Dedicated energy crops, such as hybrid poplar and willow trees, are obtainable at a higher cost than corn and wheat-based agricultural residues. Hybrid poplars are typically planted with a density of 500 to 600 trees per acre and can be ready for harvest in six years. Hybrid willow is planted at a much greater density than poplar and requires approximately four years to reach maturity.[226]

These crops require the availability of enough acreage such that trees can be planted in a manner that allows for a mature crop to be harvested every year or as needed, depending on the facility requirements and available storage. For example, enough crop land is needed to plant seedlings each year, with enough other land to have trees at the various stages of growth including a portion of mature trees. There needs to be a cycle so that as one crop is harvested, one is planted, and another nears full maturity. If the costs for production, harvesting, and hauling are included, it can be estimated that poplars cost between 55 and 70 dollars per dry ton and willows between 65 and 75 (in 2003 dollars).[226]

10.2.2.3 Forestry and Mill Residues

Forest residues are often low-value materials that result from harvesting, thinning, and land-clearing operations as a part of commercial logging. Forest residues can include tree tops, limbs, bark, and whole trees. On average, forest residues have a moisture content between 40 and 60 percent; this value is higher in actively growing plants, and lower in those that are dormant.[234] Figure 118 provides an estimate of the available forest residues by county in the US. This figure includes the production of logging residues[lxxv] and other removal processes such as thinning and weeding, or land clearing. This figure is based upon the United States Department of Agriculture's (USDA) Forest Service's Timber Product Output database for 2007.[220]

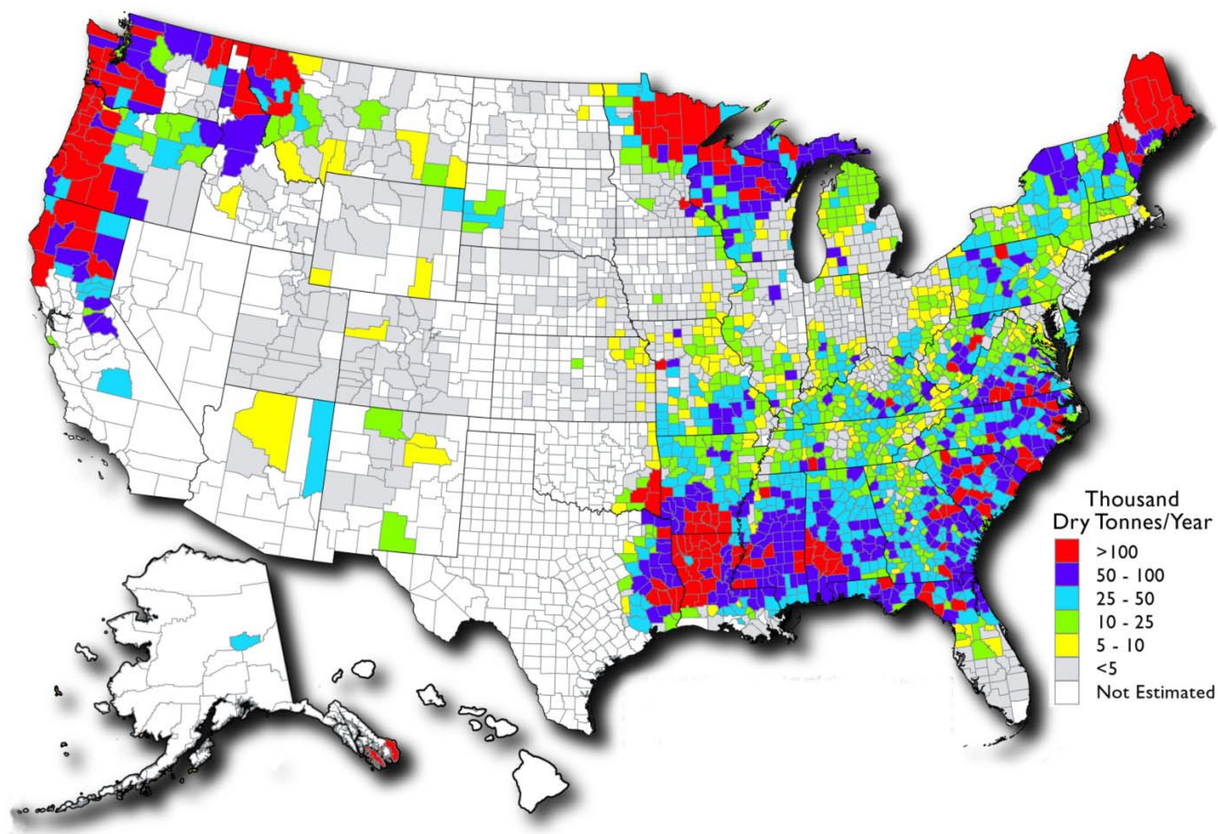

Figure 118. Estimated available forestry residues by county within the US.[220]

Mill residue feedstocks are an economical option because they consist of left over portions of wood, as well as stripped bark, sawdust, and shavings that result from the processing of raw trees into useable wood. These wood residues are often desirable due to their uniform size, cleanliness, and centralized location. In 2003, the estimated cost for mill residues with a moisture content of approximately 20 percent, including collection, processing, transportation, and mill payments was in the range of 25 to 55 dollars per ton.[226] However, as the moisture content increases, the price generally decreases. Wood is generally obtained with a moisture content near 50 percent making its handling, storage, and

[lxxv] Logging residues are the unused portions of trees, either cut or killed by logging and left in the forest.

combustion costly; however, its price is estimated to be $15 to 20 per ton makes it an attractive and cheap fuel. In fact, mill residues are considered to be the cheapest wood-based fuel available.[216]

Mill residues can be classified either as primary or secondary. Primary mill residues are the direct product of manufacturing plants and include slabs, edgings, trimmings, sawdust, veneer clippings and cores, and pulp screenings. Figure 119 provides estimations of the available primary mill residues produced within the US by county. Secondary mill residues are the byproduct of woodworking shops. These include furniture production facilities, wood container and pallet mills, and wholesale lumber yards. Data from the US Census Bureau's information on the 2002 County Business Patterns was utilized to create a chart depicting the available secondary mill residues by county, which is shown in Figure 120.[220, 231] On average, secondary mill residues have a greater energy content than primary mill residues while also having a moisture content of less than 10 percent and an ash content less than 0.5 percent.[234]

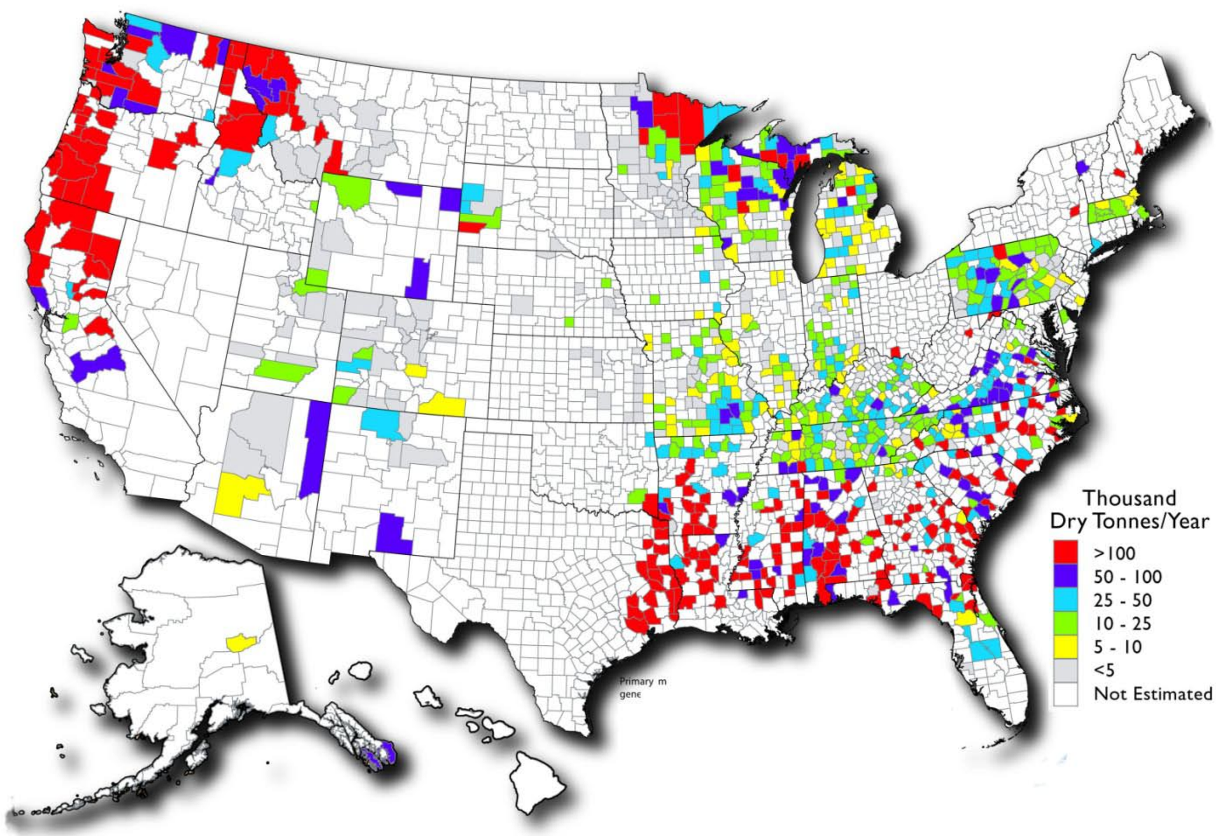

Figure 119. Primary mill residues available by county in the US.[220]

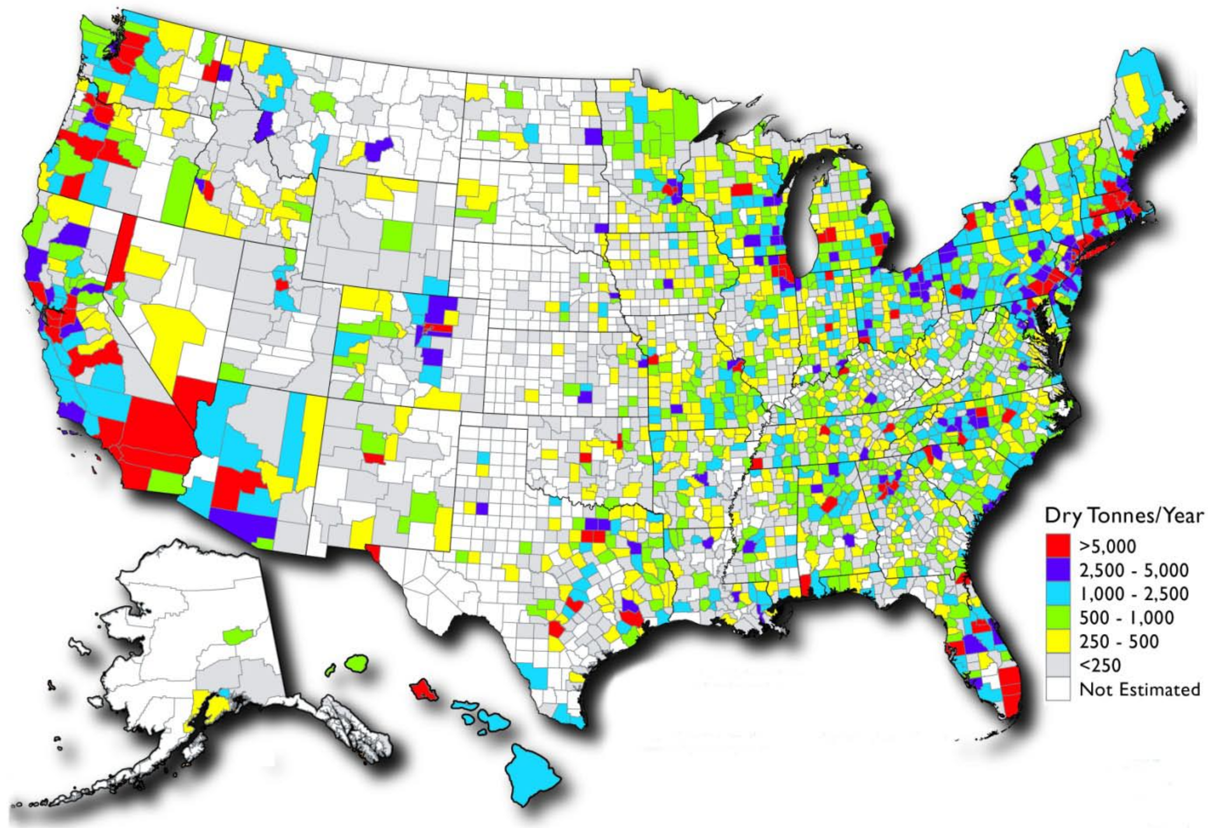

Figure 120. Secondary mill residues available by county.[220]

Forest residues can often be obtained within the same price range as mill residues. This includes the cost of collection and transportation as well as the stumpage fee[lxxvi] when applicable.[226] This term is often used interchangeably with a stumpage royalty which denotes payments to a public authority in exchange for the use of trees on public lands.[219]

10.2.2.4 Summary of Agricultural and Woody Residues

Table 51 provides a listing of the common forestry feedstocks utilized in the biopower, bioheat, and biofuel industry as well as their basic chemical compositions and physical properties. These properties are critical to determining the portion of combustible and non-combustible materials, fermentable and non-fermentable materials, and waste materials within a feedstock. The feedstock categories are divided based upon their classification (i.e., agricultural residue, woody crop residue, and herbaceous crops). Since crops are available in numerous types, the variety has been listed for completeness.

HHV is critical to determining the amount of by-product heat that can be attained from any given system based upon the feedstock and feedstock quantity used. Ash directly corresponds to waste and therefore money output since it must be removed from the bioenergy facility. Lignin, cellulose, and hemicellulose are the key components of the cell wall in any plant material. These values are most

[lxxvi] A stumpage fee is a financial concept utilized to place a monetary value on standing wood resources, or live, unharvested trees.

important when considering a fermentation or biocatalytic process since some components decompose more rapidly and with fewer processes than others. For example, it is often more complicated to separate cellulose from the other components than to separate hemicellulose; however, the conversion of cellulose is easier than that of hemicellulose and lignin. The elemental and fixed carbon values are indicators of the percentage combustible material contained within the feedstock. The volatile matter is also important in determining the quantity of material that will be available for combustion versus the total material. Overall, portions of the proximate and ultimate analyses were highlighted, meaning more reports are available. For this reason, the sum of the mass percentages does not equal 100.

Table 51. Combustion properties for various agricultural and woody feedstocks.[232]

Feedstock	Variety	HHV (BTU/lb) [lxxvii]	Ash (% mass)	Lignin (% mass)	Cellulose (% mass)	Hemi-cellulose (% mass)	Elemental Carbon (% mass)	Fixed Carbon (% mass)	Volatile Matter (% mass)
Agricultural Residues									
Corn Stover[lxxviii]	Zea mays	7,867	11.63	18.69	35.46	22.83	46.64	21.26	72.57
Sugarcane Bagasse[lxxix]	Gramineae Saccharum Variety 65-7052	8,226	3.69	23.78	41.72	25.31	48.53	17.83	79.68
Sugarcane Bagasse[lxxix]	Saccharum Species	8,149	4.00	23.10	38.60	23.00	47.57	17.10	78.68
Wheat Straw[lxxx]	Thunderbird	7,481	10.22	16.85	32.64	22.63	43.88	21.54	69.38
Woody Crops and Residues									
Hardwood									
American Sycamore[lxxxi]	Platanus occidentalis	8,416	1.05	25.47	39.82	18.00	49.66	19.06	80.33
Black Locust[lxxxi]	Robinia pseudoacacia	8,473	1.54	26.14	40.83	17.85	50.03	20.18	78.75
Eastern Cottonwood[lxxxi]	Stoneville #66	8,431	1.00	25.60	42.20	16.60	49.65	20.06	79.16
Eucalyptus[lxxxi]	Saligna	8,407	1.24	27.01	46.05	14.47	49.75	18.63	80.47
Hybrid Poplar[lxxxi]	Caudia, DN-34	8,437	1.87	26.04	41.68	17.93	50.19	19.00	79.27
Hybrid Poplar[lxxxii]	DN-34		0.71	23.81	43.38	21.74			
Softwood									
Monterey Pine[lxxxii]	Pinus radiata	8,422	0.3	25.9	41.7	20.5	50.26	19.35	80.45
Herbaceous Energy Crops									

[lxxvii] Moisture free
[lxxviii] Stalks and leaves without cobs
[lxxix] Whole residue
[lxxx] Whole plant
[lxxxi] Whole tree without leaves or needles
[lxxxii] Debarked wood

Big Bluestem[lxxxiii]	Genotype, Green County, AL, Baldwin County, GA		4.44	19.96	31.41	22.02			
Big Bluestem[lxxxiv]	Genotype, Green County, AL, Baldwin County, GA		2.97	19.09	35.52	25.22			
Serica Lespedeza[lxxx]	Serala	8,449	2.69	29.12	35.76	17.71	49.41	21.67	76.75
Switchgrass[lxxx]	Alamo	8,040	5.82	18.73	33.56	25.82	47.26	20.61	74.24
Switchgrass[lxxxiii]	Alamo		5.53	15.46	28.24	23.67	46.93		
Switchgrass[lxxxiv]	Alamo		3.08	17.27	36.04	27.34	47.02		
Switchgrass[lxxxiii]	Cave-In-Rock		5.31	15.99	29.71	24.40	47.11		
Switchgrass[lxxxiv]	Cave-In-Rock		2.77	17.62	35.86	26.83	47.34		
Switchgrass[lxxxiii]	Kanlow		5.29	17.29	31.66	25.04	47.38		
Switchgrass[lxxxiv]	Kanlow		2.73	18.11	37.01	26.31	47.54		
Switchgrass[lxxx]	Cave-In-Rock High Yield		5.985	17.465	32.105	26.96	46.61		
Switchgrass[lxxx]	EYxFF-H		6.56	18.894	32.864	27.094	46.3		
Switchgrass[lxxx]	EYxFF-L		7.126	18.388	33.31	26.79	46.078		
Switchgrass[lxxx]	Trailblazer		7.005	19.05	33.25	25.85	46.07		
Switchgrass[lxxx]	Blackwell		6.41	17.765	33.645	26.29	46.23		
Tall Fescue[lxxxiii]	John Stone		10.895	12.5875	24.585	18.5475			
Tall Fescue[lxxxiii]	Martin		10.86	14.2275	25.77	19.68			
Tall Fescue[lxxxiii]	KY31		11.98	14.605	24.845	19.14			

[lxxxiii] Leaves
[lxxxiv] Stems

10.2.2.5 Municipal Solid Waste

The costs of landfill tipping fees and processing and transportation of municipal wastes can be avoided through the use of MSW as a biomass feedstock. Although MSW is available at minimal to no cost, there are several drawbacks to using it as a feedstock. The most significant disadvantage to MSW is the requirement for specialized equipment to remove non-combustible materials from those that are combustible. This separation adds to the cost of using MSW, and it has been estimated that cost is from $25 to 35 per ton.[226] Nevertheless, waste can be obtained at almost any location where there is human activity. Transportation of the MSW to the conversion site, if it is needed, is also an already well-established process.

Raw MSW is not the only source of energy. In fact, the gas produced from the decomposition of MSW (i.e., biogas) can be utilized as well. The biogas produced is rich in methane, which can be utilized as a direct power source. Figure 121 shows the estimated methane emissions from various landfills throughout the US taking into consideration the total waste in place, the size of the landfill, and the location. Not all landfills are included in this figure, however, due to gaps in available data.

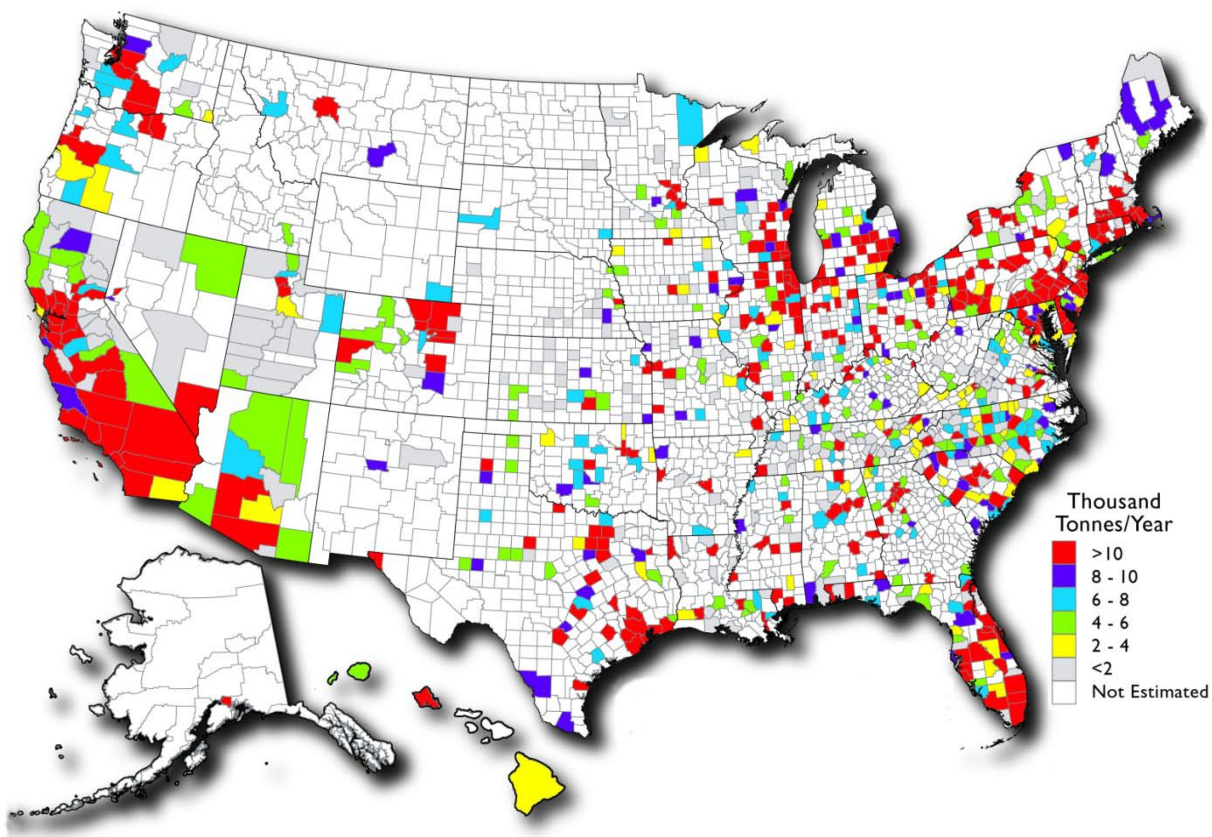

Figure 121. 2008 estimate of landfill methane emissions by county.[220]

10.3 Products

Biomass can be converted into several useful power and energy related products, including biofuels, power, and heat. Hence, the terms biofuels, biopower, and bioheat are often used to denote these products. In some instances, the products can be co-produced. There are several ways in which the desired product(s) can be obtained; many depend strongly upon the feedstock selected.

Product selection is often performed in conjunction with the feedstock and site selections as they are dependent upon one another. This is because not all feedstocks can be used for the production of the desired end product. In the same sense, the feedstocks that could be used for the desired end product may not be available in the area of consideration. Therefore, these factors must be accounted for simultaneously to estimate potential supply and product output. This can make the product and feedstock selection a complicated decision involving much compromise.

10.3.1 Biofuels

The most common feedstock in the production of biofuels is wood waste. Bagasse (sugarcane residues), and other agricultural sources such as straw, rice hulls, shell hulls, and switchgrass are becoming popular.[226] Corn feedstocks are relatively high in cost. The two common biofuels are bioethanol and biodiesel, but methanol and butanol can also be produced.

The production of ethanol from grain-based sources via fermentation is plagued by a poor energy balance. For instance, the amount of energy required to make one gallon of ethanol is approximately equal to the energy it is capable of putting out upon combustion. In addition, bioethanol has a heating value that is about 70 percent that of gasoline. It does however have an extremely low sulfur and ash content. Biodiesel is similar to petroleum-derived diesel fuels except that, like bioethanol, it has a negligible sulfur and ash content. Both biodiesel and bioethanol have lower vapor pressures and flammability potentials than their petroleum-based counterparts. These are good properties for safety reasons, but not for engines starting in cold temperatures.[216]

Biodiesel and bioethanol are currently being subsidized significantly by federal support and tax incentives for motor fuel applications. These subsidies are helping to improve the economic viability for the production of biofuels. The economics for these alternative fuels is currently complicated by high feedstock costs (partially resulting from government incentives intended to raise the rate of production, which causes the feedstock price to increase as a result of supply and demand principles).[216]

The production of ethanol from cellulosic feedstocks mitigates many of these cost and energy balance issues. If wood is used, the costs decrease and the energy used to provide the feedstock is dramatically decreased. The greenhouse gas emissions are decreased three times more than when using corn as a feedstock. Combusting biofuels derived from corn reduces greenhouse gas emissions by 25 percent compared to the combustion of conventional fossil fuels, while cellulosic feedstocks reduce the emissions by 75 percent.

Methanol is similar to ethanol. However, because it is toxic and acts aggressively on some fuel system materials, it has had limited consideration in comparison to ethanol and there are no commercial facilities.[216] Similarly, butanol is another biofuel product, but its development as a biofuel has not been emphasized to the same degree as ethanol.

There are two major methods available for the production of alcohol fuels from biomass. The first is often referred to as a thermochemical platform. In this process the biomass is gasified followed by a catalysis reaction to produce the liquid fuel. An example of this process is shown in Figure 122. The second, more common method, is referred to as the sugar platform and is a biochemical process, in which the simple sugars are derived from the feedstock and fermented using microorganisms.[216] The two major biochemical fermentation processes are presented in *Sections 10.3.1.1* and *10.4.1*.

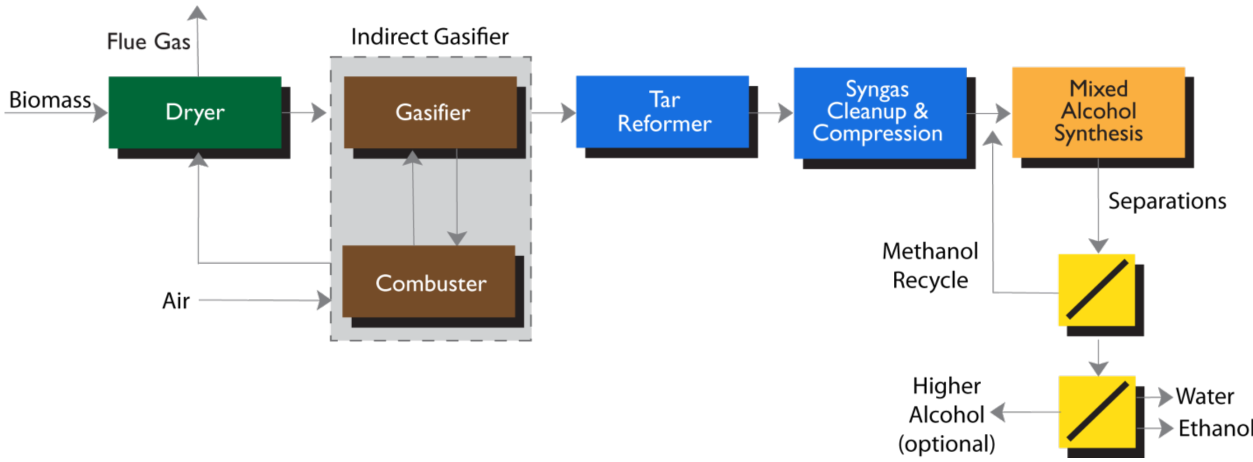

Figure 122. Example of a thermochemical biofuel production process.[235]

10.3.1.1 Fermentation

Fermentation is a common biochemical process that can be used to convert biomass feedstocks to biofuels. The fermentation process can vary according to the specific biological enzymes used for the conversion, operating conditions, and feedstock type.

The primary products of fermentation are liquid alcohols, such as ethanol and butanol. Often, these alcohols are separated and used in a refined form to power automobiles. It is also important to note that when the process is designed effectively, the byproducts can be used elsewhere. For example, the CO_2 that results from fermentation can be used as the reducing agent in a parallel gasification process that uses other waste materials from the pre-treatment and conversion steps to produce heat, electricity, and other types of fuel. Furthermore, this reduces the amount of waste generated from the process.

10.3.1.1.1 Fermentation of Grain-Based, Starch, and Sugar-Based Biomass

The fermentation of starch and sugar-rich biomass is a well developed process. This type of biomass is rich in simple sugars, such as glucose (e.g., sugarcane, sugar beets, and corn). Glucose, as shown in Figure 123, is a simple sugar that can be readily converted by fermentation, using enzymes in the presence of O_2, to form ethanol and CO_2 with minimal pre-processing of the feedstock.[236] Starch is a glucose polymer that is easily decomposed since it has α-glycosidic linkages (see Figure 124).[237] The feedstock processing occurs either by a wet or dry milling process. Wet milling (see Figure 125) involves the separation of the feedstock into its components, including starch, protein, oil, and fiber. Dry milling (see Figure 126) involves the grinding and cooking of the feedstock prior to fermentation, with the separation occurring at the end of the processing. Distillation is the most important separation process and is used to recover ethanol from the fermentation product.[236, 238]

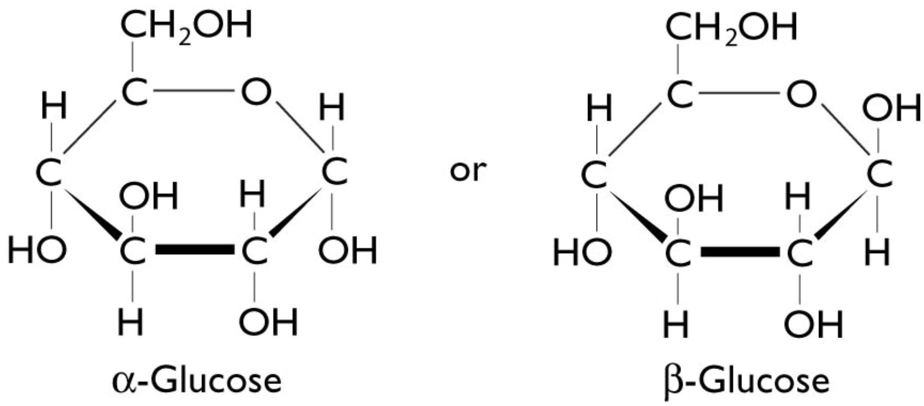

Figure 123. Two most common glucose isomers found in nature.[239]

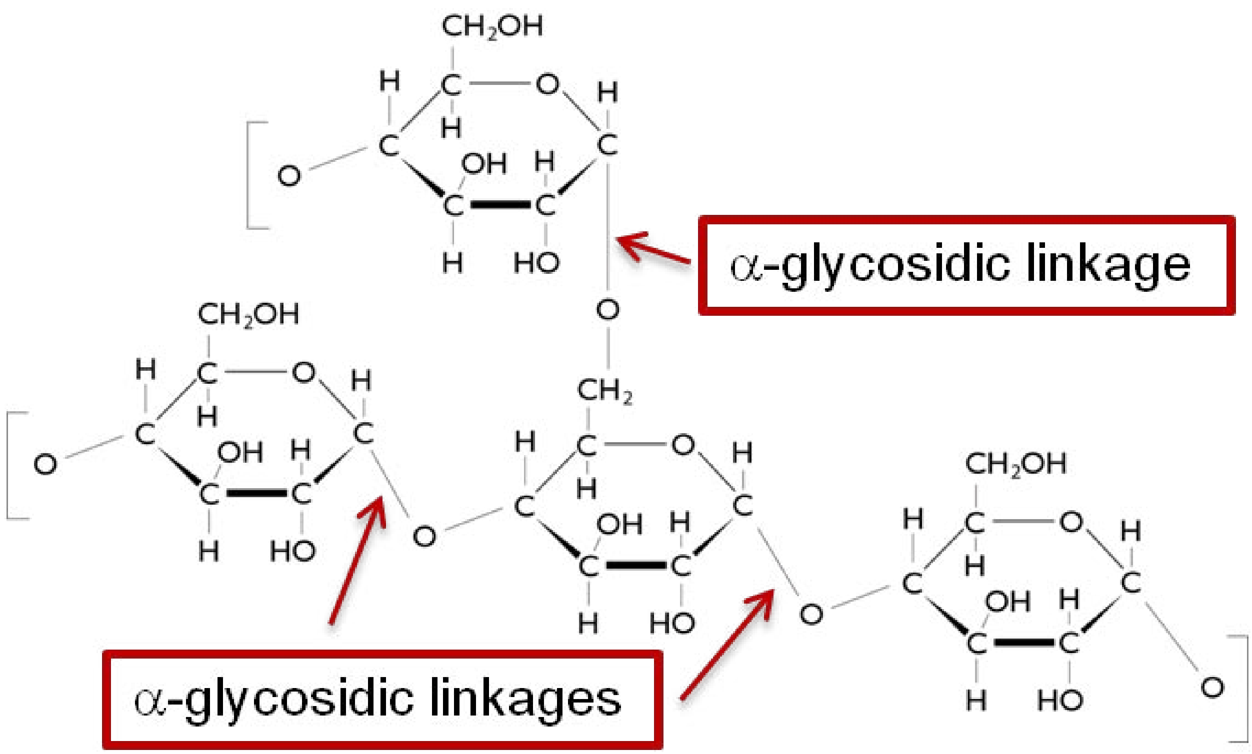

Figure 124. Starch molecule with α-glycosidic linkages, which are easier to decompose than β-glycosidic linkages.[237]

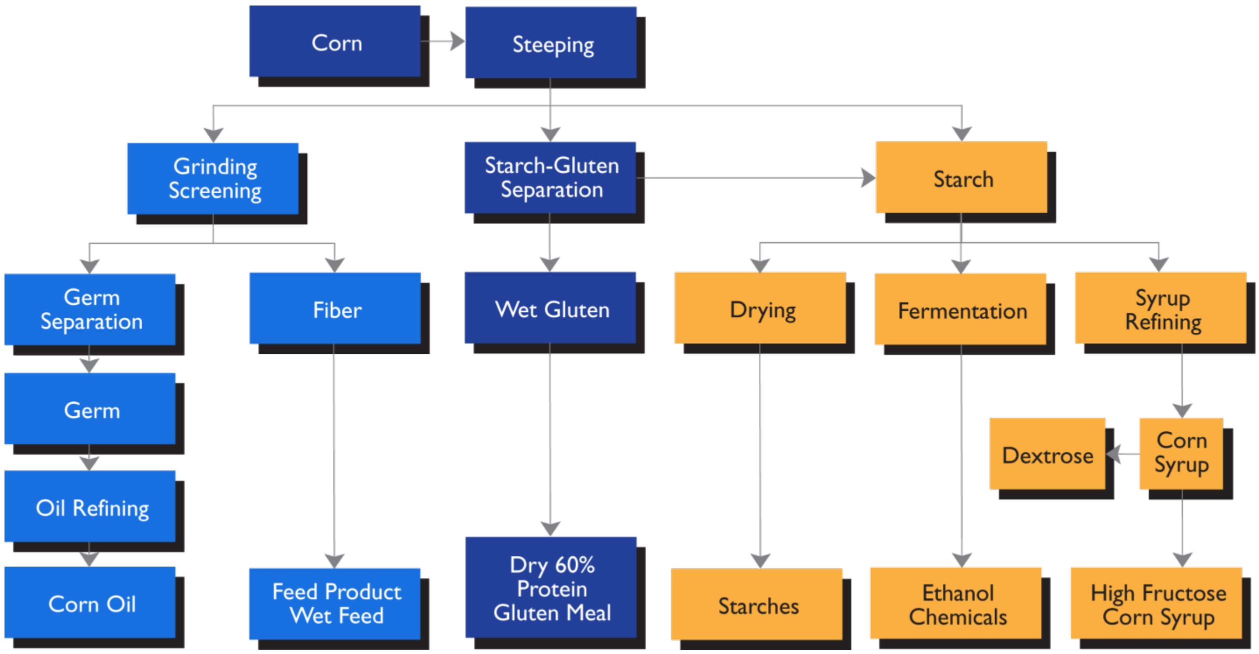

Figure 125. Example of biomass wet milling and fermentation process.

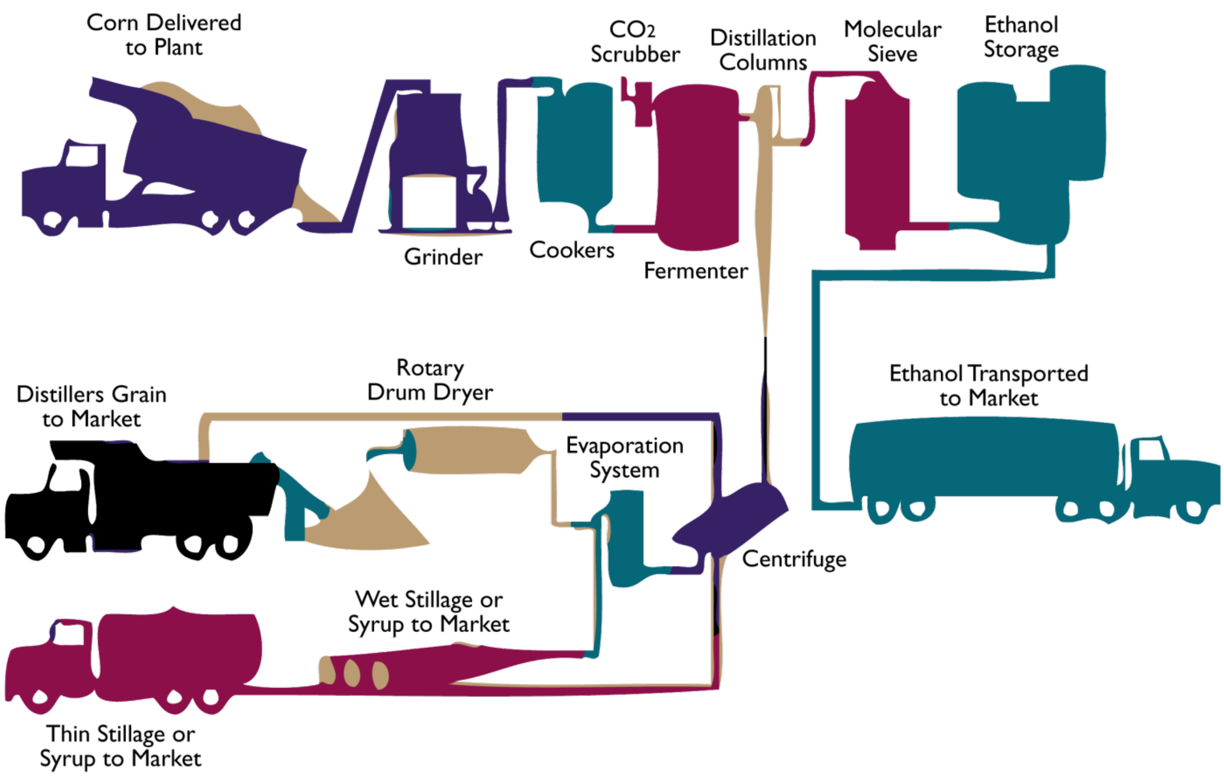

Figure 126. Example of biomass dry milling and fermentation process.[240]

10.3.1.1.2 Fermentation of Lignocellulosic-Based Biomass

The fermentation of lignocellulosic biomass is similar to the fermentation process for starch and sugar-based biomass. The main difference is that lignocellulosic feedstocks must go through an extensive pretreatment process, which decomposes the complex sugars into simple sugars. Figure 127 shows the internal structure of a cellulosic feedstock. The main component, cellulose, is a rigid, linear, glucose-based polymer that is highly stable and difficult to decompose (see Figure 128). The decomposition is difficult because the glucose molecules are held together by strong β-glycosidic linkages and hydrogen bonds (see Figure 129).[237] A hydrolysis process breaks down the cellulose polymer into glucose molecules (see Figure 130). Once decomposed, the simple sugars can be readily digested by biological organisms. This overall fermentation process is relatively expensive, however, because of the resource intensive pretreatment step, which is the largest cost after purchasing the feedstock.[236] An overview of the process is provided in Figure 131.

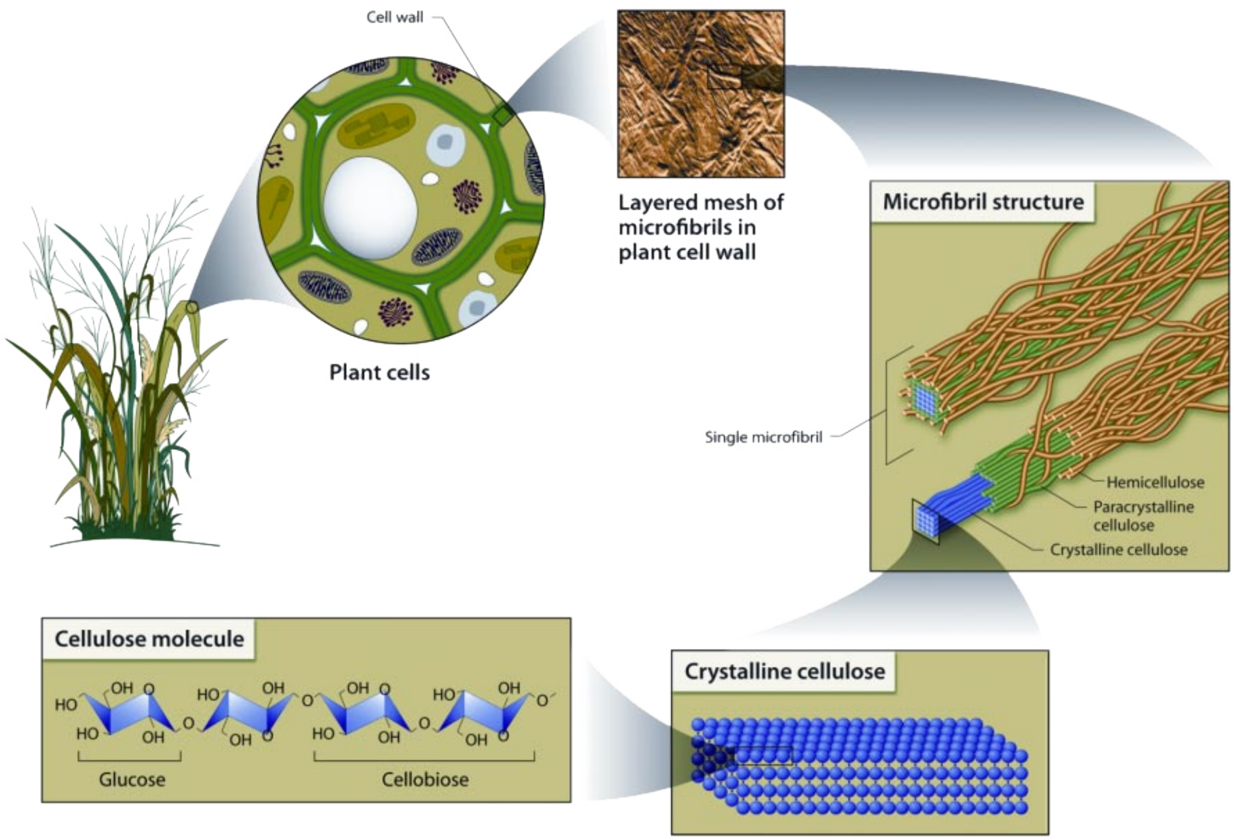

Figure 127. Internal structure of a cellulosic feedstock.[241]

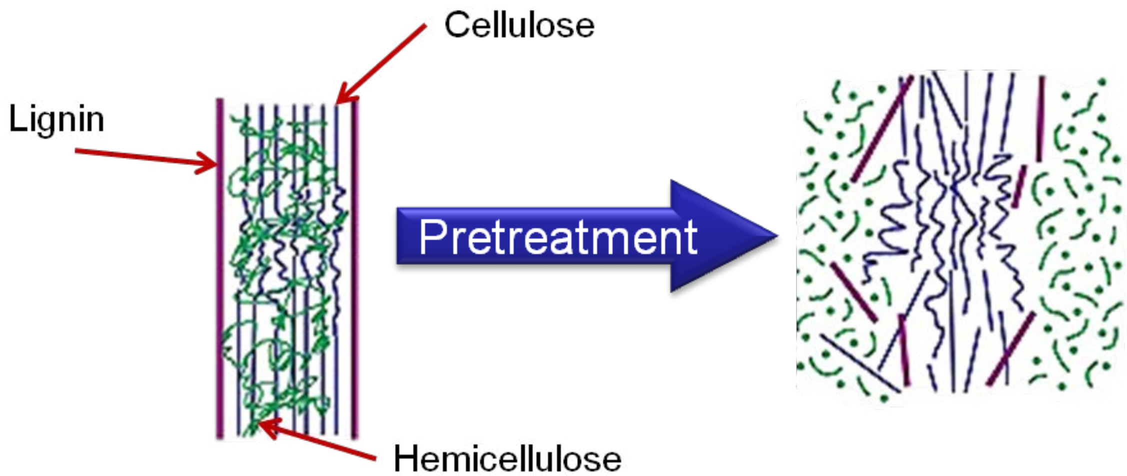

Figure 128. Illustration of lignin, cellulose, and hemicelluloses in a biomass feedstock before and after decomposing pretreatment.[242]

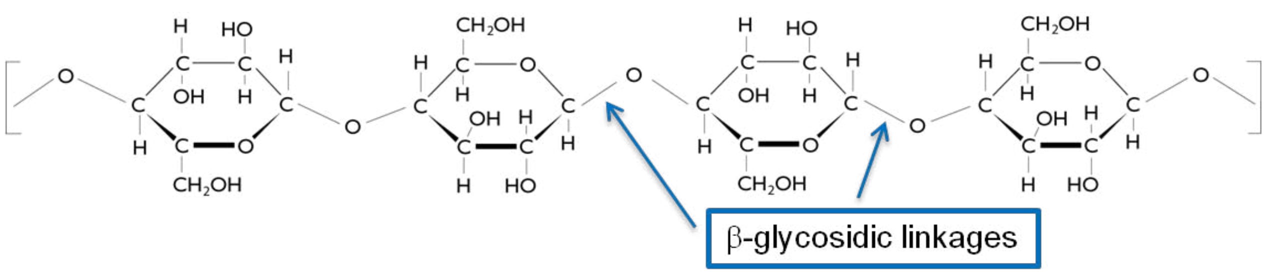

Figure 129. Cellulose molecular structure.[237]

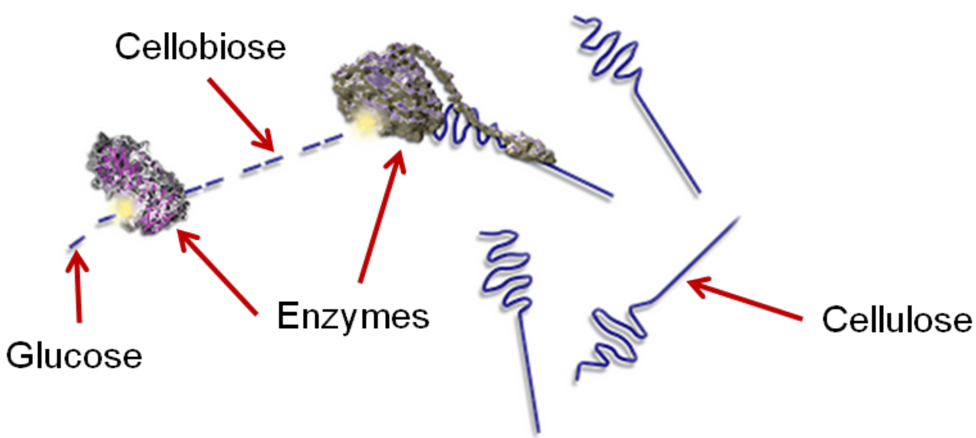

Figure 130. A hydrolysis process decomposes the cellulose into glucose molecules.[242]

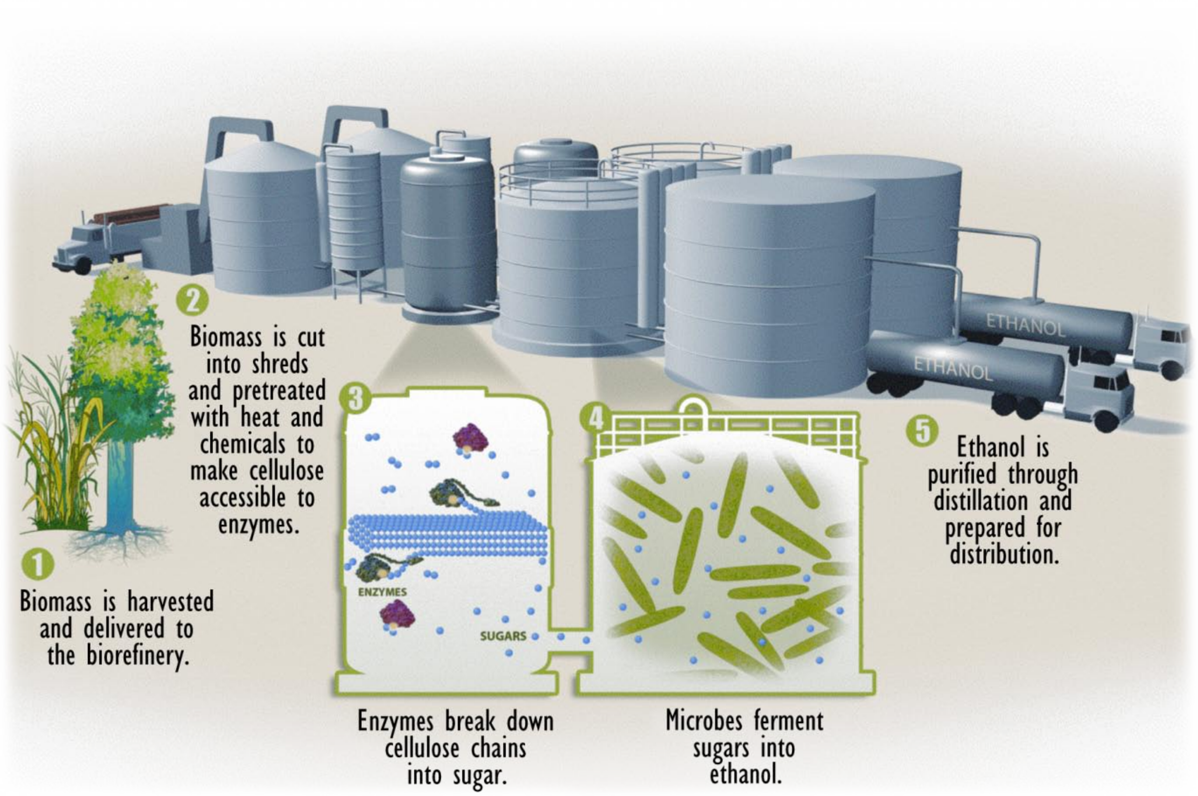

Figure 131. Overview of process that converts cellulosic biomass into ethanol. (Courtesy of US Department of Energy Genome Programs, http://genomics.energy.gov)[243]

10.3.2 Biopower

Biopower is the electricity generated from a biomass feedstock and is a proven, effective source of renewable electricity in the US. Currently, biopower accounts for 0.5 percent of the nation's power needs.[244] The US has a potential installed capacity near 11 GW. Approximately 7.5 GW of electricity can be produced from forestry products and agricultural residues and an additional 3.0 GW can be produced from MSW. The use of landfill gas would add 0.5 GW of electricity production.[245]

10.3.2.1 Plant Capacity

The typical biomass plant size is less than 50 MW in capacity. This is primarily because the transportation of biomass is inefficient as a result of its low energy density, which makes transportation cost intensive. Therefore, to minimize this cost biomass is typically harvested and produced within a close vicinity to the conversion plant, thus limiting its size.

10.3.2.2 Cost

The cost of biopower is estimated to be \$0.08 to \$0.12 per kWh assuming an efficiency of 20% with a 20 MW capacity direct combustion boiler system that uses a steam turbine for energy production.[245] These costs may decrease as equipment and processing advancements are made and new processing methods are developed.

10.3.2.3 Challenges

Although biopower has great potential and has been proven viable there are still several challenges to be overcome. First, the chemical composition differs significantly by feedstock and even within a feedstock, which causes difficulty in system design. However, the physical characteristics, specifically heating value, remain relatively constant throughout with only minor variation. Secondly, biomass contains some species of alkali metals that can lead to mechanical problems through deposition and corrosion, specifically on heat transfer surfaces.[245]

Other challenges that must be overcome include technological and non-technical issues. The technical challenges include the need for processing improvements. The non-technical issues include supplier and producer interaction, supply mechanisms, contract length or vertical integration, whether there will be development of biomass spot markets, and if the costs of governing many of these relationships remain low will the technologies still remain competitive.[246]

10.3.2.4 Industrial Biopower Case Study

In a 2007 biopower pre-feasibility study for Fort Bragg in Mendocino County, CA, a levelized cost of energy (LCOE) was estimated at $0.06 to $0.08 per kWh for a new biomass plant generating and selling only electricity. This plant would require five to six people per 1 MW of electricity capacity. Therefore, for the proposed 4.5 MW plant would require approximately 22 people.[247]

Excluding the return on equity (ROE) and profit and assuming a feed cost of $20 per dry ton, the installed capital cost of this facility was estimated to be between $1,500 and $3,000 per kilowatt-electric (kWe). These estimates were calculated using a net efficiency of 20 percent, a 5 percent interest rate on debt, a 20 year economic life, and an 85 percent capacity factor with no capacity payments and a straight line depreciation. The annual escalation in operating and maintenance costs was set at 2.1 percent with no fuel cost escalation included. The sensitivity of the LCOE at 20 percent efficiency was estimated at $0.001 per kWh for each $1 per bone-dry ton[lxxxv] (BDT) change in fuel cost.[247]

10.3.2.5 Lessons Learned from the US Biopower Industry

There have been numerous challenges that the biopower industry has had to face throughout its development. One of the most significant issues was the reliance on subsidies and regulatory policies. The state of California has accumulated many lessons learned regarding bioenergy and the effects of regulatory acts and policies on its development.

The biomass industry in California quickly developed following the national Public Utilities Regulatory Policy Act (PURPA) of 1978. Prior to this act there were very few biopower facilities, and there was a negligible amount of electricity being generated from biomass. The state's waste was being put in landfills and openly burned at unsustainable rates. However, with the passing of PURPA, existing electric utilities were required to purchase power from the private sector at a cost equal to their avoided cost of generating that power. This guaranteed small electricity producers (less than 80 MW_e) that their surplus electricity would be purchased by other, larger electric utility producers. This created a market for an independent power industry to develop within the US because PURPA allowed electric generating utilities to be owned and operated by entities other than the existing utilities.[245, 247]

During this time, California became the leader in the development of bioenergy and other renewable energy facilities. PURPA was then supplemented by many state policies and opportunities that stimulated further growth. In a period of 13 years (1980 to 1993), 1,000 MW of bioenergy generating capacity was added. Between 1985 and 1990 a total of 33 new generating facilities were opened with an average size of 17.5 MW. By the end of 1990, the state had 770 MW of bioenergy generating capacity with an addition 100 MW planned.[245, 247]

This early growth rate following PURPA was reduced when regulatory changes were put into effect. In 1994, the California Public Utilities Commission (CPUC) issued a proposal for the restructuring of the

[lxxxv] Bone-dry ton means that there is zero moisture content in the mass

state's regulated electric utility industry; this provided for competition amongst the generating sources based on the price only. Non-market factors, such as environmental impact and resource diversity, were not considered. This threatened the bioenergy market because it was much more expensive to produce energy from a renewable source as opposed to a fossil fuel source. The reorganization also allowed electric companies to buy out power purchase agreements (i.e., Standard Offer Number 4s (SO#4s)[lxxxvi]) from bioenergy generators. The low utility buyback rates, industry restructuring, and business uncertainties that resulted led to the closing of several biopower facilities. In fact, from 1980 – 1999 CA alone had 28 of its original 62 plants close, which left only 27 in operation by 2007.[245, 247]

While the PURPA and similar acts are currently no longer in effect, numerous other subsidies and tax credits are currently valid. These, however, will eventually end. Therefore, the cost of a facility should be estimated without these subsidies to ensure the plant is not forced to close after they expire. One biomass power plant manager noted the following warning:

> "*Beware of entering into a regulatory system in which the utility commission or legislature has determined that it is acceptable for ratepayers to pay the full cost of your technology. Such things do not last.*"[245]

10.3.3 Bioheat

Heat is generated as a result of the combustion of biomass, and this bioheat can be used to provide thermal utilities. In this case, heat is produced directly via combustion and subsequently radiation and convection to warm a centralized location with limited additional equipment. This is usually done on a small scale (e.g., personal home heating) using agricultural crops (e.g., corn, wheat) or wood.

Bioheat systems for a large building, such as a barracks or office building, typically use a boiler system. The heat from combustion is used to warm a heat transfer fluid, which is circulated to heat the building environment via radiation and convection.

Alternatively, heat can be obtained for thermal utilities through the cooling of the flue gas. This is done using the same principles as a heat exchanger. The heat transfer fluid is transported through a series of tubes. The hot flue gases travel over these tubes transferring their heat to the fluid. This heat is transferred from the flue gas via radiation and convection. The hot heat transfer medium is then carried to a destination, where its heat is released to the atmosphere to provide the required thermal utilities.[248]

The heat transfer fluid viscosity, specific heat, density, and thermal conductivity are important design parameters. Although water (i.e., steam) can be used as a heat transfer medium, its use becomes prohibitive at temperatures greater than 450°F. At this temperature, the pressure of steam is high and the system components are more expensive and difficult to design safely. Mineral oils can be used as the heat transfer fluid, since they operate in the liquid phase up to 600°F. At higher temperatures, thermal oils can be used.[248]

10.3.4 Cogeneration of Heat and Electricity

Cogeneration is the simultaneous production of electricity and thermal energy. When biomass is combusted in a boiler system the product heat is used to evaporate water. The resulting steam is then converted to electricity via a steam turbine or used for thermal utilities. Cogeneration is often useful for

[lxxxvi] Standard Offer No. 4's were power purchase agreements with either Pacific Gas & Electric Company (PG&E) or Southern California Edison (SCE) Co. Available between 1984 and 1985, these contracts gave the contract holders five years to bring their facilities into operation. A major part of the contract was that renewable energy sales could be based upon forecasted energy prices for the facilities first ten years of operation. These schedules had high avoided cost rates as their basis ($0.05 – $0.06 per kWh) with the expectation that rates would remain high through the term of the agreement.

independent power production, for instance, when there is no intention to sell the electricity to utility companies. The heat can be used as electricity demand drops which limits product waste and capacity variation.[248]

Steam turbines are used as the prime mover for the cogeneration process and are grouped as either condensing or noncondensing. Condensing turbines condense the system exhaust steam to a product liquid upon its exit from the turbine. With this system type it is necessary to extract any process steam required prior to its passing through the turbine. The extraction point is equipped with an extraction valve and should be at the location where the steam has the desired pressure. A noncondensing turbine creates process steam by acting as a pressure reducer. In order to properly select a turbine type, several system specifications must be known, including the boiler pressure, process steam requirements, electricity requirements, and the availability of cooling water. If the most important product is process steam, a noncondensing turbine should be used and designed to produce the proper steam pressure and flow.[248]

The generation of electricity is a direct function of steam flow. However, with a noncondensing turbine an alternate power source is often needed to meet the variations in electrical load. A condensing turbine is required if the turbine-generator set is expected to meet all of the variations in both process steam and electrical load.[248]

For condensing turbine systems, power is generated by steam flowing through the turbine; therefore, any process steam that is extracted prior to entrance to the turbine will decrease the power production. This type of turbine readily handles product demand changes by increasing steam or electricity production depending on what is needed. The disadvantages of condensing turbines include system size limitations, high costs, and overall cycle efficiency. For instance, they are not typically available in sizes below five MW. The cost is also higher due to the additional condensing component, piping, and water circulation system. Finally, due to the presence of the condensing unit, the overall efficiency is reduced because all of the usable heat within the exhaust stream is lost to the cooling medium in the condenser.[248]

The annual maintenance costs for most turbines are based on a percentage of the capital investment, typically 2 to 2.5%, or as a multiplier of the power production in cents per kWh. When deciding whether or not to utilize cogeneration systems it is necessary to consider the alternative of purchasing power and separately generating steam. Some factors to consider include purchased electricity cost, fuel cost, and the overall investment.[248]

10.4 Biomass Conversion Processes for Power and Heat Generation

Once the location, feedstock type, and feedstock supplier are determined, the next step is to determine the basic plant set-up. Direct combustion is currently the preferred method for the conversion of cellulosic and solid waste feedstocks. Therefore, the residues from forest product mills and wood sources (e.g., including urban wastes) are favored. The ash content of agricultural feedstocks often limits their use with direct combustion. Other desired feedstocks include MSW and herbaceous and wood energy crops. Figure 132 highlights the available biomass conversion methods, their inputs, and the products.[235]

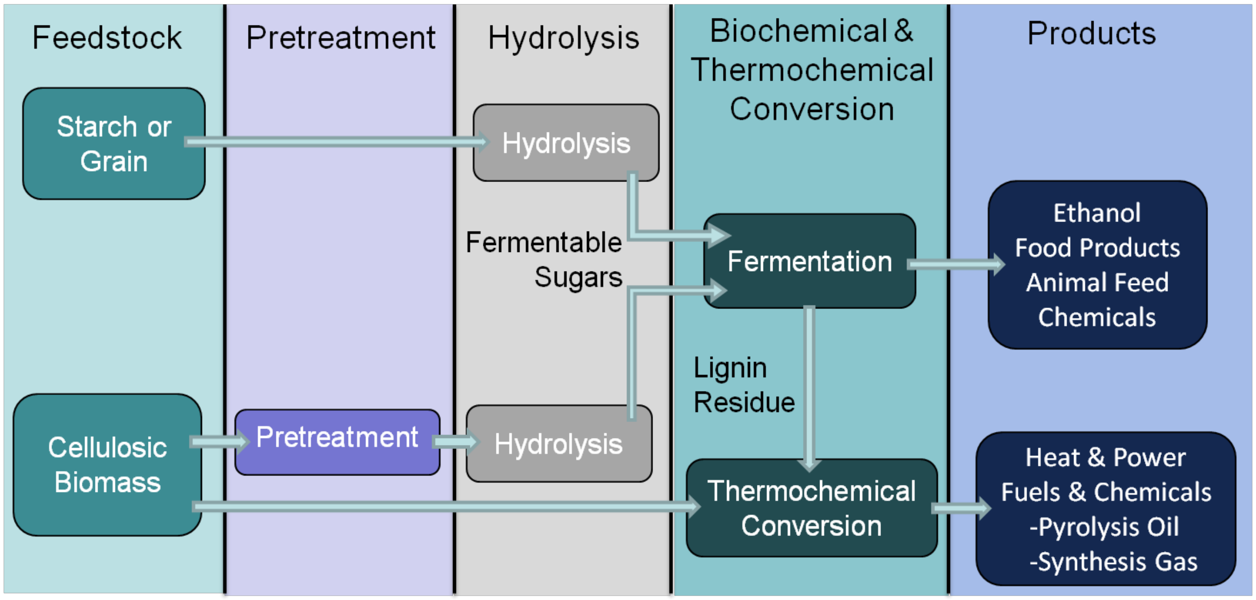

Figure 132. Overview of biomass conversion methods.[235]

10.4.1 Thermochemical Conversion Processes

Thermochemical conversion processes are based upon the principles of combustion. Combustion is the rapid oxidation of combustible materials to produce thermal energy.[249] More specifically, it is a rapid chemical reaction in which carbon and hydrogen are oxidized into CO_2 and water vapor ($H_2O(v)$), respectively, and simultaneously releases thermal energy.[248] The combustibility of a substance, therefore, depends directly upon the amount of carbon and hydrogen present within the material, either in a combined or free-state form in all fuels whether they are solid, liquid, or gas. Sulfur is another combustible material; however, the combustion of sulfur results in environmentally regulated compounds. When combined with oxygen, sulfur forms sulfur oxides (SO_x) and can be combined with other compounds to form sulfuric acid (H_2SO_4). The environmental concerns limit the potential of applicability of sulfur despite its heating value.[249]

Important combustion system parameters include temperature, residence time, turbulence of the material within a combustor, and oxygen availability. The temperature must reach the fuel's ignition temperature. The residence time must be long enough to maximize fuel combustion efficiency. Turbulence is important to allow for efficient mass transfer rates. A sufficient amount of oxygen must be present for combustion to occur. If any of these factors is inadequate, combustion will not occur or will be inefficient.[248, 249]

To ensure complete combustion within a furnace, air, which is an oxygen source, is usually supplied in excess due to incomplete mixing. The excess air also reduces the temperature of the combustion products. However, even with adequate oxygen, the combustion ignition temperature must be reached in order for ignition to occur. The ignition temperature of MSW can be approximated as the ignition temperature of its fixed carbon components. Prior to reaching the ignition temperature, many of the volatile components contained within the MSW are gasified, but do not ignite.[249]

The energy recovery from a biomass feedstock is carried out by the direct combustion of solid biomass. Alternatively, indirect methods are used, such as thermochemical conversion in which the biomass is converted to a liquid or gas and then burned to produce heat and other combustion byproducts. When burning biomass, the fuel properties should be known because the chemistry of the fuel dictates the final stack-gas flow and combustion products.[248]

10.4.1.1 Boilers

Boilers are biomass firing systems in which the combustion heat is absorbed by water or another heat transfer fluid that is subsequently used to provide thermal utilities or generate electricity. Most of the boilers used for the production of biopower operate in the 20 to 50 MW range. This is much smaller than the typical coal-fired power plant that operates between 100 and 1,500 MW.[250] The two major types of boilers are watertube and firetube. However, boilers can also be classified as either package or field-erected.[248]

10.4.1.1.1 Firetube Boilers

In a firetube boiler, heated gases flow through a series of steel tubes that pass through a water jacket as shown in Figure 133. By conduction and convection, these hot gases heat the surrounding water.[248] The rate of heat transfer between the two media depends strongly upon the resistance provided by the pipe, the thickness of the pipe, the temperature gradient between the materials, the thermal conductivity of the materials, and the overall heat transfer coefficient. Firetube boilers can be designed in a number of configurations. Most often these configurations resemble that of a traditional heat exchanger. Additionally, they can be integrated above a combustion unit separately, or designed to be housed within the combustion chamber.

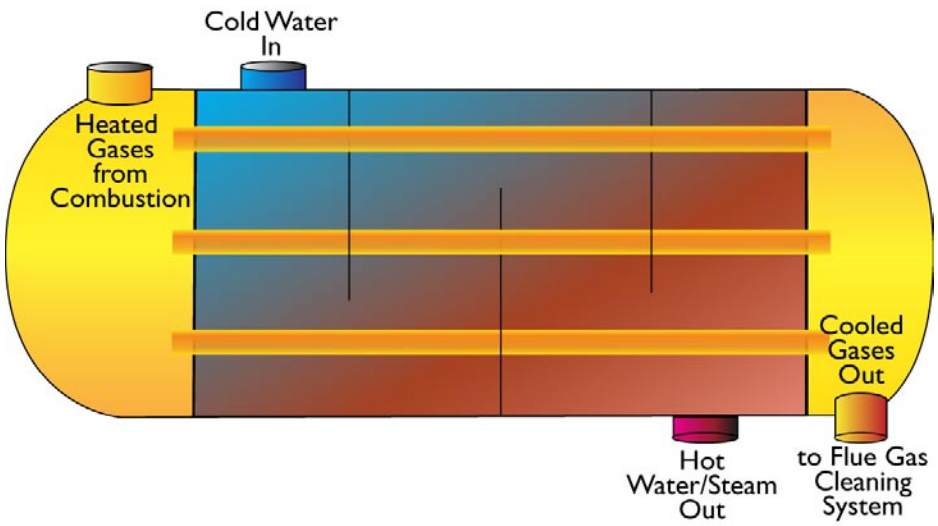

Figure 133. Illustration of a firetube boiler.

10.4.1.1.2 Watertube Boilers

In a watertube boiler, water is heated as it passes through steel tubes heated on the outside by the hot gases that result from combustion. This process is the opposite of a firetube boiler, although the same heat transfer considerations apply.[248] Figure 134 shows a watertube boiler that is integrated on top of a combustion chamber. In this configuration, the heat of combustion is used to directly warm water that flows through the boiler's tubes. The boiler/combustor combination is referred to as a package boiler. Alternatively, the boiler could be placed to the side of the combustion unit, or the tubes could be directly integrated into the combustor.

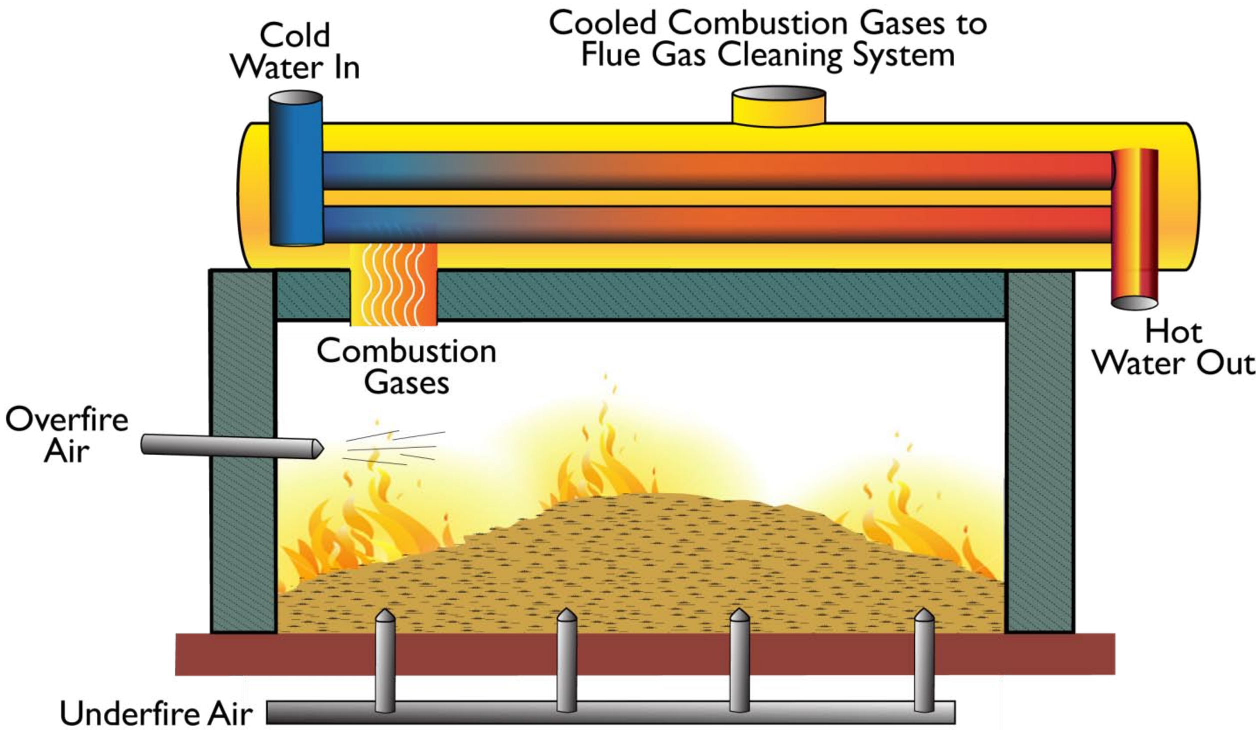

Figure 134. Illustration of a package type watertube boiler.

10.4.1.1.2.1 Firetube vs. Watertube Boilers

Firetube boilers are often considered advantageous compared to watertube boilers for low to medium capacity applications. This is because watertube boilers have high initial investment costs compared to firetube boilers. Additionally, firetube boilers have lower maintenance costs. However, for large capacity systems that operate at high pressures, watertube boilers are preferred because of their ability to accommodate expansion and smaller component sizes.[248]

Although firetube boilers are advantageous for some applications, they are limited at pressures greater than 150 psi and with gas flows between 20,000 and 40,000 lbs/hr. Additionally, if the temperature gradient within the boiler is too large, high stresses result. If the boiler was not designed to handle these stresses and gradients, the likeliness of an explosion increases significantly.[248]

10.4.1.1.3 Package Boilers

Package boilers have all of the boiler components in one assembly and can be shipped by conventional freight transportation methods. Upon delivery, the system can be mounted on a foundation and connected to an existing piping system. This requires less labor prior to start-up compared to a field-erected boiler. However, the large combustion requirements often required for biomass units limits the size of these boilers to a feed rate less than 50,000 lb/hr.[248]

10.4.1.1.4 Field-Erected Boilers

Field-erected boilers typically require the individual boiler tubes to be welded to the tube sheets or steam drum and mud drum prior to use. These boilers cost more than package boilers when comparing their cost per pound per hour of steam. Lastly, these systems have longer construction times, making them undesirable for some applications.

10.4.1.2 Combustors

Combustors or furnaces are required to convert biomass to thermal energy. Their role is to reliably and efficiently burn the biomass fuel, which releases the energy contained within the fuel.[248] The common combustor operating methods and systems are described in the following sections.

The most utilized combustor types include stoker-fired and fluidized bed due to their low NO_x emissions.[238] Nevertheless, there are numerous other combustion technologies used. The average net energy efficiency of combustion plants is 20 to 40 percent. Some plants have efficiencies between 38 and 44 percent when the plant capacity is between 100 MW_e and 250 MW_e.[238, 251, 252] Higher efficiency values can be obtained when biomass is combusted in a coal-fired power plant.[238]

10.4.1.2.1 Direct Combustion

Direct combustion utilizes an all biomass feed, which is combusted within a boiler system to produce high pressure steam (HPS). This HPS is then fed to a steam turbine and generator system to produce electrical energy.[250, 253] Alternatively, direct combustion can be used to create heat for thermal utilities.[238, 251]

Although most plants utilize direct-fire technologies, the overall efficiencies are low (approximately 20 percent). However, efficiencies greater than 40 percent can be achieved using various techniques.[250] Approximately 6.5 GW of direct combustion generation capacity (traditional biomass) exists in the US. The average plant capacity is 20 MW, and the largest is 85 MW. Of all the direct combustion technologies, stoker combustors and fluidized bed combustors are commonly used.[254]

10.4.1.2.1.1 Pile Burners

In a pile burner, which is illustrated in Figure 135, the biomass is fed into the furnace and accumulates on the furnace floor. Combustion air is injected over the top of the pile, as well as underneath it to aid the combustion process. The heat produced is harvested and fed to a boiler system where it is used to warm the heat transfer medium.

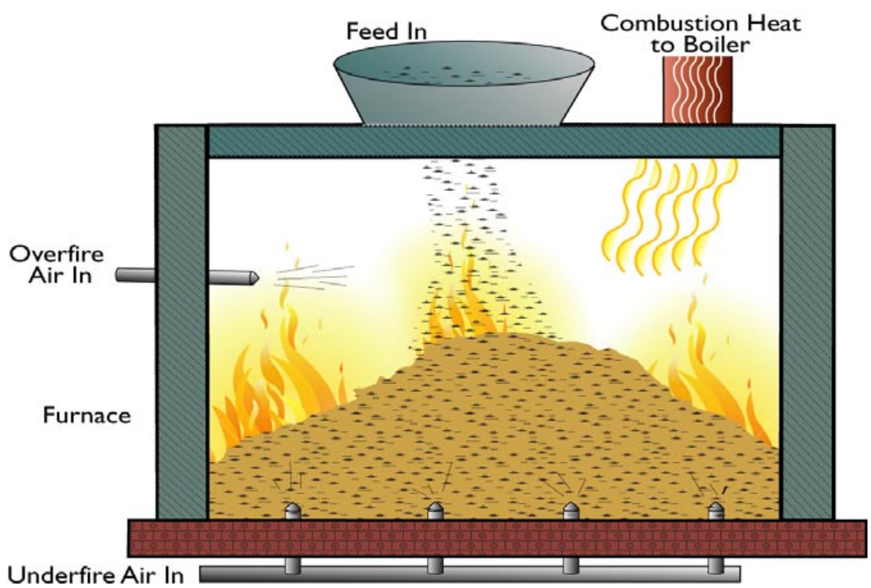

Figure 135. Pile burner concept.

Pile burners are advantageous due to their fuel flexibility (i.e., variation in the materials that can be burned), simple design, and relatively low maintenance costs.[252] The pile burner systems typically have low combustion efficiencies and poor combustion control.[252]

Boilers with pile burner designs are most often used in applications where it is anticipated that the biomass will have a high moisture content, although it should not exceed 65 percent. When using this type of system, the size of the feedstock is not as critical as with other systems allowing it to handle a more heterogeneous fuel supply. Pile burners typically pair well with firetube boiler designs for steam generation, which results in a moderate cost system.[234, 248] There are two common types of pile burners: heaped pile burners and stokers. These are described briefly in the following sections.

10.4.1.2.1.1.1 Dutch Oven

The Dutch oven is the most common type of heaped pile burner. This pile burner uses gravity to feed the biomass through a fuel chute onto the pile, which can result in significant pollution. For instance, complete combustion is hindered by required cooling of the combustion zone. As a result there is an increased probability of unburned particles leaving the combustion zone as particulates. These pollution issues were resolved by the development of the underfed stoker, in which the fuel is pushed onto the pile from underneath.

The Dutch oven contains a refractory-lined chamber in which high temperatures are used to dry the fuel. Underfire air is used to aid in the combustion of the fuel while driving off the volatile compounds. With this type of system, a secondary chamber is required for the complete combustion of the material. Overfire air is injected to this secondary chamber. Although this system can handle a wet, heterogeneous fuel, it is slow to respond to load swings because of the thermal inertia within the fuel pile. Furthermore, the combustion rate is difficult to control because the fuel-to-air ratio changes as the pile combusts. The Dutch oven also has a low efficiency because of its large surface area, which results in heat losses. There is also no efficiency gained from radiant heat from the boiler since the furnace and boiler are separate.[248]

10.4.1.2.1.1.2 Stoker

A stoker is another type of pile burner. This system (as shown in Figure 136) has an underfeed auger or similar device that pushes the biomass up onto a fixed hearth where combustion occurs. The primary combustion air is forced through the pile, while the secondary combustion air is fed over the pile to improve combustion efficiency of the biomass. The feedstock must have a particle size small enough to flow with the auger, but not too fine or wet to form a blockage. Periodically, ash must be manually removed from the system. The stoker combustor has poor emission and combustion characteristics and high operating and maintenance requirements. Although some of these systems are still in use they are becoming less common.[234, 248]

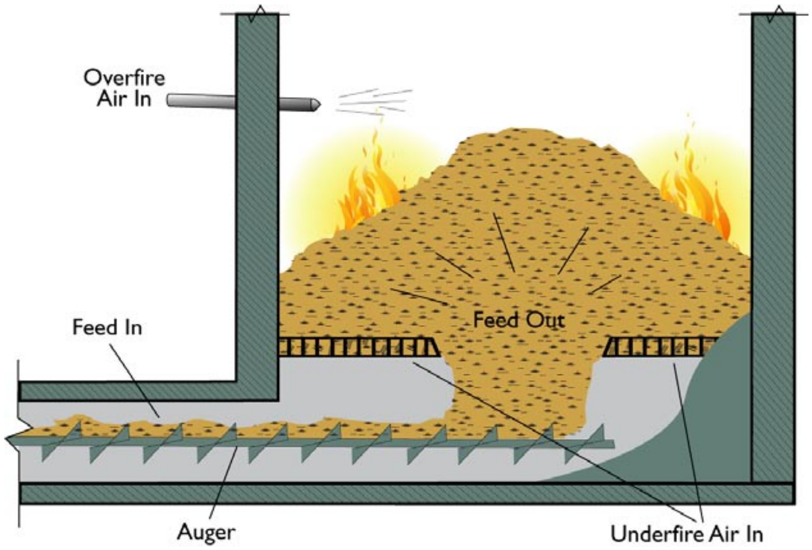

Figure 136. Stoker combustor concept.[255]

10.4.1.2.1.2 Grate-Fired Burners

The grate-fired burner is an alternative to the pile burner and is often preferred because it has greater combustion control. The improved combustion control is due to the fuel feeding system within the combustor. The fuel feeding system puts a thin layer of fuel on the grate, thereby distributing it more evenly than the feed systems in pile burners.[252] This eliminates the particulate problems associated with gravity-fed combustors.

The solid biomass material in grate-fired combustors is supported by a grate, while it is dried and the volatile compounds are driven off. Underfire air is fed through holes within the grates to supply oxygen for combustion, cool the grates, dry out the fuel, and promote turbulence within the fuel bed which enhances heat transfer rates. Overfire air is also provided to induce turbulence and to supply additional oxygen for the combustion of entrained and volatilized material.[248] The common grate-fired burners are presented in the following sections.

10.4.1.2.1.2.1 Stationary-Sloping Grate

In the stationary-sloping grate boiler, both the boiler and the grate are stationary. The slope of the grate allows the biomass to slide, and the fuel is burned as it moves.[252] The slope of the grate varies to accommodate various conditions of the fuel. For instance, if the fuel is dry it will slide down the grate much easier than if it were wet. Therefore, the grates are pitched at different angles within the different regions of the furnace (e.g., drying, combustion zones). This allows for a more uniform air distribution and an increased combustion rate. Wet biomass fuels can also be used with sloping grate burners, however, they do require more size homogeneity in the fuel compared to pile burners.[248]

There are two main disadvantages to this type of grate-combustor. First, the fuel is prone to sliding down the grate and accumulating, which is also known as avalanching. Secondly, while there is improved combustion control compared to pile burners, it is still difficult to control.[252] Moreover, this type of combustor has size limitations and is typically smaller than spreader-stoker systems (see *Section 10.4.1.2.1.4*).[248] Figure 137 shows the basic concept of the stationary sloping grate combustor. The integration of the combustor is highly dependent upon the situation and overall required plant configuration.

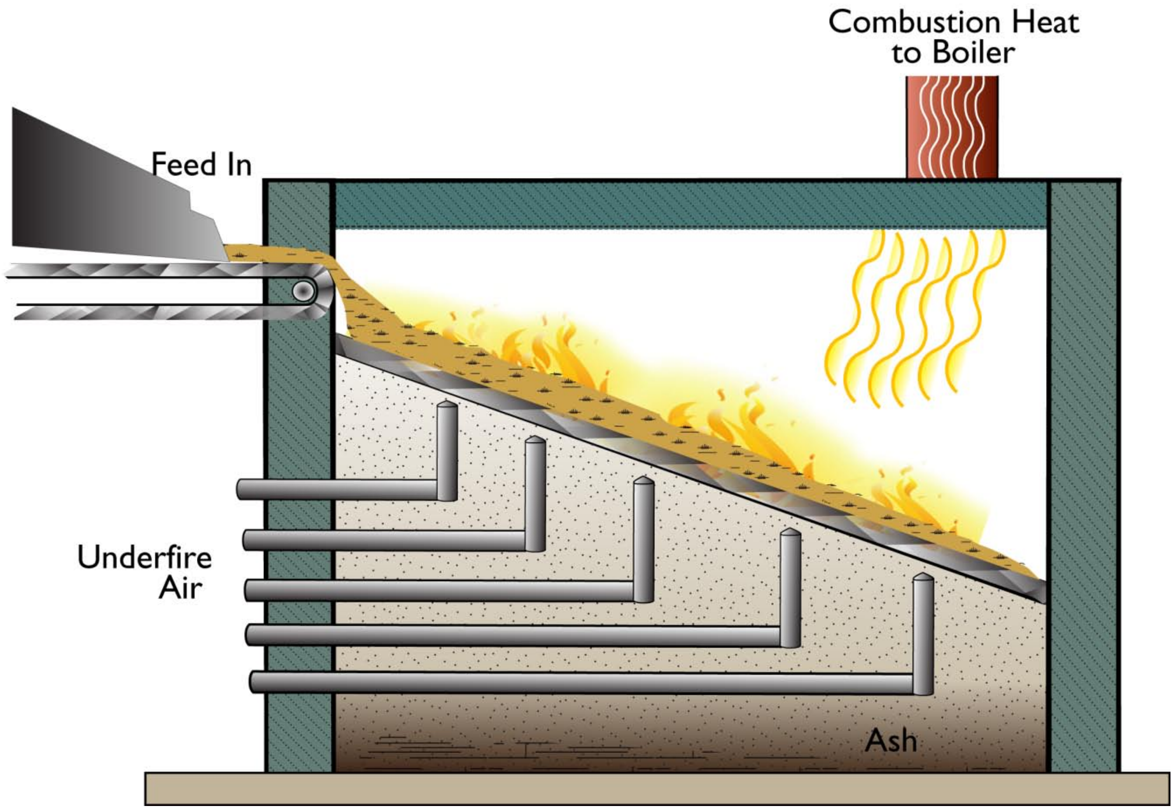

Figure 137. Stationary sloping grate combustor.[248]

10.4.1.2.1.2.2 Travelling-Grate

Travelling-grate combustors often mitigate the combustion control problem associated with stationary-sloping grate style as they offer improved combustion control and provide for greater carbon burnout efficiencies. This is because the travelling-grate combustor uses a thinner layer of fuel.[252]

With this type of combustor, the biomass is fed in at one side of the grate. The grate then moves in the opposite direction burning the biomass as it moves. Upon reaching the other side of the combustor, after combustion is complete, the grate continues travelling to the ash dumping site of the furnace where the ash is removed from the grate and the cycle repeats.[252] Figure 138 shows a stand-alone travelling-grate combustor concept. When installed with watertube steam generators, these combustors can respond rapidly to load changes. Travelling-grates have high maintenance costs and a fast turnaround time, which sometimes inhibits the complete combustion of particles that may fall out of suspension. The latter typically occurs when the travelling-grate combustor is used with a spreader-stoker configuration.[248]

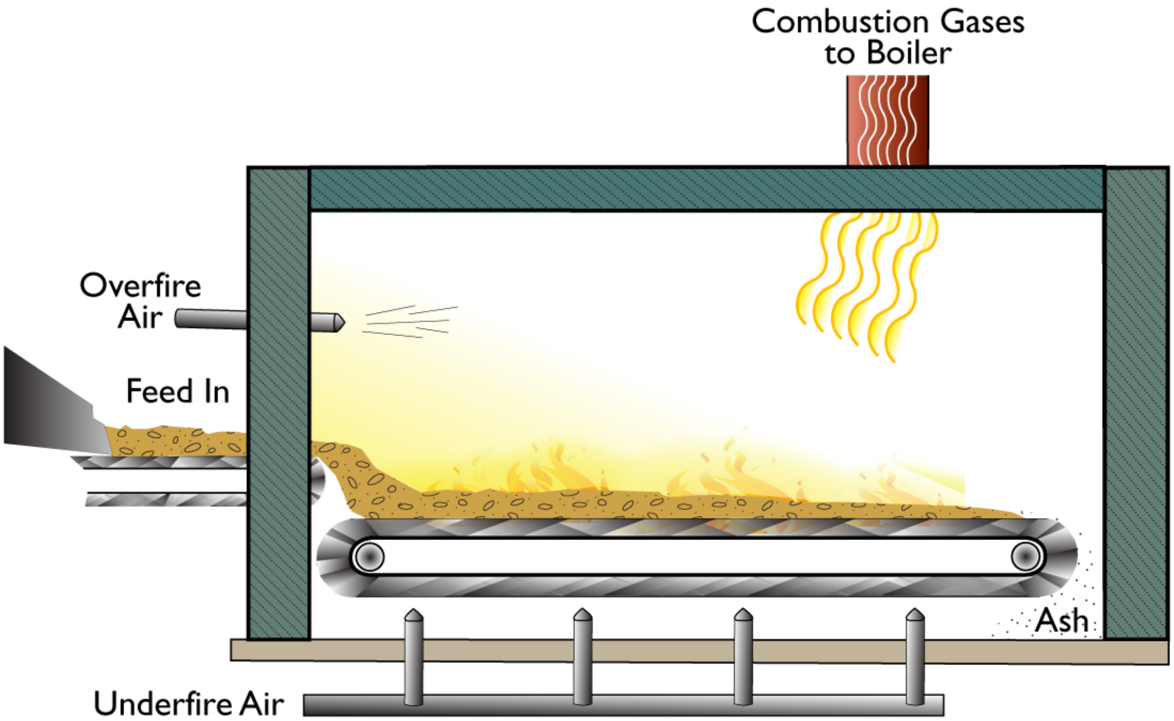

Figure 138. Travelling-grate combustor.

10.4.1.2.1.2.3 Vibrating-Grate

Vibrating-grate combustors distribute the biomass over the entire grate. As the grate vibrates, the shaking movement causes the biomass to spread evenly over the entire surface, which enables a more efficient combustion of the biomass.[252] This concept is demonstrated in Figure 139.

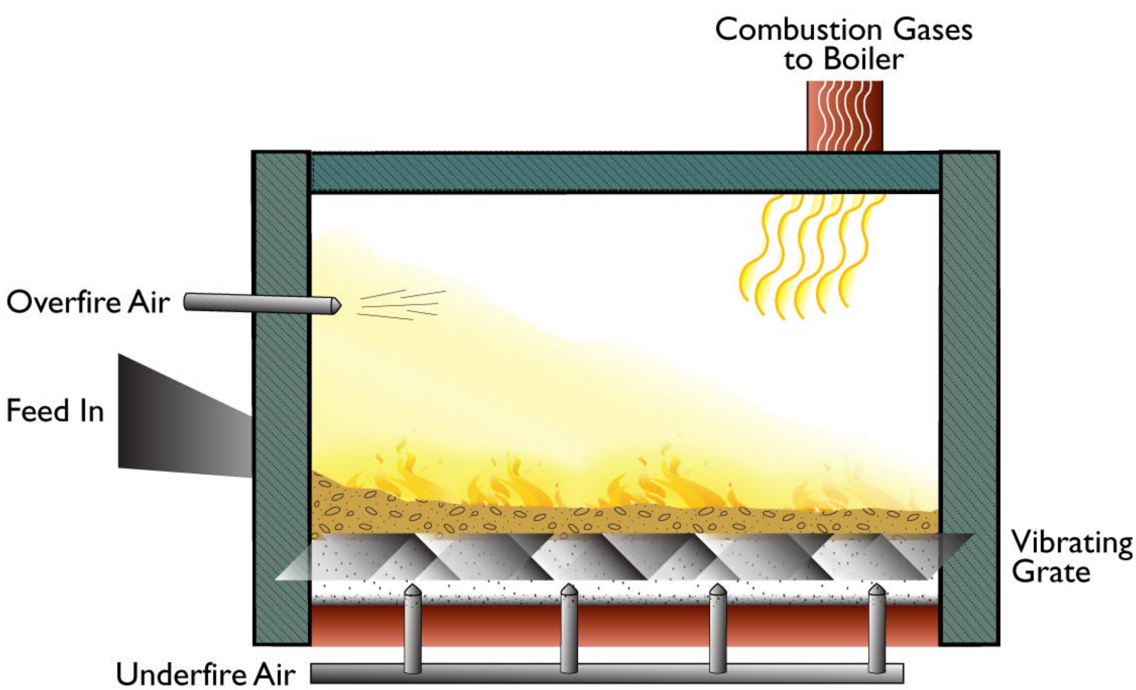

Figure 139. Vibrating-grate combustor.

Vibrating-grate combustors have numerous advantages over the stationary-sloping grate and travelling-grate combustors. The vibrating-grate boiler has fewer parts that the travelling-grate boiler, and therefore it often has fewer maintenance requirements and thus is less expensive to operate. They also have improved carbon burnout efficiencies and form less thermal NO_x. The use of water cooled grates makes it possible to control the amount of overfire air.[252]

10.4.1.2.1.3 Suspension-Fired Burner

Suspension-fired burners are similar to those present in pulverized coal-firing plants (see Figure 140). This type of boiler requires a feed that has been processed into small particles to increase the surface area of the feed making it more combustible. In typical pulverized coal-firing plants, these burners start on fuel oil; once the particles continuously ignite and the fuel oil is no longer needed, it is shut off and the process continues.[252, 256] Therefore, this type of combustor requires an auxiliary fuel source to initiate combustion. This fuel is no longer needed and can be shut off once the particles combust continuously and thus sustain combustion.

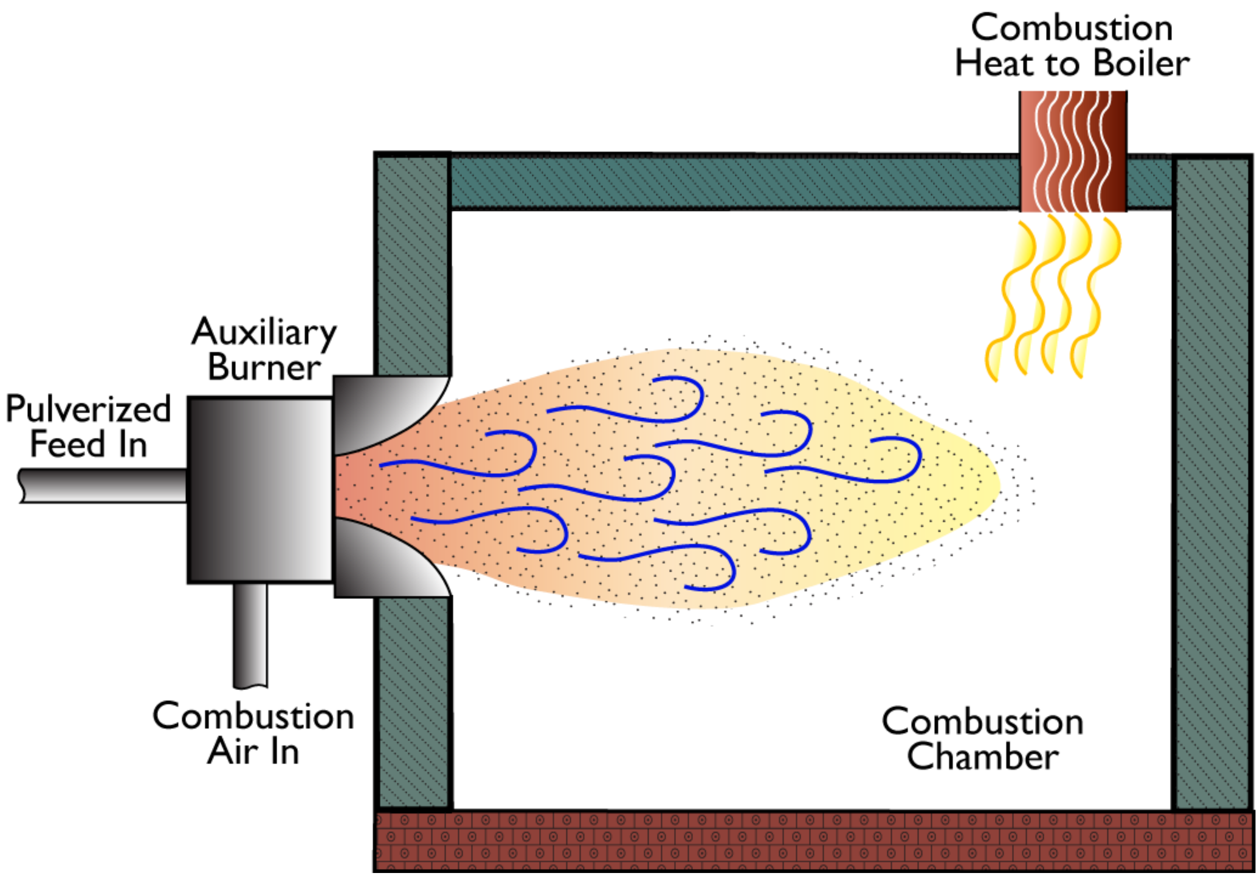

Figure 140. Suspension-fired combustor.[248]

Suspension-fired burners have high efficiencies, but the biomass feed requires a considerable amount of pretreatment prior to use.[252] More specifically, the fuel must be dried to less than 15% moisture and have a size that is less than a quarter inch. This type of combustor uses forced air to turbulently mix the fuel and enhance combustion. Because of the small particles used, the risk of an explosion increases with increasing fuel dryness. As a result, many systems come equipped with a flame safeguard device to ensure that fuel is not fed in the event that the flame is extinguished. Boilers that contain these combustors typically have high efficiencies and excellent responses to changes in load. However, they can suffer from slag build-up if agricultural fuels with high ash contents are used.[248]

10.4.1.2.1.4 Spreader-Stokers

Spreader-stokers are commonly found in wood-fired boilers, and the stoker can be either mechanical or pneumatic. The mechanical stoker resembles a paddle wheel and essentially throws the fuel into the combustor, while pneumatic stokers use air pressure to blow the fuel into the boiler. If the biomass feed is inconsistent in size, a pneumatic stoker may be preferred. These combustors have high heat release rates because many of the smaller particles are burned in suspension while the heavier particles fall to a grate where they are combusted. Wet fuels can be burned with this system. Often, spreader-stokers are used in conjunction with travelling grates to simplify the ash removal process.[248]

10.4.1.2.1.5 Fluidized Bed Burners

Fluidized bed systems use a combustion chamber with a distributor plate consisting of several drilled holes to allow for underfire air to pass through it. A bed of small solid particles, such as sand or another inert solid material, is contained within the combustor and kept in suspension by forced air, while initially being heated by an auxiliary fuel source. Solid biomass is fed into this combustor as small particles, and is suspended by the air. The air is blown into the system at a high velocity using a series of jets to induce turbulence. This induced turbulence forces the solid particles to mix with the air, which aids in particle ignition and combustion. When the bed reaches a temperature sufficient to ignite the fuel the auxiliary fuel source is shut off and the biomass is fed at a rate that sustains combustion. The turbulence induced by the jets improves combustion.[46, 248, 252]

Fluidized bed systems are desired for their short residence time due to rapid combustion. In fact, any portion of the biomass is rarely in the combustion zone for more than 30 seconds. This enables fluidized beds to quickly respond to load changes. These combustors have high combustion efficiencies, fewer unburned hydrocarbons in the ash, and as a result can handle high ash content biomass fuels. They can also handle wide variations in the fuel's moisture content, size, and heating values. If the fuel bed is kept clean, fluidized beds can be operated continuously without having to be taken off-line. In general, less cleaning is needed due to the simpler grate design and air distributors used. Nevertheless, when using agricultural-based fuels, precautions must be taken because of the increased ash production that can subsequently lead to slagging[lxxxvii] and severe operating problems.[248]

Fluidized beds are also beneficial in terms of their reduced emissions. Most importantly, NO_x and SO_2 emissions are low.[252] The NO_x emissions are low because the combustion temperatures used in fluidized bed systems are much lower than those of other systems. These temperatures are well below those required for NO_x formation. The design of these systems also allows for the addition of chemicals to the bed. SO_2 emissions, for example, are significantly reduced because of the mixing that occurs, which allows the flue gases to come into contact with chemicals, such as limestone, that absorb sulfur.[46] Upon contact, the limestone and sulfur react to form a salt that precipitates to the bed and is later removed.[248] Additionally, these burners have good fuel flexibility and can burn most combustible materials.

Fluidized beds operate by one of two operational modes: bubbling or circulating. Bubbling fluidized bed behavior occurs when the air velocity is great enough to cause the feed particles to exhibit the same properties as a boiling liquid. As the velocity of the air continues to increase the bubbles will disappear and the particles will be blown out of the bed. In order to keep the system stabilized, some of the particles must be recirculated. The circulating fluidized bed is illustrated in Figure 141.[257]

[lxxxvii] Slagging in combustors is often caused by the melting of salts and mineral in the ash. This leads to fouling on the heat transfer surfaces, increased operating costs, and added down time. Slagging can be mitigated by adding small amounts of "fireside additives" to the system; these additives increase the ash melting point. If tube fouling is occurring, the required maintenance is much more complicated.

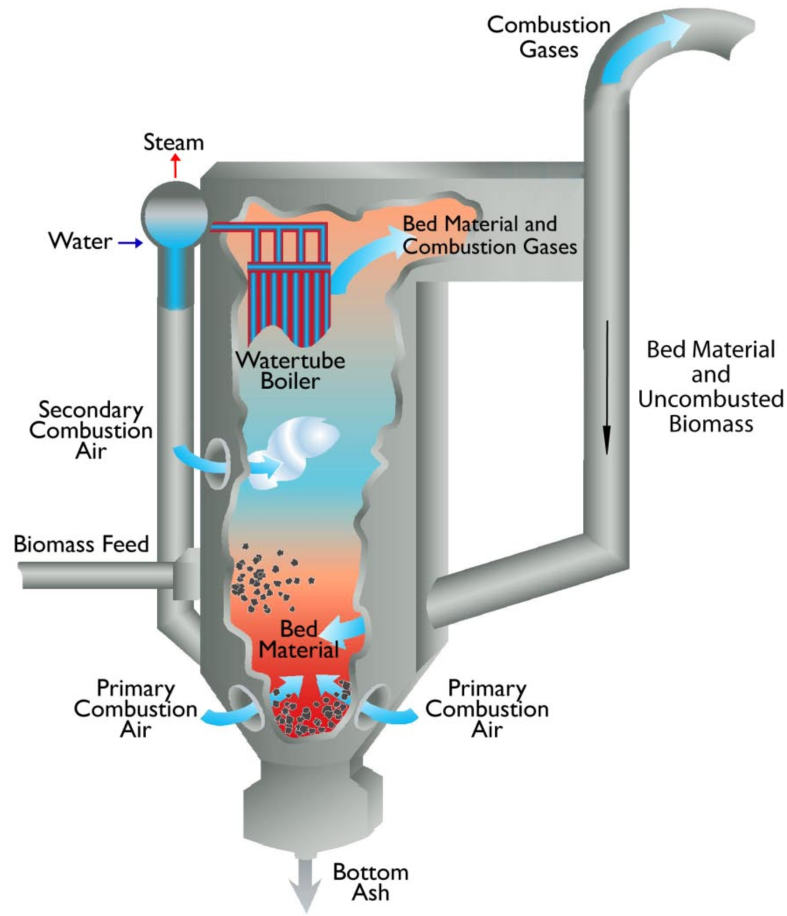

Figure 141. Circulating fluidized bed with integrated boiler system.[258]

The bubbling fluidized bed is often considered better than the circulating fluidized bed when the capacity is less than 20 MW_e because it requires a lower capital investment. However, circulating fluidized beds typically have better carbon burnout efficiencies, and by adding lime to the solid particle bed it exhibits better absorption of acid gases. The major disadvantage of fluidized bed systems is that they require large fans for fluidizing air, which results in a higher electricity demand.[252]

10.4.1.2.2 Co-Fired Combustion

Co-firing is considered one of the most economic near-term options for the introduction of biopower generation. Instead of using an all nonrenewable feedstock, co-fired plants replace a portion of the nonrenewable fuel used with biomass. The fuels are typically fed into a boiler to produce steam, which is subsequently used to generate electricity.[253]

Co-firing is often desirable due to the relatively low start-up and operating costs. This is often because existing facilities and nonrenewable fuels are converted to a co-fired plant. Most of the systems that utilize co-firing technologies originally started as coal-fired facilities. In these coal/biomass co-fired facilities, SO_2, NO_x, and other air pollutants are reduced. Modern co-fired plants can achieve efficiencies between 33 and 37 percent.[250] Co-firing is also advantageous because it provides baseload renewable power and is one of the most efficient utilizations of biomass for power generation.[254]

10.4.1.3 Gasification

Gasification is the endothermic decomposition process by which a diverse, highly distributed, low value cellulosic biomass is converted to a gaseous mixture of carbon monoxide (CO), hydrogen (H_2), and methane in the presence of limited oxygen. The product gas has a low energy value and as a result can be converted to heat and steam by burning it or alternatively used to generate electricity through the use of a gas or steam turbine.[219, 236, 238, 250, 251] In a single-chamber unit, the product gas typically has a heating value of 150 BTU/ft^3; if two chambers are used, the heating value is nearly double this value.[248]

It has been reported, that when using biomass integrated gasification or combined gas-steam cycles that conversion efficiencies near 50 percent could be reached.[238] Generally, the gasification of biomass leads to efficiencies between 40 and 50 percent.[219, 250] For gasification combined cycles to be efficient the moisture content of the feedstock and the degree of drying are important parameters. The gasifier performs better when the feedstock has a lower moisture content, which also reduces the cost associated with drying the feedstock.[259] Nevertheless, it is recommended that the moisture content be no greater than 20 percent; a moisture content between 15 and 25 percent increases the gas production (of the product gas, e.g., H_2, CO, and CH_4). Fluidized bed gasifiers, however, can handle fuels with a moisture content from 15 to 65 percent.[234]

Gasification systems, which are commonly known as gasifiers, can be located near to existing natural gas or coal boilers. When using this configuration, the product gas can be used to supplement or to fire these boilers. Otherwise, the product gas must be cleaned and filtered to remove harmful and damaging compounds. After cleaning, this gas can be used in a combined-cycle system for power generation. These systems often use steam or gas turbines to create electricity as mentioned above.[250]

Although many gasification systems show promise, their lack of long-term operational use by some manufacturers makes them undesirable to some. Additionally, they can cause problems in the piping and burners by depositing tars and other liquids. For these and other reasons, gasifiers require operator attention at all times.[248] There are several gasification systems available. The most common types are: updraft, downdraft, fluidized bed, and cross-flow.

10.4.1.3.1 Gasification Systems

In both fixed and moving bed systems, syngas is produced with large quantities of either char or tar. This is a direct result of the low and non-uniform heat and mass transfer rates between the gasifying agent and the solid biomass. However, these types of gasifiers are a simple and reliable way to economically gasify large amounts of wet biomass.[251]

Fluidized bed gasification has been and continues to be largely used in biomass gasification processes. These systems utilized a bed of hot, inert materials, such as sand, with a small portion of biomass, typically 1 to 3 percent. The use of a fluidized bed system allows for uniform heating, a higher heating rate, and in turn a higher productivity.

Fluidized bed systems have fewer ash related problems compared to fixed bed gasifiers, and thus are often more desirable. The reduction in ash related problems is because the temperature can be kept uniform and below that of the ash slagging temperature. The volatility of the ash elements, such as sodium and potassium, in the syngas is also reduced. This significantly improves the syngas quality, especially considering that the alkali compounds can be easily separated from the syngas with the use of a cyclone.[251] Although these systems are favorable for minimizing the effects of ash, fluidized bed configurations for gasification are typically only feasible when the plant capacity ranges from 5 to 300 MW.[238]

10.4.1.3.2 Gasifier Design Considerations

When designing a gasifier, there are several factors that need to be considered. The most important consideration is the polymerization of furfurals and unsaturated compounds present in the product tar.

The polymerization occurs at low temperatures with the aid of free radicals that result from the biomass or tar-water sitting at these low temperatures for too long.[251] The formation of coke or char can be reduced by using fluidized bed gasification because it achieves higher heating rates and thus generates much less char than a fixed bed. However, it has a reduced conversion efficiency because as the biomass is fluidized, the particles may become entrained above the fluidizing bed resulting in the formation of large bubbles. Circulating fluidized bed gasifiers can increase the recycling of solid material, which increases the resonance time, and consequently, increases the conversion efficiency compared to a bubbling fluidized bed gasifier.[251]

The char and tar formation within a gasifier are affected mainly by temperature, pressure, and the equivalence ratio (ER). When the gasification temperature is too high, the carbon conversion increases and often becomes too high. However, the tar content in the syngas is low. High temperatures increase the risk of ash sintering and agglomeration, while simultaneously decreasing the energy efficiency. Methods to decrease the formation of tar have been investigated, including the use of pressurized gasification. This method would eliminate the need for costly syngas compression systems in the downstream synthesis of fuels and chemicals from high pressure syngas.[251]

The ER is found by dividing the amount of oxygen required for gasification by the amount of oxygen required for the complete combustion of a given amount of biomass. The ER is of great importance when air or oxygen is used for gasification. As the ER increases, the tar content has been shown to decrease because of the reaction of the tar volatiles and the oxygen within the gasifier. However, if the ER is too high the concentrations of CO and H_2 present in the product gas are low, while the CO_2 concentration is high. This occurs when the ER is greater than 0.2 but less than 0.4.[251]

10.4.1.3.3 Gasifying Agents

The most commonly used gasifying agents are: air, O_2, steam, CO_2, or a mixture of these gases. Of these, purified air is a widely used gasifying agent because of its low cost. However, the large amount of diatomic nitrogen contained within the air decreases the heating value of the syngas product. Consequently, there is less energy to be recovered. The heating value of syngas can be preserved or even increased by using pure O_2 as the gasifying agent. However, pure O_2 must be produced or purchased, thereby adding to the process operating cost.[251]

Steam can improve the syngas quality even more. Both the H_2 content and heating value of the syngas are increased when steam is used as the gasifying agent. The syngas product has a heating value in the range of 270 to 400 BTU/ft^3 (normal conditions, i.e., 0°C and 1 atm) when using steam as the gasifying agent, whereas this heating value is only 80 to 160 BTU/ft^3 (normal conditions) when pure O_2 is used. CO_2 can also be used as a gasifying agent with minimal adverse affects because it is already a component of the syngas. Steam and CO_2 typically have added costs because they require a heat supply (either external or indirect) to provide the necessary heat for the endothermic gas reactions.[251]

Even with a wide availability of standalone gasifying agents, many choose to use mixtures. Frequently, air is combined with oxygen because it imparts several benefits to the gasification process and subsequent gasifications. When such a mixture is used, it can help dry the biomass and provide heat to raise the temperature of the biomass. This is particularly useful for the subsequent endothermic gasification reaction and for generating water and CO_2 for use in future reduction reactions.[251]

In addition to the selection of an appropriate gasifying agent, catalysts can be added to the gasification system to improve the process. For example, nickel/aluminum (Ni/Al) catalysts enable CO_2 to transform the char, tar, and methane into H_2 and CO. This increases the concentration of these components in the syngas.[251]

10.4.1.4 Pyrolysis

Pyrolysis is a thermochemical conversion technology that heats biomass in the absence of oxygen (O_2) to produce oil, charcoal, and a non-condensable gaseous mixture.[236, 238, 248, 251] The product gases and some of the char can be burned augment the supply of process heat, while some of the char can be sold. The pyrolysis oils can be used for power generation. Therefore, pyrolysis is often used with lignocellulosic biomass and solid wastes to provide for energy densification prior to additional processing.[260] However, pyrolysis oil is often limited in use and application because of the complicated downstream processing requirements.[248, 251] Pyrolysis oil is not stable in storage and is acidic. The acidic nature and water content of pyrolysis oil also limits its use.[254]

Currently, mobile pyrolysis systems are being developed to reduce logistical issues and handling costs associated with biomass. Traditionally, biomass handling has included harvesting, any required onsite processing, loading, and transportation to the conversion facility. The handling process is labor intensive and has a significant impact on the total cost of the energy. However, a mobile pyrolysis system can simplify the process. By pyrolyzing the biomass into oil, a compound with a much greater energy density than raw biomass, the handling process could be significantly reduced, and thus increase the feasibility of large scale bio-refineries. A mobile pyrolysis system must be able to handle a wide variety of feedstocks to withstand crop production declines and ever changing feedstock supplies over the life of the mobile facility.[261]

Currently, fast pyrolysis systems are in development. These rapidly decompose biomass using heat to produce pyrolysis oil in the absence of oxygen.[261, 262] These systems could lead to the ability to locate energy generation plants separate from those for biomass energy densification, and thus allow for more optimal facility sizing.[262] In addition, there may be limited additional processing of the pyrolysis oil should it be used as a replacement for No. 2 fuel oil. This is because pyrolysis oil can be used anywhere that No. 2 fuel oil is currently used.[261]

10.4.1.5 Modular Systems

Modular systems, which use conventional biomass conversion methods, are emerging concepts that can operate near the biomass source. They are much smaller than plants and use smaller equipment. These systems have great potential in areas where the electricity is limited and biomass feed is abundant, such as remote areas, in developing countries, at overseas base camps, and at forward operating bases.

One such system is the Portable Waste to Energy Refinery (POWER). POWER is a semi-permanent, non-tactical variant of the Tactical Garbage to Energy Refinery (TGER). Both of these systems are transportable.

10.4.2 Other Bioenergy Conversion and Collection Processes

Thermochemical conversion processes are the predominant methods for converting renewable energy inherent in biomass to usable energy. However, there are other ways to convert biomass resources and collect bioenergy. Some of these are briefly described in the following sections.

10.4.2.1 Anaerobic Digestion

Biogas is a mixture of CH_4 and CO_2, and it results from the conversion of biomass via bacterial action in the absence of oxygen (i.e., anaerobic). This technology has been commercially proven and is typically used for the conversion of high moisture content biomass, such as municipal solid waste. Anaerobic digestion can also be used at large-scale dairy farms to convert manure into useable CH_4.[236, 238, 260] The bacteria used for anaerobic digestion are typically selected based upon their temperature tolerances. For example, psychiophilic bacteria are preferred for cool temperatures, mesophilic for intermediate temperatures, and thermophilic for warm temperatures.[236]

10.4.2.2 Biogas Collection

Electricity can be generated from the CH_4 and CO_2 produced by the decomposition of waste within a landfill or from the anaerobic digestion of animal wastes. Landfill gas can be directly burned in a boiler combustion system for the recovery of thermal energy; otherwise, if the water vapor and SO_2 are removed, it can be used directly to power an internal combustion engine. If used with fuel cells or turbines, electricity can be generated as well.[263] Biogases produced from landfills or animal wastes are not readily transportable. Therefore, their use is typically limited to locations on-site or within a close proximity off-site.[248]

Landfill gas projects typically can yield approximately 300 standard cubic feet per minute (scfm) of recoverable landfill gas per one million tons of MSW. Thus one ton of MSW has a power generating capacity of approximately 800 kW. If a landfill gas project were to consume 300 scfm of biogas, it would have an environmental impact equivalent to removing 6,000 cars per year from the road.[264]

10.4.2.3 Transesterification

Oils from biomass, waste oils, and greases can be converted to a combustible material for the generation of electricity using the transesterification process.[236, 260] Transesterification is a chemical process in which a reaction occurs between an alcohol, catalyst and oil. The alcohol functional group (-OH) bonds to the fatty acids from oils, greases, and fats, which reduces their viscosity. This converts these materials to a combustible form. An esterification pretreatment may be required.[236, 260]

10.4.3 MSW Conversion

The conversion of MSW remains a category of its own due to the numerous chemical, biochemical, and thermochemical processes that can be used to convert this feedstock. Although the same basic technologies are used for the conversion of MSW as are used for other biomass, there are added complexities in the conversion methods used. Additionally, there are also complicating factors in facility design and operation, which sets it apart from other biomass feedstocks, such as agricultural and forestry products and byproducts. Therefore, the conversion of MSW will be discussed in more detail in *Section 10.8*.

10.4.4 Selection of a Biomass Conversion Technology

When choosing a biomass conversion technology, there are many factors to consider. These include the type and quantity of the biomass resources available, the energy carrier and end-use application, the environmental standards, economic conditions, and ultimately the most suitable energy form for the desired end use application must be considered.

To completely satisfy these considerations, the moisture content, cellulose-to-lignin ratio, and ash content should all be considered since these indicate the types of conversion methods that are suitable. For example, if the moisture content of the biomass is greater than 50 percent, a wet conversion process should be used, and if it is below 50 percent, then a dry conversion process should be used. Dry conversion methods include thermochemical processes such as combustion and gasification. The cellulose-to-lignin ratio should only be taken into account when considering a biochemical process. In general, biomass with a high cellulose content should likely use a fermentation process. A low ash content is better for both thermochemical and biochemical processes.[238]

10.5 Biomass Facility Design

As in the design of any power generation facility, there are many factors to consider when designing biomass facilities. In addition, there are some factors that are unique to biomass facilities. Many of the important factors to consider are described in the following sections.

10.5.1 Siting

Important considerations when selecting the location for a biomass conversion facility include accessibility, permitting, and land characteristics. In general and if possible, biomass conversion facilities should be constructed near highways or other highly traveled roads with wide shoulders and few curves; in areas of low land cost, and in industrial areas. If located near highways, there should be no need for additional transportation infrastructure. If land costs are low, the initial capital investment required to purchase the land is low. If the plant is located in an industrial area, the accessibility is not problematic, and many of the unnecessary fees, fines, and other expenses that may result from locations in or near residential areas could be avoided or minimized. When a facility is located in a residential area, there are usually higher tax rates, higher labor rates, and potentially neighborhood opposition to odors, pollutants, and noise.[245]

It is generally most effective to place a conversion facility within 20 miles of the feedstock source for practicality and cost optimization. For biomass plants, however, the feedstock source is often in a less populated area, which may lead more limited accessibility. When biomass must be transported more than 20 miles, the cost grows significantly. When it must be transported more than 100 miles the viability of a plant is low.[226, 265] The biomass cost is directly related to transportation distance due to its low energy density when compared to other fuel sources, especially fossil fuels.[260, 265]

10.5.2 Feedstock Procurement

When designing a biomass facility, the highest priority is to obtain the lowest cost fuel possible once the site is selected.[265] Often site and feedstock selection are coupled. However in many instances the location may be predetermined, which makes feedstock selection a key to successful operation.

When the fuel cost is low, more of the budget can be appropriated to other functions, such as process improvements and development of enhanced efficiency. This can result in decreased product cost. However, procuring the cheapest fuel can result in tradeoffs between fuel cost and fuel quality. Fuel quality often cannot be sacrificed for cost. This is because many of the plant operations can be affected by varying feedstock quality outside the plant's tolerance levels. This can be avoided though by procuring both high quality feedstocks and cheap feedstocks, and mixing them to obtain the desired combination for optimal results with a reduced overall cost. Generally a dilute mixture would be required to limit the effects of the poor quality feedstock and allow for both to be useable.[265]

Often, even if the desired feedstock can be obtained at a reasonable cost, there are other obstacles, such as permitting.[265] For this reason, in addition to feedstock cost and quality, the assessment should also be based upon length of contract. If short-term contracts are used, it is much easier to handle a drop in the capacity factor, while with a long-term contract such a drop could lead to added fuel supplier charges or stagnant fuel stock.[265]

In general, fuel should be procured using short term contracts, and the supply should also be diversified. Diversification can eliminate many of the issues that arise when the fuel supply begins to decline, such as increased fuel cost.[265] Diversification can result in lower quality feeds, which may reduce the overall plant efficiency and may require additional processing to enable its use in the existing equipment. However, by procuring several feedstocks several high quality feedstocks may be in the mixture as well.[265]

Feedstock procurement efforts are typically executed via brokers or directly through operating firm personnel (e.g., consulting foresters, or the local agricultural extension agent). The average price of agricultural feedstocks varies based on location and whether any other end use currently exists. If using wood the price is based on several factors including the type (i.e., softwood or hardwood) moisture content, hauling distance, local supply and demand, and the quality purchased.[248]

Overall, it may be most effective to focus on fuel cost, in terms of dollars per kWh, rather than on fuel efficiency (BTU/kWh). Using this method, a steam co-generation plant in Tacoma, Washington saved more than $600,000 per year in coal costs. Additionally, by using opportunity fuels[lxxxviii], potential fuel costs can be eliminated. However fuel procurement is addressed, it remains as one of the most important requirements for the successful operation of a biomass facility. Another important element is to design for fuel flexibility since it enables the conversion facility to adapt to changes in fuel sources.[265]

It is also important to consider that many biomass crops are produced seasonally and thus may pose potential problems in terms of availability. Additionally, much of the biomass supply is geographically scattered, which increases the costs and complexities associated with collection, transportation, and storage.[238] Weather can also affect the availability of crops.[248]

10.5.3 Receiving, Storage, Handling, and Feeding of Biomass

The average fuel processing and handling costs account for 20 to 40 percent of the total facility cost.[234] The moisture content and size of the feedstock influence the storage and handling procedures, equipment, and facilities.[248] These factors are critical because they affect the way that the feedstock moves and the quantity of space that will be needed to store the required amount. It is also important to consider any potential feedstock changes. If the storage and handling equipment is designed for a wet fuel, such as greenwood, it can be used on dry feeds. The opposite, however, is not true. Therefore, in many cases it is important to design for flexibility.[234]

10.5.3.1 Handling

Feedstock handling is required in all steps from delivery to feeding. Biomass feedstocks can be transported by various means and common methods include belt conveyors, chain conveyors, augers, and front end loaders.

Belt conveyors are limited to inclines less than 15 degrees to prevent material slippage; however, they are useful for the transportation of materials over long distances and for large capacities. Chain conveyors are for short transportation distances, moderately sized materials, and low speed, high load devices. This type of system is used with a shear pin or motor overload safety devices to ease the handling of jams. They are also easy to maintain.[248] Augers and screw conveyors can be used to transport material horizontally or on an incline. They are typically used when the feedstock must be retrieved from a silo or bin. Front end loaders come in two types and can be used to transport material located in open or covered storage. Agricultural front end loaders are lightweight and are not expected to maintain heavy-duty cycles, while construction loaders have an articulated design for maneuverability and are expected to perform continuously in heave use applications.[248] Small front end loaders cost between $22,000 to $26,000 and can be used to unload a semi-trailer in less than one hour.[234]

As a general rule of thumb, the fuel handling system should be designed to handle half of the daily delivery volume in a third of the business day. This is done to accommodate numerous trucks at once since they often arrive at the same time or in groups.[234]

10.5.3.2 Processing

Almost all biomass feedstocks require the removal of debris, such as dirt, metals, and stones prior to use. The type of debris to be removed depends upon the type of feedstock used. For instance, if using a wood based or agricultural based feedstock, it is more likely that dirt and stones need to be removed than metal. However, if using MSW, it is likely that metal removal will be required. It is important to

[lxxxviii] An opportunity fuel is any biomass feedstock that a power plant would be paid to take, with no cost for delivery to the plant location, or any biomass feedstock that is obtained at no cost with no additional processing requirements once delivered.

remove the bulk of the debris as soon as possible to eliminate the risk of damage on the fuel preparation and combustion equipment.[234]

In the case of metal removal, ferrous metals can be removed using a magnet, whereas non-ferrous metals must be detected using a metal detector and subsequently removed by manual methods. The removal of dirt and stone can be accomplished using equipment, such as a rotary trammel screen. However, it is much more cost effective to write into the contract that the feedstock provided must be free of dirt and debris.[234]

In addition to contaminant separation, some feedstocks may require that their size be reduced. Numerous types of equipment exist for this application. Disk screens are one type, commonly used for energy applications. They consist of a series of rapidly rotating disks that are attached to several parallel, horizontal rotating shafts and can be used to sort material ranging in size from 25 to 150 mm. Disk screens are advantageous because they are non-clogging, self-cleaning, have a high capacity, and allow for variations in the screen size to be used. Hog devices are often utilized for woody feedstocks to reduce their size to a range between 25 and 125 mm. They consist of knives which chip wood, followed by a hammermill which beats and grinds the wood against a screen or spaced bar.[234]

10.5.3.3 Receiving

Of the four common delivery methods there is no best solution. Often the type of delivery method depends upon the feedstock and the distance that it must be transported, which can make the design of the receiving equipment difficult. The common delivery methods are: live-bottom vans[lxxxix], tractor-trailers, dump trucks, and railroad cars.[248] A general rule of thumb can also be utilized for this decision: if the plant to be constructed is less than eight GW_t, dump trucks, live-bottom vans, or tractor-trailers should be used. Alternatively, if the plant is to be greater than eight GW_t, the facility should have a truck dumper for tilting tractor-trailers as shown in Figure 142.[234]

Figure 142. Tractor-trailer biomass delivery.[266]

[lxxxix] A live-bottom van is a self-unloading trailer with a conveyor in the floor.[248]

Live-bottom vans are typically 40 x 8 x 13.6 feet and transport up to 23 tons of material per load. They require approximately ten minutes to unload. If the facility requires less than six deliveries per day, the use of live-bottom vans is feasible; however, for high capacities, a different method is preferred. These self-unloading vans cost approximately $40,000.

The trailer of a tractor-trailer has the same dimensions as that of a live-bottom van. The truck adds an additional 20 ft to the trailer. This type of delivery method is typically required for more than ten deliveries per day. Furthermore, the trailers are not self-unloading, and therefore a truck dump is required.[234, 248]

A truck dump can be installed at the plant site and is used to tilt the trailer or both the truck and trailer at a 75 degree angle with a hydraulic system. With this system, no more than 20 minutes is required per truck for unloading. A truck dump installed to handle the trailer costs approximately $75,000, while those seeking to handle both the tractor and the trailer cost approximately $175,000. The complete system, including a live-bottom receiving hopper costs approximately $250,000.

Dump trucks are typically used for short-distance transportation of the feedstock if the fuel use rates are low. Dump trucks have an average capacity of 12 m^3 and cost between $35,000 and $65,000 depending on the condition and load rating.

Railroad delivery, if it is available to the plant, is the lowest cost feedstock transportation method for distances that exceed 70 miles. The plant must utilize a large quantity of feedstock.[234, 248]

10.5.3.4 Storage

The type and size of the storage facility depends on the facility's heat requirements, the available land area and its location, the moisture content of the fuel, the fuel preparation requirements, the reliability of the fuel supply system, and the severity of the climate. Often, fuel sources, such as agricultural residues, pose storage problems if wet because of the potential for biological action. Silage emits NO_x and if contained in a confined space without proper ventilation, these emissions can be deadly. Dry agricultural residues are less problematic; however, they require covered storage to ensure that they remain dry and the moisture uptake is minimal.[248]

Biomass is typically stored in a bin, silo, or building. In an open storage system, the feedstock is not protected from precipitation. This type of storage typically holds a 10 to 30 day supply to enable the facility to handle variations or interruptions in the fuel delivery. These open storage facilities should have a concrete floor to prevent the fuel from being contaminated by dirt. They should also be pitched to enhance drainage. These facilities should not be located in areas prone to flooding. Fuels lose their net available energy as a function of time in storage. Therefore, this should be considered when feeding the conversion process. Open storage is the lowest cost option for storing large volumes of biomass.[234]

When using a building as the covered storage method, it is generally sized to handle a 3 to 4 day supply. It protects the biomass from precipitation. This type of storage is a necessity for dry fuels. Silos are most often used for the storage of wood under certain conditions. If used for crops that are not wood-based, the fuel requirements should be small (e.g., less than one fuel delivery per day) and there should be an automated feeding system.[248] The average height of a silo is 2 to 2.5 times the diameter.[234]

10.5.3.5 Feeding

It has been found that of all the existing renewable energy based power plants, a majority had problems with their fuel yards and fuel feeding systems.[265] Most of these plants during the initial phases of operation had costs and labor associated with correcting issues. Problems encountered included fuel pit odors and equipment wear, fuel hang-ups and bottlenecks in the feeding system, metal separation problems, and wide fluctuations in fuel composition. Feeding system bottlenecks and jams can be designed for if an adequate survey of the feed has been completed to determine the supply extremes.

For example, if using conveyors, making them reversible could eliminate fuel jamming issues. Additionally, the minimization of fine particles could eliminate potential fuel system plugs.[265]

10.5.4 Emissions Regulations and Control

Although the combustion of biomass has had a positive impact on the production of renewable heat and energy, it is plagued by undesirable emissions and byproducts. These include ash, NO_x, acid gases, SO_2, and particulate emissions. Biomass materials are often low in chlorine, sulfur, and nitrogen contents, and therefore the acid gas, SO_2, and NO_x emissions are often negligible. Thus, ash and particulates are of greater importance; ash however depends strongly on the fuel source.[248]

The EPA AP-42 is a guide to emission rates and contains a compilation of the air pollution rate estimates for industrial stationary sources and other air pollution sources. It also provides emissions estimates for various applications.[267] Current emissions regulations, although regulated on a national scale, vary from state to state and are often impacted by the overall air quality and type of application.[248]

When considering emissions control equipment, it is important to consider the entire system. The fuel, burner/boiler design, and boiler operation greatly influence the emission control system. The size and size consistency of a fuel are important because oversized particles become difficult to distribute evenly and burn slowly, resulting in an incomplete combustion of the fuel. If the particles are too fine, they can become entrained in flue gases. Therefore, the fuel should be consistent the specifications of the equipment. Fuel cleanliness can also limit emissions.[248]

Boilers are often designed for maximum efficiencies and limited emissions. Furnace gas velocities can be minimized by increasing the grate area. As the grate area increases, the air flow per unit decreases resulting in an overall decrease in velocity. This increases the residence time within the combustion zone, which consequently decreases the emissions due to more complete combustion.

Boiler operation is another critical factor in limiting emissions. The operating methods and firing techniques directly affect the stack emissions. Biomass installations generally require full time operator attention to achieve the maximum possible efficiencies. This is because rapid condition changes must be accommodated quickly. Often, the air quantity needs the most adjustment and has a great impact on the efficiency of the process.[248]

For an emissions control system to be effective and comply with regulations, the emphasis should be placed on system design. Before purchasing combustion equipment, the equipment design firms should be consulted to ensure that the equipment will meet the required emissions standards. In addition, the air pollution regulatory authorities should be involved from the earliest possible stage in the facility design to eliminate any potential problems and system redesigns.[248]

10.5.4.1 Particulates

Particulates result from the combustion of biomass, and their existence is often indicated by the presence of smoke. Particulates are composed of unburned carbon, ash, sand and other silicate contaminants, and condensed droplets. The smoke that accompanies particulate emissions is comprised of inorganic ash, non-combustibles, particles of carbon, small liquid aerosols, and other combustible materials that were not completely combusted. The dark plume of smoke accompanying most industrial stacks is a direct result of poor maintenance and operation or an unavoidable situation, such as a rapid change in load or a boiler issue.[248]

Important particulate emission parameters include the particle size distribution, particle strength, particle resistivity, and the gas carriers. If the particulate is less than ten micrometers, it can be difficult to collect. Additionally, those particles, such as carbon, that break easily into smaller ones complicate the collection process. If a dry electrostatic precipitator (ESP) is of interest, the electrical resistivity is a key consideration; it must be high in order for this collection method to be effective. Resistivity is not a factor with wet ESPs.

There are five major particulate control devices: mechanical collectors, baghouses, wet scrubbers, dry scrubbers, and electrostatic precipitators. These are described briefly in the following sections. A simplified process for selecting an appropriate particulate control device is provided in Figure 143.

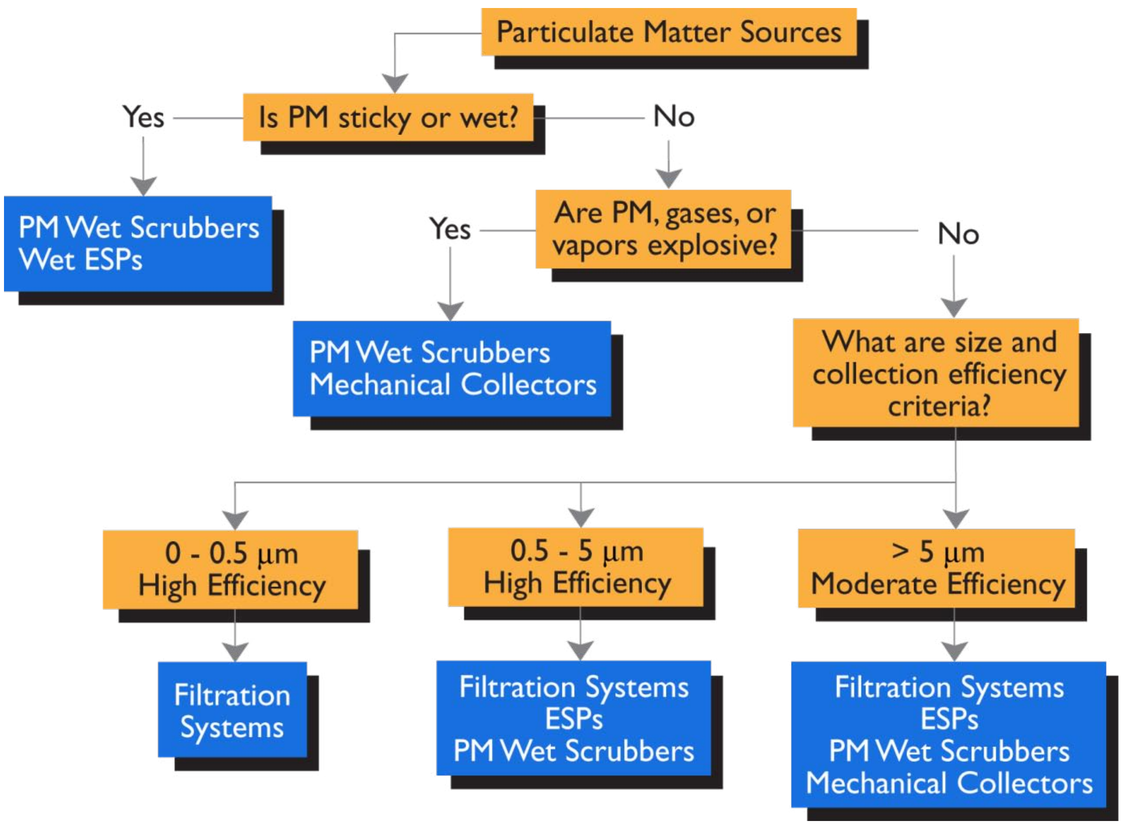

Figure 143. Process for selecting a particulate control system.[268]

10.5.4.1.1 Mechanical Collectors

The most common form of mechanical collector is a cyclone, often referred to as a centrifugal dust collector. These collectors collect large particles and as the particle size decreases, the efficiency of the collector decreases. Cyclones create a double vortex to separate the particles from the gas. In this environment the inert gases spiral downward to create a centrifugal force that causes the particles to move toward the wall. As the gas changes direction and spiral upward toward the exit these particles fall toward the bottom.

The diameter of the cyclone has an impact on the efficiency. As the diameter increases, the efficiency decreases because the particles must travel further before reaching the wall. Multiple cyclones used in parallel can mitigate this issue, as illustrated in Figure 144.[248]

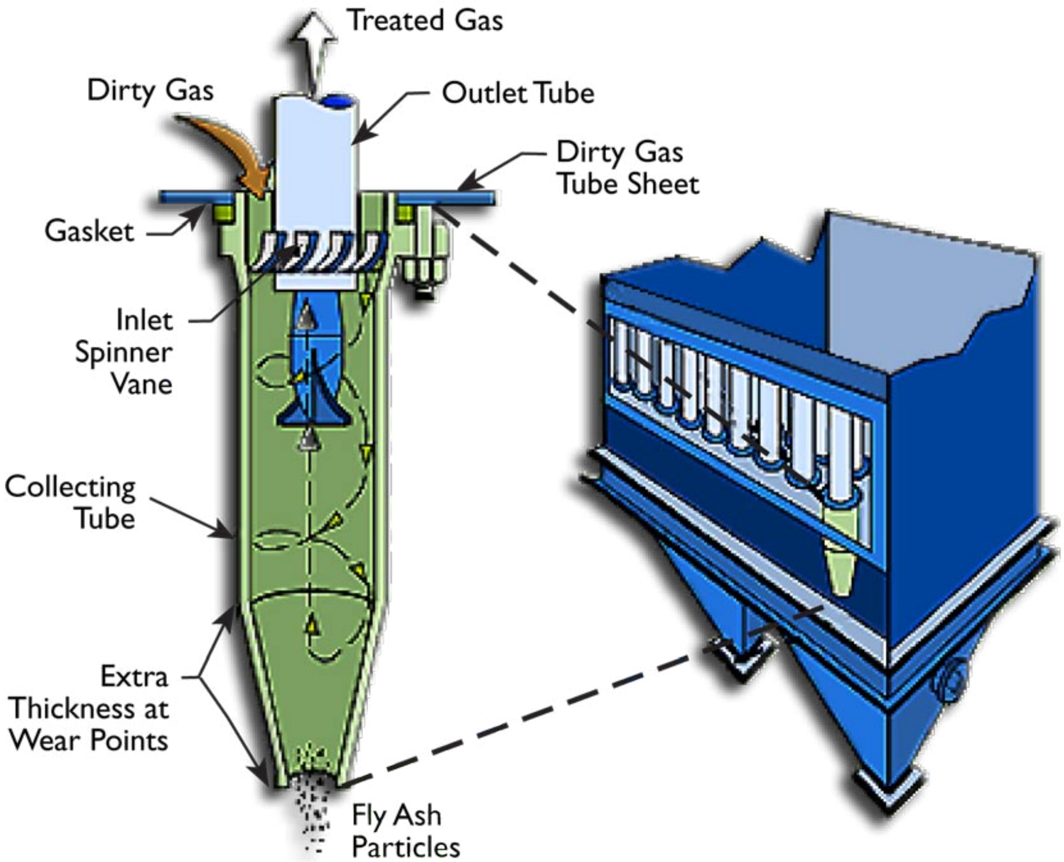

Figure 144. Illustration of a multi-cyclone collector.[268]

10.5.4.1.2 Baghouses

A baghouse functions similarly to a large vacuum cleaner. It has multiple bags that stretch over wire cages. The most popular type is the pulse jet (see Figure 145), in which the air enters at the bottom, flows through the bags, and then out the top. As the air flows through the bags, the particulates are trapped and a dust cake is formed. The rate of filtering increases as the dust cake forms. These particles must be removed from the bags periodically, which can be accomplished by a brief reverse pulse of high pressure air. This type of particulate filter has an extremely high efficiency, a low pressure drop, and has low horsepower requirements. Baghouses have exhibited an efficiency of 99 percent for the removal of submicron particles.

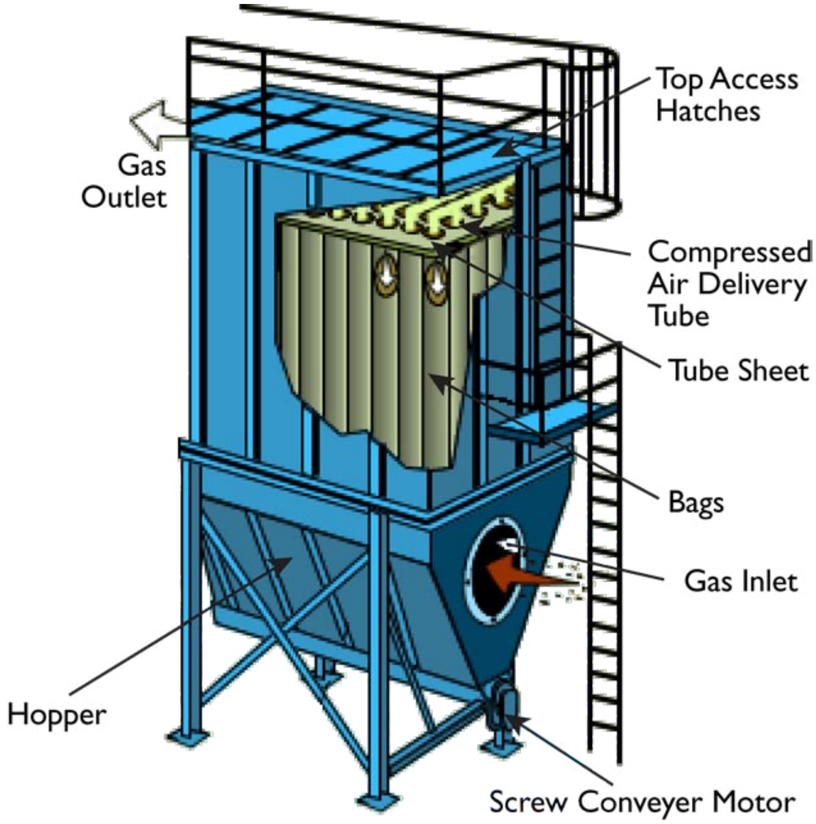

Figure 145. Illustration of a pulse jet baghouse.[268]

The bags in these collectors need replacement every 18 to 24 months, and they are limited to operating at temperatures less than 500°F. These systems operate under a positive pressure within a low O_2 atmosphere to prevent any potential air leakage and to reduce the possibility of fires from the entrapment of particles.[248]

10.5.4.1.3 Wet Scrubbers

Wet scrubbers are designed to develop an interface between the scrubbing liquid and the gas that requires scrubbing. In this type of system, the particles are trapped by liquid droplets, collected, and removed. The most common designs are: baffle and spray, Venturi, and impingement (see Figure 146 and Figure 147). Often, the type of scrubber needed is selected based upon the allowable emissions, the particles size distribution, and the conditions of the entering gas. Wet scrubbers have a high efficiency, even with small particles; low initial cost, low maintenance cost; and resistance to fire damage.[248]

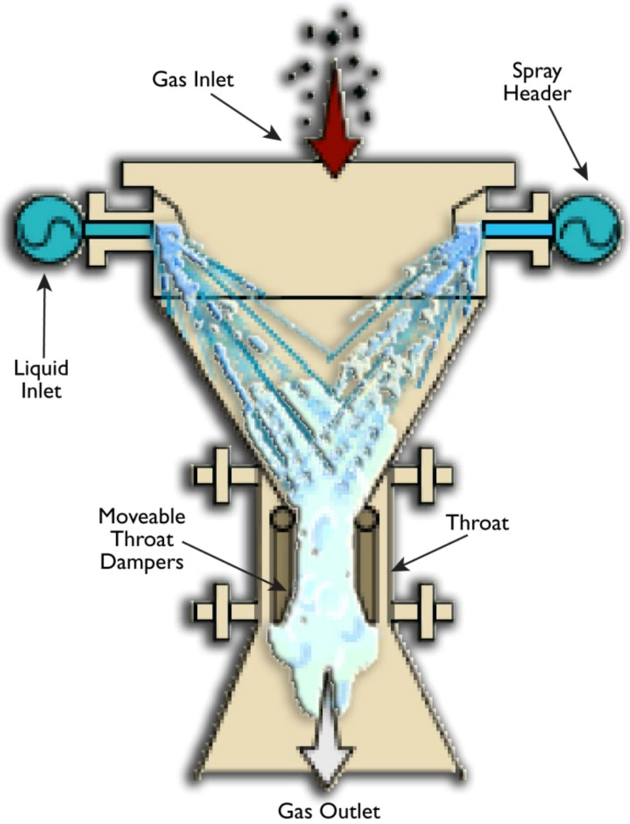

Figure 146. Illustration of a Venturi wet scrubber.[268]

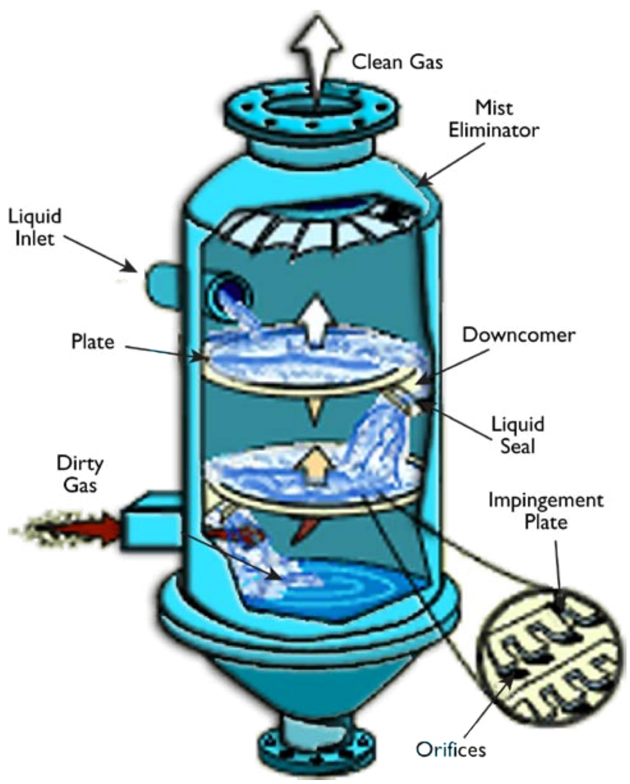

Figure 147. Illustration of an impingement plate wet scrubber.[268]

Wet scrubbers may not be suitable for areas that have a low water supply. They require an average of five to ten gallons of water per actual ft^3/min (AFCM) of particulate-laden emissions. Sludge disposal can also be problematic. In many instances, the liquid is cleaned of its particles through the use of a clarifier or settling pond. In addition, the energy requirement for a wet scrubber increases as the particle size decreases.[248] Wet scrubber vessels are the main component in a larger wet scrubber system, such as the one illustrated in Figure 148.

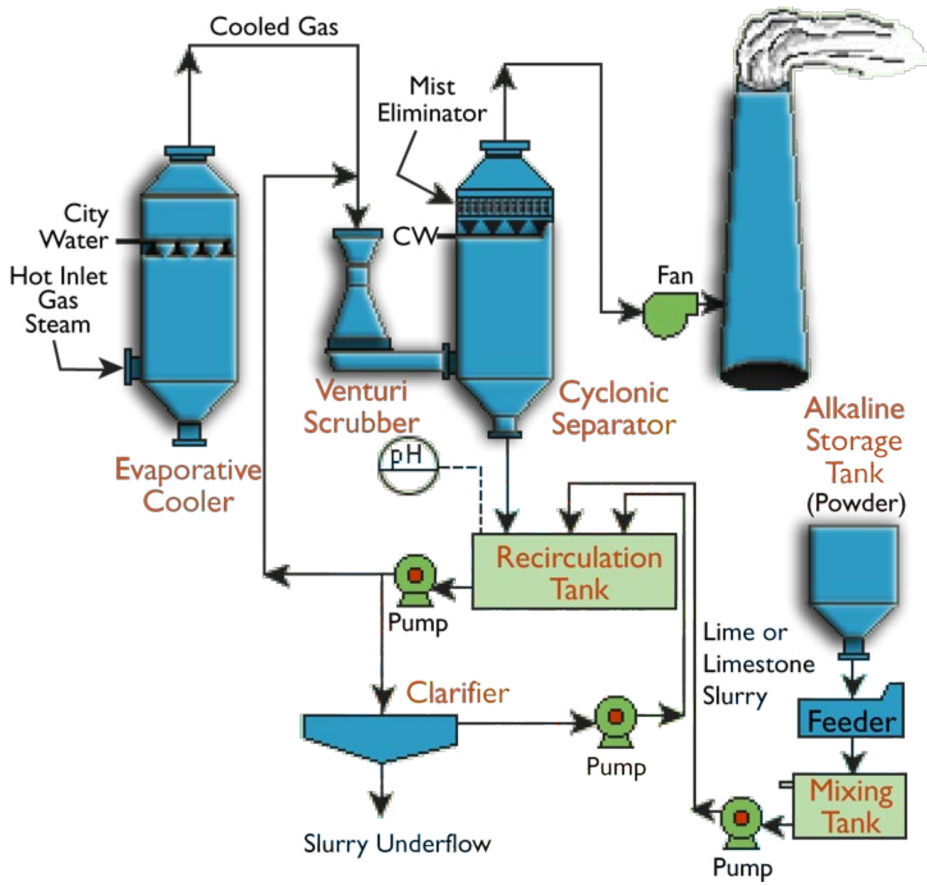

Figure 148. Illustration of a wet scrubber system.[268]

10.5.4.1.4 Electrostatic Precipitators

Electrostatic precipitators operate by ionizing (charging) the particles as they enter the device (see Figure 149). The charged particles (ions) are attracted to oppositely charged plates that are cleaned by periodic maintenance. The particle resistivity strongly impacts the efficiency of collection within a dry ESP. A lower efficiency results from a higher resistivity.[248]

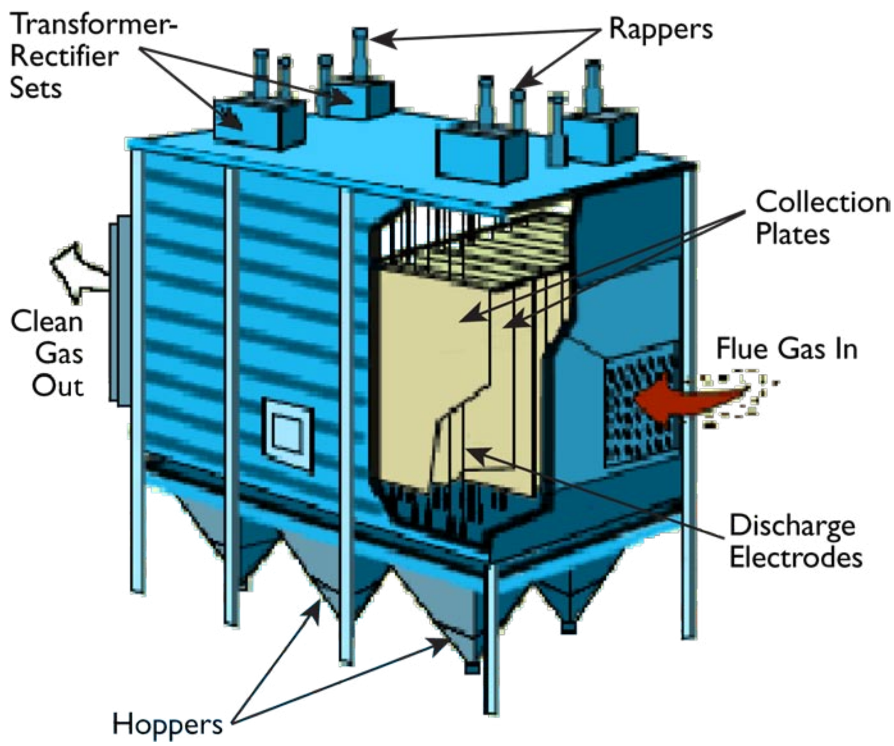

Figure 149. Illustration of an electrostatic precipitator.[268]

10.5.5 Reliability and Partnerships

Reliability and dependability of a plant are important factors in the design, construction, and operation of a plant. Proactive maintenance programs can enhance the plant performance and improve availability and productivity.[265] Furthermore, many of the successful renewable energy facilities in the past have developed both formal and informal relationships with the facility's key consumers and suppliers.[265]

10.6 Current Uses of Biomass within the DoD

Within the DoD, biomass is gaining popularity. With several biomass facilities in operation, plans for more continue to evolve. Table 52 presents a list of the current and planned biomass projects within the DoD.

Table 52. Biomass projects within the DoD.

Facility	Location	Biomass Project
Fort Knox	Kentucky	Biofuels Plant
Fort Stewart	Georgia	Wood Chip Burning Plant
Redstone Arsenal	Alabama	MSW for Thermal Utilities
Red River Army Depot	Texas	Scrap Wood Fuel to Fire Boilers
Dyes Air Force Base	Texas	Waste-to-Energy Cogeneration
Hill Air Force Base	Utah	Landfill Gas-to-Energy
Marine Corps Logistics Base	Georgia	Landfill Gas-to-Energy

One of the most current attempts to utilize biomass within a DoD facility is being demonstrated by the Marine Corps Logistics Base (MCLB) in Albany, GA. This joint effort between MCLB, Albany, and Chevron Energy Solutions will cost the Marine Corps $14M, but will provide the MCLB with an annual savings of $1,150,790 in utility operations. This project is being built in conjunction with a 20 year partnership with Dougherty County. This partnership allows the county to sell landfill gas, produced from its Fleming/Gaissert Road landfill to the base. Additionally, Chevron Energy Solutions will provide a complete lighting retrofit to 82 buildings on the base to reduce MCLB's carbon emissions by 19,300 tons per year. Chevron Energy Solutions has also developed and designed the project and will maintain the landfill gas-to-energy facility, pipeline and landfill gas processing equipment. MCLB will be responsible for the processing, compression and transmission of the landfill gas to the base.[269]

Hill Air Force Base, UT, also has a landfill gas-to-energy project. This plant, however, has been in operation since 2005. Hill AFB is more than 16M square feet, contains 2,100 structures, and employs approximately 26,000 people. Its annual electricity demand is between 40 and 45 MW, with its annual utility costs exceeding $26 M. Within the first two years of the plant's commissioning, it had produced 13.2 MWh and saved the base $635,000 in electrical costs. Due to the great success, the base planned to add a third generator to the two previously existing to increase the production capacity to 2.25 MW.[270]

10.7 Potential Uses of Biomass within the DoD

The DoD has an abundant supply of waste. The DoD generated 5.9M tons of solid waste, which consisted of 3.4M tons of construction and demolition (C&D) debris and 2.5M tons of non-hazardous MSW. With the diversion rate[xc] of 60% overall: 73% for C&D debris and 40% for non-hazardous MSW; the remaining 40% would be available for use in waste-to-energy (WTE) facilities at various locations throughout the US.[264] In addition to the potential waste supply, there are abundant resources of biomass near federal installations. There are approximately 4,700 raw wood processors within fifty miles of 1,800 large federal facilities, which renders the use of wood residues for energy production a possibility. Approximately 1,200 federal facilities are located within 15 miles of a landfill. Five hundred of these landfills do not have any active biogas projects. Furthermore, 850 large wastewater treatment plants are located within 15 miles of approximately 1,400 federal facilities.

The MSW from Army facilities generally consists of 25.7% paper, 25.4% C&D debris, 18.9% organics, 8.5% metal, 2.6% glass, 15.7% plastic, and 3.2% of special materials.[264] In terms of individual soldiers, each generally produces an average of 7.2 pounds of waste per day containing 41% fiberboard, 16% plastic, 10% paper, 8% food, 21% metal and glass, and 4% miscellaneous material.[264]

10.8 Municipal Solid Waste

The conversion of MSW is perhaps one of the most generically suitable forms of energy production from a renewable resource. Although MSW is not renewable in the same sense an agricultural crop or forest is, it can be considered renewable due to the large and relatively reliable production rates. MSW production increased continuously until 2008 as shown in Figure 150.

[xc] Diversion rate is the percentage of waste that is not sent to landfill and is recycled or put to other use.

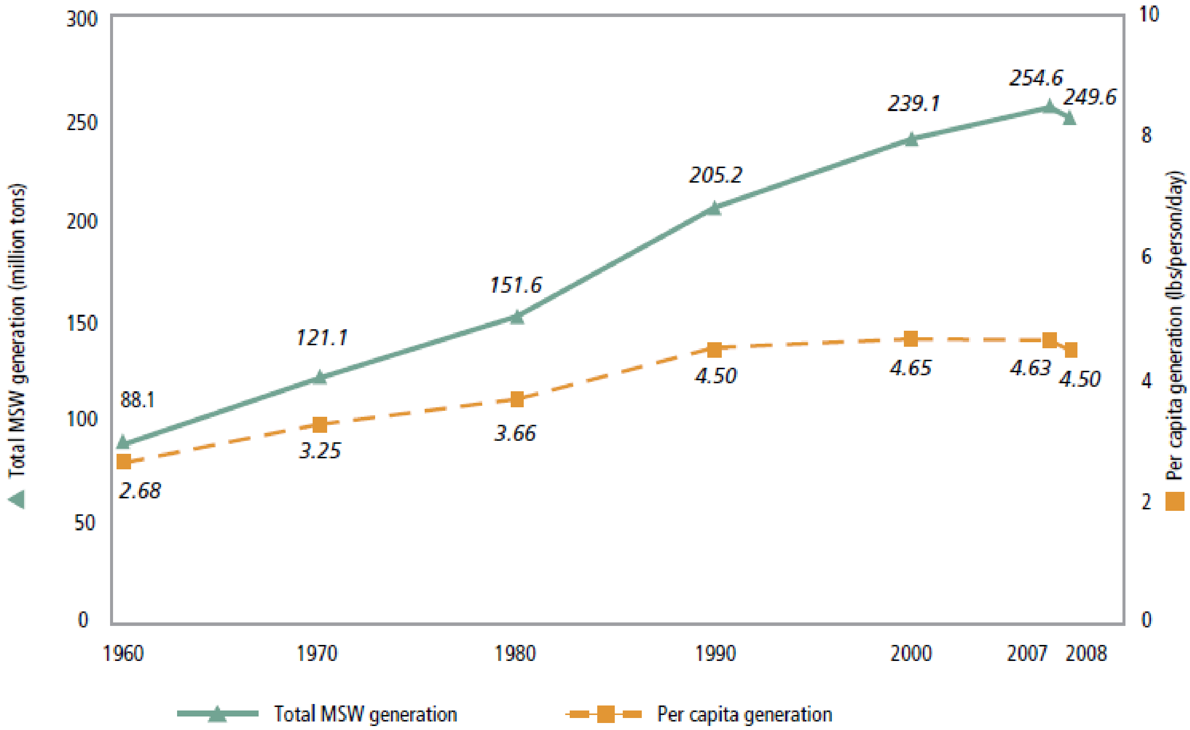

Figure 150. Rates of MSW generation from 1960 to 2008.[271]

10.8.1 Overview

Over the past fifty years, there has been increased waste production. In 1970, 120M tons of MSW was produced. This increased to 220M tons by 1998.[249] By 2008, 250M tons of MSW was generated.[271] This has contributed to the creation of one of the most critical, ongoing issues in the US: solid waste handling and its impact on the environment.[263]

The average person produces 4.5 pounds of MSW per day.[271] The residential MSW production rate in urban areas is approximately 2.0 lbs/capita/day, while industrial and commercial facilities contribute approximately 20 lbs/capita/day.[249] These values are lower in rural communities since there is more onsite disposal, including composting. Location however is not the only factor in waste production; seasonal changes have also been correlated to differences in MSW production.[249]

Waste, specifically municipal solid waste, is a unique feedstock in that it is generated almost anywhere humans exist. Moreover, MSW is one of the few feedstocks that a facility could be paid for using, specifically if the generation facility were to own the waste collection equipment. The use of MSW for power generation would also lead to decreased land filling rates. The use of MSW for power generation could also increase the self-sustainability of townships and cities.

10.8.2 The Challenges of Using MSW

MSW varies significantly in both physical and chemical composition. Therefore, it is often necessary to study the composition of MSW prior to any design activities. The purpose of such a study is to highlight the extremes that might occur within the solid waste that the potential facility may be required to handle. Through the study, several factors should be considered including the physical sizes and shapes of the waste components, variation in the density and noncombustible content; and an overall analysis of the general composition. The best way to obtain this information is through a field-based inspection.

This information enables the design of a materials handling system that can accommodate the variation in size of the waste materials. Ruggedness of the designed system is also important to ensure that the equipment can handle the plant's material demand. Designing for ruggedness can decrease the amount of equipment downtime for maintenance, which can be costly.[249]

The chemical and physical characteristics of the MSW also influence the combustor and boiler design. Important factors for combustor and boiler design include moisture content, calorific value, and percentage of non-combustibles. Heavy metal, chlorine, and sulfur content are also important because their presence may require a flue gas clean-up system to reduce emissions. In general, approximately 35% – 40% of the combustible material in MSW is cellulosic-based. Even with increased recycling efforts over the past decades, this percentage has remained relatively constant. The remaining percentage is mostly comprised of leather, plastic, and rubber.[249]

Generally, the capacity requirement for a combustor or boiler is inversely proportional to the waste's calorific or heating value. On a dry basis, cellulose releases approximately 8,000 BTU/lb of heat when burned. This value is higher on a per pound basis for plastic, rubber, and leather. However, the overall heating value of MSW on a dry basis is slightly less than that of burning cellulose on a dry basis.

Most waste has a moisture content in the range of 50 to 75 wt.%. The range is typically 15 to 30 wt.% for cellulose. The moisture content of MSW is highly variable (i.e., varies from 15 to 70 wt.% moisture) but is often considered to be 25 wt.%.[249]

The average higher heating value for the combustible portion of MSW, when moisture and ash free, is approximately 9,400 BTU/lb. With recent recycling initiatives, slight compositional changes have resulted and caused the HHV to increase to 9,500 BTU/lb. As long as the HHV is greater than 4,000 BTU/lb the MSW will combust without supplementary fuel.[249]

10.8.3 Facilities

Waste-to-energy facilities are often classified based upon the MSW pretreatment method used. Wastes can be treated by physical or thermal methods.

Physical pretreatment methods process wastes using mechanical methods to produce more suitable fuels: refuse-derived fuel (RDF) and solid recovery fuel (SRF). Prior to forming alternative fuels, however, wastes must be processed to remove glass, metal, and other non-combustible materials. RDF is produced by heat-treating or shredding MSW, C&D debris, or sludge and consists largely of organic materials that have been removed from solid waste streams.[249]

If heat treatment is used, the waste is typically placed in an autoclave, which uses high pressure steam to kill viruses and potential pathogens. This also softens plastic components and subsequently causes them to flatten. This process also disintegrates fibrous materials, such as paper, and causes labels to peel from metal objects. Autoclaving reduces the overall volume of the waste by 60%. RDF is a cleaner and more efficient fuel to burn rather than using traditional incineration methods. The residuals that are present following the autoclaving process can be compressed into pellets or bricks and sold as a solid fuel-SRF.[249]

Thermal waste treatment methods use either combustion methods or heat to decompose MSW. Combustion of wastes can be carried out directly in an incinerator or via other methods. When MSW is combusted, the combustion heat is absorbed by the water within the waste, causing it to change phase to steam, which can be used to spin a turbine and create mechanical energy. This mechanical energy is further converted to electric energy using a generator. Alternatively, the hot water can be used in heating systems (i.e., radiant heating systems) rather than allowing for its conversion to steam.[249]

10.8.3.1 RDF Facilities

RDF facilities are typically large in size and utilize already processed MSW. This feed is already processed, and therefore the MSW is relatively homogeneous. RDF can be created in various forms including fluff, powder, coarse, and densified forms. Each type requires a different processing facility depending on the size of the particles produced and whether or not the material is compacted under pressure into a pellet or briquette. RDF has the flexibility to be burned as a primary fuel or co-fired with a conventional fossil fuel in an existing boiler.[249]

10.8.3.2 Mass-Burn Facilities

Mass-burn facilities, unlike RDF facilities, burn as-received MSW. Because this waste has not been processed it is heterogeneous. These facilities are typically large and can handle more than 200 tons per day of unprocessed MSW. With mass-burn systems, the MSW is burned in a single combustion chamber with excess air. Often, these systems have a sloping or moving grate to aid in the agitation of MSW, which allows it to mix more readily with the combustion air. In 2007, there were a total of 86 mass burn and RDF facilities, which accounted for 98 percent of the total waste combustion capacity.[249]

10.8.3.3 Siting

Siting is one of the more critical issues in developing a WTE facility. There are several key criteria that must be satisfied prior to site selection. First and foremost, the desired site must be easily accessible to allow for the delivery of the MSW feedstock to the facility. The access roads that will be used or built must be able to handle the increased truck traffic required to deliver the desired amount of feedstock. It should also be located in a commercial or industrial area to eliminate any issues that could result from the noise produced by the industrial equipment as well as the dust and odors that result from MSW processing. Lastly, if there is any indication that a community would fight a project it should be avoided.

Ideally, plants should be located near major highways to minimize the impact of increased truck traffic. Likewise, depending on the type of facility, the topography of a specific area should be exploited. For example, it is advantageous to place mass-burn sites on sloping or hillside sites. This is because the residues can be dropped at the top of the hill or sloping area and picked-up at the lower elevation thus decreasing the equipment requirements. Overall, it is important to consider the size and centrality to determine the economy of scale.[249]

10.8.3.4 Sizing

The size of a WTE facility depends on the proposed location, area, population, and the rate of waste production. Small waste processing plants do exist, typically processing 100 tons per day of MSW with no energy recovery. However, if energy recovery is desired, the facility should be designed to process more than 400 tons per day of MSW. When constructing a plant of this size, equipment operating conditions and economics push toward seven day a week operation with three shifts per day.[249]

10.8.3.5 Conversion System Design

There are several primary factors that must be considered in the design of an MSW conversion plant. These include fuel handling, storage, processing, feeding, combustor and boiler design, by-products, and emissions. These are described briefly in the following sections.

10.8.3.5.1 Fuel Handling

Fuel handling within a WTE facility typically includes receipt of the feedstock and its ensuing storage and processing. These are described briefly in the following sections.

10.8.3.5.1.1 Refuse Receipt

When receiving the MSW feedstock, it is important to know the quantity of waste being received. Therefore, every facility should install a scale to measure the weight of the waste and transport vehicle entering and the empty transport vehicle leaving to obtain approximate estimates of the quantity of feedstock entering the facility. Secondly, it is important that the receipt facility be designed to adequately handle waste tipping. The waste tipping facility should be an enclosed area to prevent the MSW feedstock from blowing around.[249]

To determine the number of tipping sections needed, it is first necessary to determine the number of trucks per hour that would be entering the facility. The estimated peak number of trucks is a good starting place to determine the number of tipping stations. In addition to the expected peak number of trucks, it is also important to consider any planned expansion that may cause this number to increase. The tipping stations should be able to store two to three days worth of fuel to account for any changes in delivery or the possibility of not having weekend feedstock deliveries. This could also help to accommodate any seasonal or cyclic variation in the feedstock availability.

10.8.3.5.1.2 Refuse Storage

The storage of the MSW feedstock often is dependent upon the conversion method selected. With mass-burn facilities, deep pits that are long and narrow and extend the length of the furnaces are used because they allow for the feedstock to be easily fed to the furnace with minimal material losses. Conversely, in RDF facilities, floor dumping is used and the MSW is stored on the floor or within a shallow, wide pit.[249]

Generally, it is much more complicated to calculate the size of the storage facility rather than to decide on a specific layout. When calculating the storage facility size, it is necessary to know the bulk density of the feedstock. Once the amount of the feedstock needed is known, the total feedstock volume can be calculated by dividing the mass of the material by the bulk density. The total volume can then be used to determine the length, width, and height of a storage facility. Most commonly, MSW has a bulk density that ranges from 400 to 600 lb/yd^3 or 240 to 360 kg/m^3.[249]

In addition to feedstock storage, the storage facility should also be designed with a length in excess of that required by the trucks for dumping or tipping their wastes. Tipping typically requires at least 14 feet of unobstructed width for operation and takes an average of ten minutes. However, provisions for 20 ft provides for convenient truck access and space for armored building support columns should they be desired. Armored building supports are used to prevent the occurrence of damage if accidently impacted. Overall, the plant layout and operations, site constraints, and empirical data of the MSW should be considered when designing a storage facility.[249]

The total storage volume should be equivalent to the total volume in the pit up to the tipping floor, plus the total volume above the tipping floor. It is recommended that the pits span the length of the combustors and are 30 to 45 feet deep. Pits should also be able to hold a three day supply of fuel at the maximum continuous rate of consumption of the facility to ensure no production declines should the feedstock supply decrease.[249]

10.8.3.5.1.3 Processing

The processing of MSW often occurs upon receipt of the MSW or before it is fed into the combustor. The main goal of MSW processing is to remove the non-combustible waste materials from those that are combustible. Other processing steps can also be performed to shed or decrease the size of the waste materials received. In several of the newer facilities, specifically RDF, the waste is fed onto a conveyor upon receipt and transferred to flail mills or trammels with bag-breaking blades. This allows for some of the metals and glasses to be removed, and subsequently decreases the waste volume. The remaining waste is then reduced in size by the processing equipment. The removal of glass is desired to prevent glass shards from contaminating the combustible material.[249]

10.8.3.5.2 Fuel Feeding

In most MSW conversion facilities, cranes are used to transfer the MSW from the storage area or pit to the furnace or boiler through a charging hopper. These cranes are often equipped with a grapple and are operated from a central control room. These control rooms are frequently fixed at the charging floor elevation and located opposite the charging hoppers or over the tipping positions. The size of the crane grapple is determined based on the quantity of material that must be moved, the distance of which it needs to be moved, the specified crane speed, and the need for pit material re-handling. Grapples are usually 1.5 to 8 yd^3 larger than that required, and the crane's specifications are based upon the grapple weight and the weight of the material that it will be transporting.[249]

The waste material is then moved from the charging hopper to the furnace using a chute. This chute is typically 4 ft (1.2 m) wide or greater to ensure proper waste flow and to avoid larger items from becoming stuck. Often, these chutes are kept full to prevent the entrance of undesired excess air into the furnace.[249]

10.8.3.5.3 Combustor Design

Although MSW can be combusted in either a furnace or a boiler, the design considerations differ greatly between each. Both are described briefly in the following sections.

10.8.3.5.3.1 Furnace Design

Furnace design is directly dependent upon the amount of combustible material to be burned and the amount of moisture within that material. It also depends on the volatility of the MSW being converted.

Within a furnace, MSW is heated via contact with preheated air or hot combustion gases and by the radiation of heat from the furnace walls. The biomass is dried between 122 to 302°F (50 to 150°C), with volatile matter being formed at higher temperatures due to thermal decomposition reactions. This volatile material is combustible and often produces flames once the ignition temperature is reached.[249]

Grates are often used to support the solid material within a furnace. These grates often move to allow for the non-combustibles to be continuously removed from the furnace while also supporting combustion. Additionally, grates enhance bed agitation and the redistribution of burning material, while also enabling quenching if needed. In mass burn facilities reciprocating, roller, and rocking grates are most common. RDF facilities however typically utilize traveling grates. Reciprocating, rocking, and rolling grates use the grate movements and incline to agitate and move the refuse material through the furnace. Reciprocating grates have drops in elevation between the grate segments that allow for additional agitation. Rotary combustors on the other hand slowly rotate and tumble the waste through the inside of cylinders that are inclined to allow gravity to assist in the material motion through the cylinders. Travelling grate systems move through the furnace carrying waste materials from one side to the other. Agitation of the MSW occurs if the grates are designed with multiple sections and a drop in between.[249]

When used in mass burn facilities, these grates often have air openings that occupy between 2 to 30 percent of their surface, while RDF facility grates typically have fewer air openings. Smaller openings are preferred over larger ones because they limit the amount of siftings that can pass through, while also creating a pressure drop that helps to control the introduction of underfire air. When larger openings are present, it is much more complicated to control the underfire air; yet, they do allow for the continuous removal of fine waste materials that could potentially interfere with the combustion process. Underfire air is important for two reasons. First, it serves to provide the necessary supply of oxygen for combustion, and secondly it is used to cool the grates.[249]

In a typical mechanical grate, continuous feed system, the height of the furnace is dependent on the required volume with the general shape being rectangular. Under optimum conditions, the furnace should have sufficient volume to retain the gases in the high temperature zone of the maximum fuel volatilization for a long enough period to guarantee complete combustion. Turbulence should be provided to improve heat transfer and maintain the ideal temperature. Overfire air is used to ensure that the volatile gases released during combustion are completely combusted. When overfire and underfire air is used, the furnace is typically equipped with two blowers, one for each air stream. The underfire air blower should be designed to provide half to a third of the total required combustion air, while the overfire air blower should be designed to provide the remaining air required.[249]

The underfire air in most US type mass burn units is provided at a pressure in the range of two to five inches of H_2O, while overfire air is provided at pressures greater than 20 inches of H_2O. These high pressures are required to produce the desired turbulence without encroaching upon the opposite wall when introduced into the furnace.

The furnace volume is determined using the feedstock's rate of heat release. The average heat release rates of MSW range from 12,500 to 20,000 BTU/ft^3/hr (450 to 750 MJ/m^3/hr).[249] Conservative estimates will use the lower value. A conservative estimate is typically used if a system is prone to change, such as when a volatile feedstock is used or the end product demand is volatile.

Grate design, if using a grate fired furnace, is based around a desired burning rate. For example, it is suggested that grates be designed to allow for a burning rate greater than 60, but no more than 70 lb/ft^2·hr (290 to 340 kg/m^2·hr) of grate area. The heat rate loading on the grate should also be limited to 250,000 to 300,000 BTU per square foot of grate area per hour. Grate design also plays a key role in setting the resonance time of the furnace. Resonance time, or the time that the biomass remains within the furnace, is important because if the biomass does not remain in the furnace long enough, combustion may not be completed and consequently some of the feedstock will be wasted.[249]

Following the determination of the furnace capacity, based upon the values for furnace volume and grate area, several additional considerations are required. Often, several byproducts are produced. For instance, flue gas often contains environmental pollutants that must be removed prior to release or use. This removal is most frequently accomplished using a pollution control system. However, after the pollutants are removed, some of the flue gas can be recirculated into the system to reduce costs through its use as a portion of the underfire air, and thereby reducing NO_x emissions and increasing thermal efficiency. However, because these flue gases contain significant portions of acid gases, the duct work and pipes used for its transportation are susceptible to corrosion.[249]

10.8.3.5.3.2 Boiler Design

Boiler systems are used to recover a portion of the thermal energy produced by the thermal decomposition of the combustible components in MSW. Although boiler systems often contain furnaces, they exist in several configurations. These include mass fired refractory combustion chambers followed by a convection boiler section. A mass fired water wall unit is where the water wall furnace enclosure forms an integral part of the boiler system. There is also an RDF semi-suspension fired spreader-stoker boiler unit.[249]

MSW boilers often have tribulations with tube fouling due to the soft, semi-molten particles that gather on the boiler tubes and the gaseous metals and salts that condense on the colder boiler tubes. This slagging often causes metals to corrode at high temperatures as a result of the fouling.[248]

10.8.3.5.3.2.1 Refractory Furnace-Boiler Systems

Refractory furnaces with waste heat boilers often have low energy extraction efficiencies when compared to other boiler configurations. With this type of system, only 50 to 60 percent of the combustion heat generated is recovered with this system. Typically, two to three pounds of steam are produced per every pound of MSW[xci] consumed. These lower heat generation efficiencies result from the heat losses that are directly related to the excess air quantities required.[249]

10.8.3.5.3.2.2Mass-Fired Water Walled Units

Currently, the most widely used heat recovery boiler unit is the mass-fired water walled unit. With this type of system, the primary combustion chamber consists of closely spaced steel tubes used to circulate water. The combustion chamber is followed by a convection type boiler surface, which produces greater than three pounds of steam per pound of MSW and has heat recovery efficiencies between 65 and 75 percent.[249]

10.8.3.5.3.2.3RDF Semi-Suspension Boiler Units

Semi-suspension fired spreader-stoker boiler units are commonly used to burn RDF. With this type of unit, the RDF is introduced through air swept spouts in the front water wall, where it partially burns in suspension and then falls to the grate when combustion is completed. These RDF fired water wall units have efficiencies ranging from 65 to 80 percent, and they produce steam at a rate similar to the mass-fired water walled units. However, if the material lost during processing is included, the steam production falls to less than three pounds per pound of MSW.[249]

Sometimes, and specifically when the recovered energy is to be used for electricity generation, it is necessary to superheat the biomass. When this is required, the primary combustion chamber of the water walled system is followed by a superheater and then the typical convection boiler, heat transfer surface, and an economizer. Caution should be taken if a superheater is required because these surfaces are more prone to warping than other boiler parts.[249]

10.8.3.5.4 Byproducts

Byproducts are an important consideration when developing any processing system. In MSW biomass conversion, there are several common byproducts that must be handled. These include ash, pollutants, minerals, and organic compounds. These are described briefly in the following sections.

10.8.3.5.4.1 Ash

Ash mostly consists of the noncombustible components of MSW. Typically, no more than 3 percent of its composition is combustible material. Many of the materials contained within ash are inert and have a low solubility. Ash contains carbon and several transition metals and nonmetals; these comprise 10 percent of the ash. The two common types of ash are fly ash and bottom ash. In general, bottom ash is composed of many of the less volatile metals, whereas fly ash contains the volatile and semi-volatile metals. Additionally, many of the chemicals, such as polycyclic-aromatic hydrocarbons (PAHs) and phthalates are contained in the bottom ash, while the dioxins, furans, and polychlorinated biphenyls (PCBs) are concentrated in the fly ash. Even though the dioxin and furan levels in ash have decreased as a result of improved technologies in more modern facilities, they still are present. This coupled with the volatile metals causes fly ash to be considered hazardous and often acid. This effect is countered by mixing fly ash with the non-hazardous alkaline bottom ash prior to disposal.[249]

In most modern facilities, bottom ash is discharged from the end of the furnace grate (if a grate-type system is used) and sent into a chute that transfers this ash to a water trough. The ash is removed from this trough and sent to a conveyor via a ram discharger. Alternatively, a flight conveyor can be used to send the ash to an elevated hopper where the ash is then transferred to a transport vehicle after being screened to remove large items. Flight conveyors typically have two troughs so that either can be used. Fly ash is the waste recovered from pollution control systems and is often discharged with the bottom ash.[249]

[xci] With a heat content of 4500 BTU/lb

Important design considerations include sealing the discharge end of the furnace to prevent unwanted emissions, placing the discharge chute at least six inches below the water's surface to ensure complete transmission, and if using a conveyor, it should be designed to handle any potential material that may pass through without contributing to blockages. Although estimates suggest that 5 to 15 percent of the originally procured material will be disposed of in the end, most plants in operation only show 40 to 50 percent waste reduction. This value is slightly increased (65 to 75 percent) if using a ram discharger.[249]

10.8.3.5.4.2 Emissions

MSW combustion produces several emissions as particulates, gases, organic compounds, and trace metals. These are described briefly in the following sections.

10.8.3.5.4.2.1 Particulates

If particulates are present in high concentrations, they can contribute to health problems and have adverse effects on the environment. Current particulate control efforts are focused on submicron-sized particles. Fabric filters have been a common particulate control method, since the particulate emissions regulations of 1995. They have high removal efficiencies when operated to remove sub-micron sized particles. The efficiency, however, is also dependent on temperature. Thus they may be coupled with a scrubber system for increased performance over a broader temperature range.

10.8.3.5.4.2.2 Gaseous Emissions

The gaseous emissions of a MSW facility include, SO_2, hydrochloric acid (HCl), CO, and NO_x. Acid gases, such as HCl and hydrofluoric (HF) acid, are controlled by scrubbing devices, while NO_x, CO, and other hydrocarbon emissions are controlled by good combustion practices and sometimes additional air pollution control systems. Although proper combustion practices are generally suitable for CO and hydrocarbon emissions, NO_x emissions are often removed using a selective non-catalytic reduction (SNCR) system to achieve the desired emissions levels prior to release. The release of CO and hydrocarbons can be attributed to incomplete combustion or upsets in the combustion conditions. NO_x emissions, however, are caused by high combustion temperatures and the recirculation of flue gases. Independently of combustion, acid gases and sulfuric oxides (SO_x) are a direct result of the chlorine, fluorine, and sulfur content of the fuel and are best controlled by acid gas scrubbing devices that use chemical treatments.[249]

NO_x emissions are typically removed by an SNCR process at temperatures between 1,600°F and 2,100°F, because at lower temperatures a catalyst is typically needed to convert the NO_x to nitrogen and water. A catalyst incurs more costs, and therefore selective catalytic reduction is not commonly used. SNCR, however, has been shown to reduce the NO_x emissions from MSW combustion to 150 ppm, which translates to a reduction between 45 and 55 percent.

HCl can be very effectively removed, while SO_2 and SO_3 are much more difficult to remove. HCl can be removed at a 99 percent efficiency using highly reactive slake lime; however, under the same conditions, SO_2 is only removed with an efficiency between 60 and 90 percent. These removal efficiencies can be increased by injecting lime into a fabric filter or scrubber system.

Combustion control is yet another way to control gaseous emissions, although it is frequently much less effective. One of the key considerations in emissions control is the amount of combustion air used. If there is too much combustion air, the system temperature will be reduced, which leads to a significant reduction in the rate of chemical decomposition during combustion. As a result, large quantities of hydrocarbons will be released in the flue gas. Alternatively, if the MSW is not adequately mixed with air, fuel rich pockets that are high in hydrocarbons will form. These hydrocarbon rich pockets can be released from the combustion system.[249] Additionally, adequate resonance times and perfect mixing are often required to minimize hydrocarbon emissions.

10.8.3.5.4.2.3 Organic Compounds

Organic compounds, such as PCBs, PAHs, polychlorinated dibenzofurans (PCDF), polychlorinated dibenzodioxins (PCDD), chlorophenols (CP), and chlorobenzenes (CB) are commonly present as chemical contaminants. The most common are PCBs and CPs. These compounds are often present in MSW as a result of fungicide and bactericide use. PCBs have also been used in the past for heat exchanger and capacitor fluids, which results in their presence in MSW as well. The presence of such compounds is not significant unless excess air is used, which cools the gases to a temperature below that required for decomposition to occur. Dioxins and furans are synthesized between 400°F and 800°F, with their formation being dominated by free radical reactions within an MSW combustor. They also result from the condensation reactions of chlorinated phenols and biphenyls. Similarly, if chlorine is present, dioxins and furans may form. The presence of water-cooled surfaces also assists in the oxygenation of polycyclic compounds.[249]

Fabric filter scrubber systems have been shown effective at removing dioxins and other organic compounds. CBs, CPs, PCBs, and PAHs are removed at efficiencies between 80 and 99 percent. The use of activated carbon injection can further reduce the emissions levels by another 50 percent.[249]

10.8.3.5.4.2.4 Trace Minerals

Trace minerals are typically not consumed during combustion and as a result appear later in the process. When less than 0.2 μm in size, these trace minerals are often carried off with the flue gases that pass through the furnace. These volatilized materials can condense later in the process in a cooler section of the furnace as an aerosol (<1 μm) or on the surface of the fly ash with preference to fine ash particles.

10.8.3.6 Costs

Obtaining accurate and reliable cost data for WTE facilities is a difficult task for several reasons. A primary reason is that much of the data is not provided using a consistent format and thus is not comparable. This causes numerous issues when attempting to project the costs of a new plant during a project's study period.

10.8.4 Conversion Technologies

Although many of the basic conversion technologies are similar, there are several additional factors that need to be considered when dealing with waste, which do not need to be considered when using an agricultural or wood-based crop for energy production. The primary purpose for building waste to energy facilities is also quite different from that of other methods. The purpose of most WTE facilities is not to generate renewable energy, but instead to reduce MSW and other waste materials to inert residues that can be land filled with no adverse environmental impacts. The second primary goal is to achieve a maximum thermal efficiency. This is the efficiency of capturing the energy released during combustion versus that which is actually released.[249]

10.8.4.1 Incineration

Incineration is one of the most basic methods for the decomposition of MSW. Even after recycling 30 percent of waste, the incineration of the remaining material MSW could provide an electrical power output equivalent to that of eight large nuclear or coal powered generation facilities.[249] In 2007, incineration facilities processed 14 percent of the waste produced in the US alone, providing electricity for 2.8M homes.[263]

The incineration of MSW is a popular source of electrical energy since it can provide electricity at prices competitive with baseload coal-fired power plants and could provide 1 to 2 percent of the electrical needs in the US, while also reducing the MSW for landfill disposal. Incineration results in a nine-fold decrease in the volume of the MSW put in landfills. Nevertheless, incineration has experienced much opposition due to the adverse pollution concerns. This is accounted for in modern facilities via the installation of safe and cost effective environmental safeguards that provide adequate monitoring.[249]

In the past, when there were limited pollution regulations, incineration was a simple process, and fixed-grate plants were popular. Most of these facilities operated on a single or double-shift basis. Yet, with air pollution regulations becoming increasingly stringent and the requirement for flue gas clean-up systems, plant configurations have become much more complex.[249]

10.8.4.2 Modular Systems

Modular systems consist of factory-prefabricated components joined together to form an operating unit. The individual units are built with an average capacity of 100 tons per day and can be combined to form plants with capacities in excess of 400 tons per day. With these systems, the unprocessed MSW is combusted in one of the two combustion chambers, and it is fed into the system using a hydraulic ram. This ram pushes the MSW over a series of hearths where combustion occurs. These systems generally come in one of two types: starved air or excess air, and often do not have the amount of equipment redundancy that exists in larger facilities.

Modular systems are relatively low cost and the construction period is relatively short. However, these systems often have lower efficiencies, increased ash quantities, and decreased combustion control. Within the US, modular systems burn approximately 2 percent of all the MSW burned.[249]

10.8.4.3 Fluidized Beds

The use of fluidized beds for the combustion of MSW is nearly identical to the fluidized bed systems for converting traditional biomass sources. The main difference is the operating conditions. Fluidized bed technologies are not as common as other systems, and therefore there is not enough information to assess their long-term effectiveness. The units are much smaller in size than those required to meet the US WTE need.[249]

10.8.4.4 Pyrolysis and Gasification

The pyrolysis and gasification of MSW is nearly identical to this conversion method using traditional biomass. However, when used as an MSW conversion process, there are several additional challenges. Primarily, the heterogeneous nature of MSW makes the reactions complex and difficult to control.[249] Gasification is also used to convert waste, and plasma-arc gasification provides the potential for the consumption of any waste input.[263]

There are several pyrolysis and gasification plants in operation for the conversion of MSW. The following presents an overview of some of the technologies currently being used, as well as their overall environmental impact. This assessment can be performed based upon their formation of pollutants, the formation of acidifying agents, terrestrial eutrophication as a result of excessive NO_x emissions, and photochemical ozone formation.

The two stage pyrolysis and gasification of MSW has been demonstrated commercially throughout Europe and Japan. With this configuration, raw MSW is pyrolyzed to produce a gas. This gas is then passed through a series of scrubbers and then gasified converting any remaining waste to inert residues.[272]

Commercial and semi-commercial facilities for the thermal cracking gasification of granulated MSW also exist throughout Europe. This type of gasification plant requires a MSW pretreatment process in which the MSW is shredded, dried, and granulated. The molecular bonds of the granulated MSW are then broken under intense heat and in the absence of oxygen. The product gas is rapidly cooled prior to release or further processing.[272]

Other waste conversion technologies include the pyrolysis of MSW; the combined pyrolysis, gasification, and oxidation of MSW; the steam gasification of wood; fluidized bed gasification of organic wastes; and the gasification of RDF.[272]

Presently, the US has demonstrated the effectiveness of the gasification of scrap tires on a bench, pilot, and semi-commercial scale. With this system, the scrap tires are shredded and dried to achieve a moisture content no greater than 30 percent. They are then converted to syngas using a gasifier and an external fuel source. The char and particulates are removed from the product gas and then recycled to the gasifier using a dust removal device. The gas is then cooled so that any aerosols will condense. Lastly, it is passed through an electrostatic precipitator.[272]

10.9 Overall Economic Considerations (All Biomass)

When determining the viability of a desired project, it is necessary to determine several factors including capital investment costs, operating costs, tax rates and insurance information (if applicable), fuel costs, annual income, annual savings, payback period, and return on investment. In many instances, it is difficult to predict a fuel cost over the entire lifetime of a project. This is a particularly problematic challenge since the fuel cost is one of the greatest costs in a biomass conversion facility. Nevertheless, many plants use similar economic factors to determine the overall facility cost.[248] Most use a three year payback period based on first year economics. Using a longer period results in a higher risk and lower probability that the facility will be constructed and have positive economics. The total cost of all a facility's components can be approximated from supplier estimates and based on estimated feed and production rates. In most cases an interest rate of 15% over a 25 year period is used for loan calculations. The maintenance costs, tax rates, and insurance are all typically a fixed percentage of the capital cost developed from existing facilities.[248]

11 GEOTHERMAL ENERGY

The phrase geothermal energy describes the thermal energy that is contained below the earth's surface. This energy is abundant throughout the world, but only certain regions have sufficient, accessible energy to sustain major power plants.[273] For example, there was approximately 3.2 GW of geothermal power capacity in use throughout the US in August 2009. Out of this total, 2.6 MW was in California and 450 MW were in Nevada. US geothermal power plants are located in California, Nevada, Hawaii, Utah, Alaska, Idaho, New Mexico, Oregon, and Wyoming. No other state generated any significant amount of power from geothermal resources.

Over the past 25 years, the global production of electricity using geothermal sources has increased significantly. In 1975, the worldwide installed generating capacity of geothermal power plants was approximately 1.3 gigawatts-electric (GW_e) and currently it is greater 10 GW_e.[274]

Despite a growing interest and several incentives, the number of geothermal power plants in the US only grew modestly in 2009. Six new plants, with a total useable capacity of 176 MW, were the only new additions to the geothermal power landscape.[275] However, there are still a number of reasons to remain optimistic about the potential for geothermal power growth. Geothermal heat, like other renewable options, is available across the country and offers some advantages compared to traditional energy sources.

To illustrate the potential impact that geothermal energy could make in the electricity industry, it is important to examine its dynamic potential. For example, if only one percent of the thermal energy resources located within the ten uppermost kilometers of our planet could be tapped, this energy would be 500 times the amount contained in all oil and gas resources in the world.[276]

Despite this potential, geothermal energy has yet to experience any rapid growth rate. Generally, the reason why geothermal energy projects and geothermal power plants (GPPs) do not get beyond the conceptual stages has to do with high upfront costs (i.e., before electricity is produced). Geothermal is often at a commercial disadvantage to fossil fuels, because of the high cost of drilling enough wells to supply full plant capacity at startup. To become competitive with other power sources the short-term challenge is to continue to lower the cost of production without compromising safety. In many cases, the cost of drilling wells to capture enough capacity for a GPP is the economic equivalent of purchasing most of the fuel required for the next 20 years in a fossil fuel power plant. Thus, these substantial costs often cause potential geothermal investors and developers to pause, sometimes permanently stop, the reservoir exploration and development.[274] However, a significant opportunity for geothermal development is emerging due to their low greenhouse gas emissions compared to fossil fuel plants.[274]

In the medium-term, the development of technology to recover stranded heat in geothermal reservoirs will generate more opportunity for geothermal energy. In the long-term, enhanced geothermal systems (EGS) have the greatest promise. Cost effective heat mining technology will require coordinated efforts from government and industry over the next few decades. Extracting a significant fraction of the available geothermal heat presents a considerable challenge, but an eminently worthy one, as the nation faces an increasing need for renewable energy in the decades to come.

Over the short-, medium- and long-term, production engineering will play an integral part in advancing the use of geothermal energy throughout the world. However, like other renewable energy technologies, the area of geothermal energy cannot continue to evolve as a viable, cost-effective electricity producing method without further technological advances.[274] The following sections examine geothermal energy technology, its benefits, potential drawbacks, and some examples of its success as a viable energy production method.

11.1 Basics of Geothermal Energy

Geothermal energy is a plentiful, essentially inexhaustible resource that is available throughout the world. Since it is practically inexhaustible, geothermal energy is considered a renewable resource. By definition this thermal energy is stored within the earth's crust. In general, it is available for both small-scale applications on a widely available basis and for large-scale applications on a more limited basis. The following sections provide some background about geothermal energy including where it comes from, where it is available, and what it can be used for.

11.1.1 Sources of Geothermal Energy

The temperature at the center of the earth has been estimated to be more than 11,000°F, which is approximately the temperature at the surface of the sun. The earth's thermal energy is derived from several natural processes.[277, 278] A portion of the earth's thermal energy remains from when the planet was originally formed by the condensation of hot gases and particles under gravitational forces. Additionally, as denser components were drawn to the center during the earth's formation, the less dense materials were displaced toward the surface. This differentiation process involved friction, in which heat was generated, and some of the heat from this process was also retained. Moreover, latent heat is released from the core as it cools and expands in volume. Most of the earth's heat, however, is derived from the isotopes of radioactive elements, such as plutonium, uranium and thorium, which are contained in the earth's mantle and crust (see Figure 151). These radioactive materials release energy as they decay to become stable elements.[277] The cumulative thermal energy provided by these sources travels primarily by conduction through the various layers of the earth.[279]

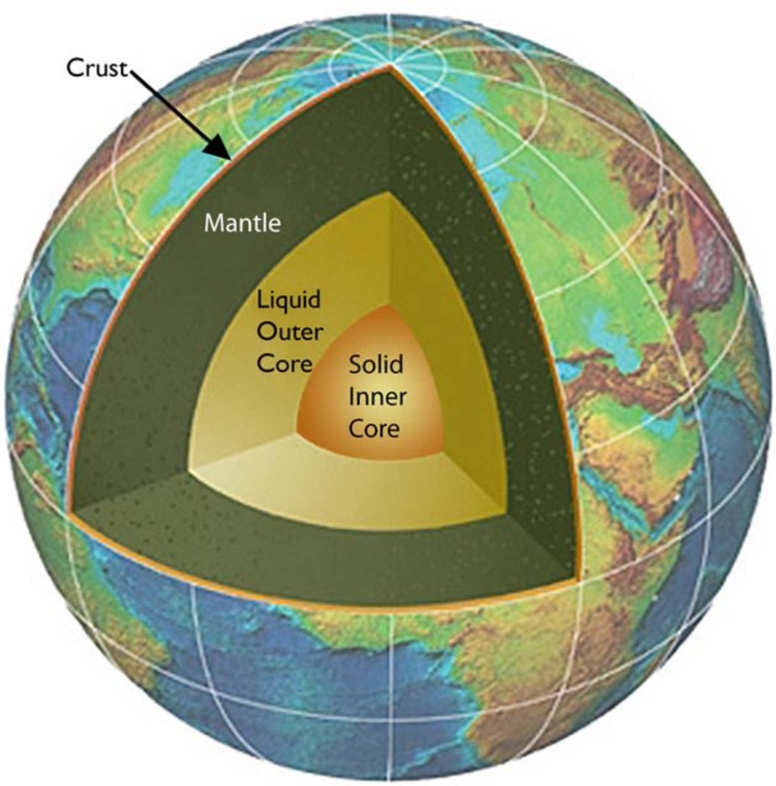

Figure 151. Most of the earth's heat is generated in the mantle and crust.[277]

11.1.2 Availability of Geothermal Energy

Geothermal energy is considered a renewable resource because the heat continuously emanating from inside the earth is, for all practical purposes, limitless. The heat continuously radiating from the earth is estimated to be 42 terawatts (TW, or 42,000 GW) of power. (For comparison, the average global power consumption is approximately 15 TW.[280]) This level of power production is also projected to remain constant for billions of years, which ensures the practically inexhaustible supply of geothermal energy.[279]

The thermal energy from the earth is dispersed across the surface relatively uniformly, and temperatures increase as depth below the surface increases. However, deeper within the earth's crust there are concentrated areas that contain more geothermal energy than others and these are commonly referred to as reservoirs or heat pockets. Furthermore, it is well-known that even deeper there is hot molten rock, or magma.

There are geological features where these reservoirs or geothermal energy in general can be more readily accessed. For instance, subsurface temperatures are higher near tectonic plate boundaries. Iceland has an advantage over other nations because the country is located where two tectonic plates meet. Other geological features include volcanoes, hot springs and geysers. Many geothermal studies, models, and surveys have been performed to map the availability and accessibility of geothermal energy.

11.1.2.1 Potential Geothermal Reservoirs in the US

The US has a wide range of reservoir temperatures available for geothermal energy production. While small-scale geothermal projects can be implemented almost anywhere in the US, the Southwest and West have the greatest potential for large-scale geothermal projects as shown in Figure 152. Hawaii and Alaska also have geothermal resources.

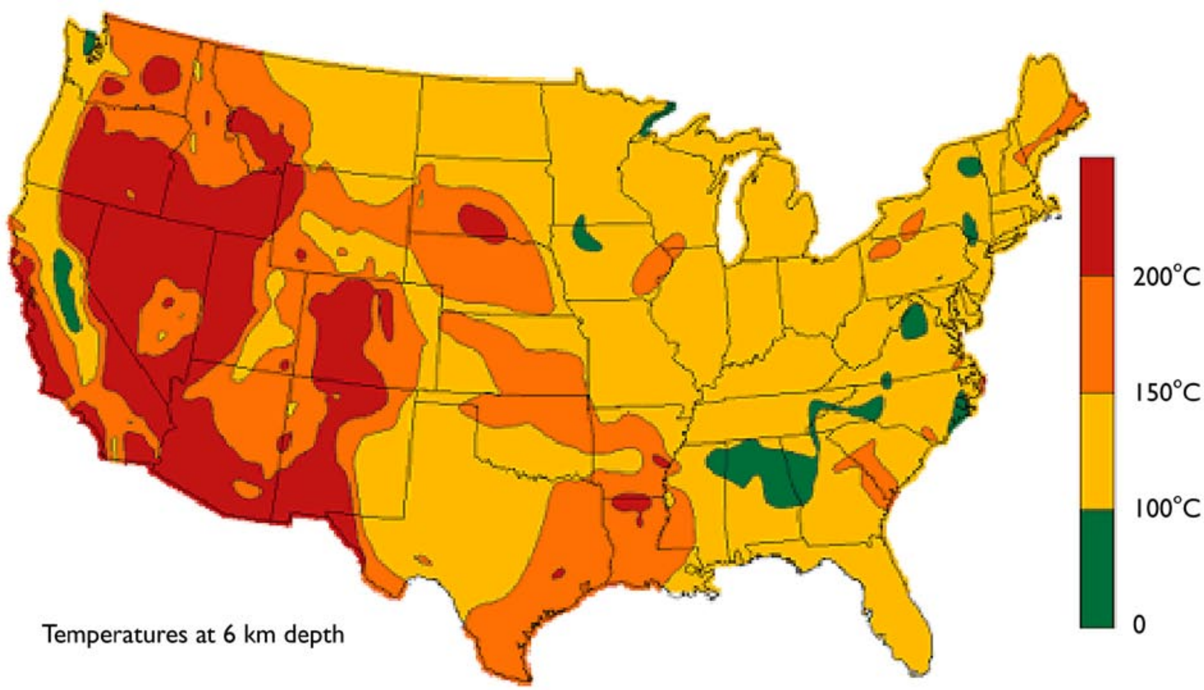

Figure 152. Geothermal reservoir temperatures across the US.[281]

While there are many areas where there are substantial pockets of geothermal energy, not all have nearby aquifers, from which hot water may be drawn. Therefore, in order for these geothermal resources to be readily harnessed, a fluid must be injected and then retrieved to extract the heat for use in large-scale power production. Several such sites with high geothermal potential are located in the southern part of Texas (see Figure 153). One possibility for extracting this energy is to leverage nearby abandoned, deep oil wells, which are either dry or were dry when they were drilled.[282] The earth's thermal energy is a valuable resource, but the challenge is in how to capture and use it. This will be described in sections to follow.

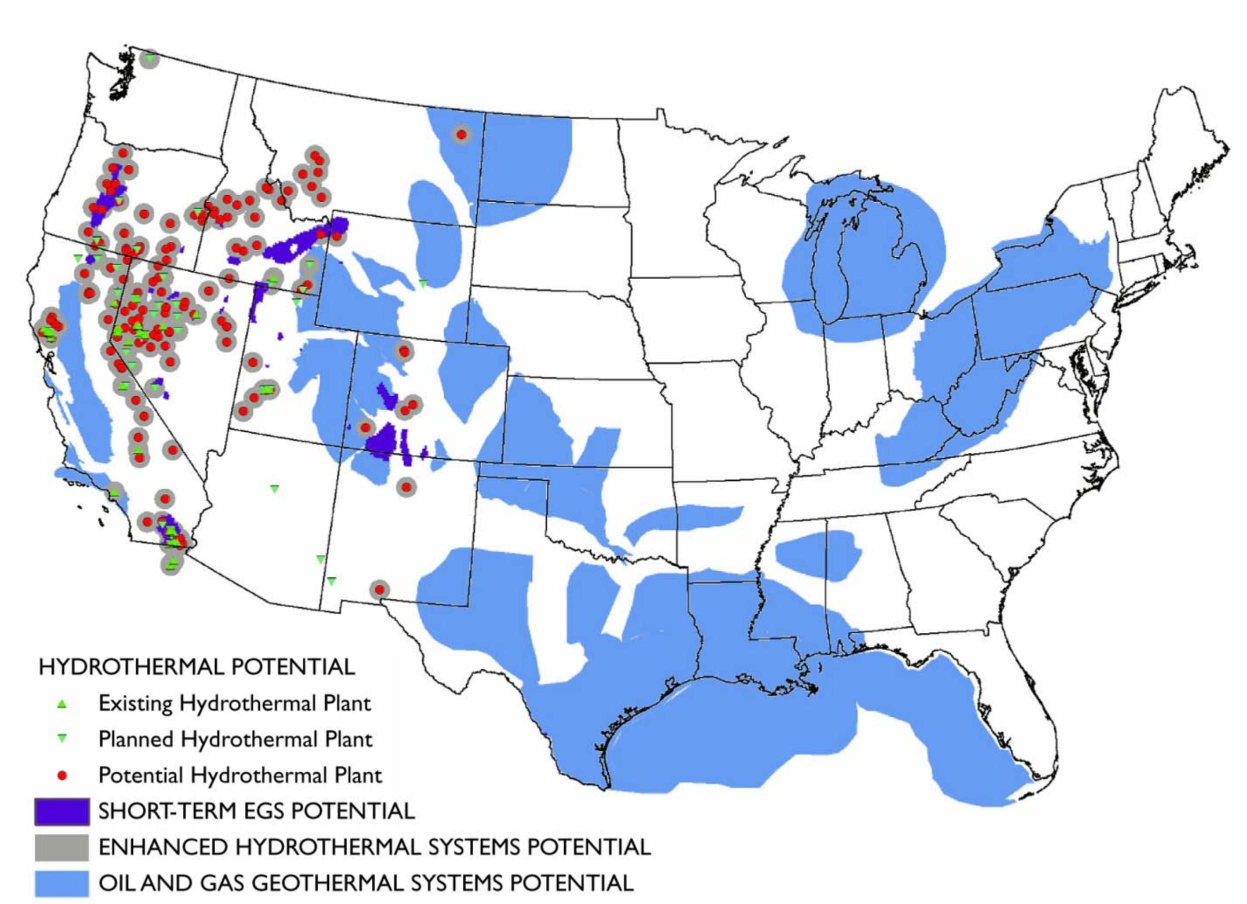

Figure 153. Short-term geothermal energy potential across the US.[283]

11.1.3 Types of Geothermal Resources

There are several different types of geothermal reservoirs, which basically can be categorized as hydrothermal, hot dry rock (HDR), geopressure, or magma. These are briefly described in the following sections and applicable systems are described thereafter.

11.1.3.1 Hydrothermal Geothermal Reservoirs

A hydrothermal reservoir is characterized by the presence of liquid water or water vapor. These are the only reservoirs that have been tapped for the production of commercial power. There are two basic types of hydrothermal reservoirs: vapor-dominated and liquid-dominated.

11.1.3.1.1 Vapor-Dominated Geothermal Reservoirs
Vapor dominated geothermal reservoirs consist primarily of steam and the presence of liquid water is limited or insignificant. An example of a vapor-dominated geothermal reservoir that is being tapped to produce power is the Geysers in CA. This resource is rather unique and rare in that it produces nearly pure steam with no liquid water. Systems built to harness the energy from these reservoirs can be relatively simple, as the steam pressure can be directly applied to power turbines. Since these types of reservoirs are tapped only for their steam, separators are generally not required. This type of geothermal reservoir is sometimes referred to as a dry-steam reservoir. *Section 11.2.2.4* provides more information on systems that use this type of reservoir.[273, 276, 279, 284]

11.1.3.1.2 Liquid-Dominated Geothermal Reservoirs
Liquid-dominated geothermal reservoirs are more common and much more commonly used to produce power than any other type of geothermal reservoir. In these reservoirs liquid water is the predominant media that carries the thermal energy. These types of reservoirs are tapped to directly utilize their thermal energy (see *Section 11.2.1*). They also are ideally suited for single and double-flash power plants (see *Section 11.2.2.1*), which are the most common types of geothermal power plants in the US and worldwide.[273, 279]

11.1.3.2 Hot Dry Rock

There is a considerable amount of geothermal energy that is relatively close to the surface, but traditional hydrothermal processes cannot be used because there is either a lack of fluid or a lack of natural permeability in the rock layer. These resources are known as hot dry rock. While HDR resources have great potential regarding their geothermal energy, there are no commercial production systems yet in existence. However, research and development of systems to harness the energy contained in HDR resources continues and several demonstration projects have been implemented. Recent advancements in technology have increased the commercial potential of HDR-based systems, particularly with enhanced geothermal systems (EGS), which is described in *Section 11.3.1*.

11.1.3.3 Geopressured Resources

Geopressured resources contain highly pressurized pockets of hot water that also contain dissolved methane. Such resources, for example, are found near the coastlines in the Gulf of Mexico. These systems are unique in that they offer potential for production of power via three mechanisms. First, since these resources are characterized by pressures that are greater than hydrostatic pressure, they could potentially be used to power a hydraulic turbine. Second, the thermal energy contained in the fluid can be converted to useful work via processes used to convert hydrothermal energy. Finally, the methane can be combusted to produce power.[273] The DOE successfully demonstrated a commercial pilot scale geopressured power plant.[285]

11.1.3.4 Magma

Magma is a thermally energy-dense resource that exists within the earth's mantle and crust. The temperature of magma is typically in the range between 600°C and 1300°C. While there is a practically inexhaustible supply of geothermal energy from magma, some of this energy is used to heat the other geothermal resources. The concept of extracting this energy directly from the magma and converting it to useful power is relatively simple, yet the technology is still in development and does not merit further discussion.

11.1.4 End-Uses of Geothermal Energy

Geothermal energy is a clean, renewable resource that is available around the world to support a variety of applications and end-uses. Geothermal energy can be used for electric power generation, as well as for thermal utilities. If the thermal energy is sufficient, geothermal resources can also be used for hydrogen production. The energy resource from geothermal is commonly categorized in terms of its temperature. Table 53 shows the three basic classifications of geothermal energy resources and corresponding applications.

Table 53. Applications of geothermal energy based on temperature range of resource.[286]

Classification	Temperature Range (°C)	Applications
Low Temperature	< 90	• Heating • Cooling
Moderate Temperature	90 – 150	• Heating • Cooling • Power generation
High Temperature	> 150	• Heating • Cooling • Power generation • Hydrogen production

11.2 Methods for Converting and Using Geothermal Energy

Geothermal energy is by definition available as heat, which can be used directly to provide thermal utilities or indirectly to generate electricity or other energy carriers, such as steam and hydrogen. The common methods that are employed to harness geothermal energy are described in the following sections.

11.2.1 Direct Use of Geothermal Energy

Geothermal energy can be used directly to provide thermal utilities. In many regions where there are natural bodies of water underground, geothermal energy transfers heat to these water sources, thus elevating the temperature of the water. These are considered hydrothermal sources of energy. Hot springs are natural springs that absorb geothermal energy. Hot water from these resources can be pumped directly into facilities to provide heat. Cities in Iceland utilize this inexpensive form of energy to heat entire districts.

Areas with telltale signs of hydrothermal sources, like hot springs, are obvious and are often the first geothermal resources to be tapped for their inherent energy. However, other less obvious, but equally as useful sources of hydrothermal energy exist. For instance, geothermal energy continuously flows outward, and occasionally this heat, typically contained in magma, reaches the surface as lava. However, it is more common for the magma to remain below the surface and heat the surrounding rock and water.[xcii] When water is heated by geothermal energy, hot water or steam can be trapped in permeable and porous rocks under a layer of impermeable rock. When this occurs, the resulting formation is considered a geothermal reservoir.[279]

The majority of water and steam in a geothermal reservoir stays underground and is stored in cracks and porous rock formations. Some geothermal water may reach the surface (e.g., geysers or hot springs) but these are quite rare. The resources typically must be released via drilling.

Once a geothermal well is in place, the hot, natural fluid can be released and sent through a heat exchange unit and a working fluid can be used to provide thermal utilities to the facility. The geothermal fluid can be injected back into the reservoir.

[xcii] Rock and water inside the earth's crust can sometimes reach 700°F.

The direct use of geothermal energy has many advantages, and one of the most important advantages is it has a minimal environmental impact. Direct use produces essentially zero emissions of both greenhouse gases and thermal pollution.[279] In the past, a lack of an adequate resource database, risk of failure in exploration and drilling, and the lack of a dedicated industry have prevented geothermal direct use from achieving its full potential. However, direct use of geothermal energy has the potential to make a significant impact in the energy industry today and in the future.

11.2.2 Conversion to Electricity

Geothermal power plants are capable of providing baseload electricity, which makes it one of the few renewable power sources that can substitute for coal. In 2009, geothermal power replaced the need for coal-fired electricity that otherwise would have added 22 million tons of carbon dioxide to the atmosphere. This power offset the total per capita emissions of approximately one million Americans. It is estimated that GPPs have 90% lower CO_2 emissions compared to a pulverized coal power plant and 75% lower emissions compared to a standard combined cycle power plant.[287]

Geothermal power plants work by generating electricity from the hot water, brine, or steam that is collected from hydrothermal resources. In some locations these resources are readily accessible, but other locations require drilling geothermal wells that can be one to two miles deep. The wells are used to bring the geothermal energy to the surface so it can be converted into electricity via a steam turbine and electric generator.[279] The geothermal fluids used in GPPs, however, have chemical composition characteristics that can vary significantly from one site to another. Dissolved minerals and gases must be taken into consideration for each plant. For example, geothermal steam can contain 0.2 wt.% to greater than 25 wt.% noncondensable gases (NCGs), including CO_2, H_2S, NH_3, N_2, and CH_4. These can have a significant impact on the performance of a geothermal plant. [288]

Geothermal power plants operate at much lower temperatures (typically between 50°C and 250°C) than analogous fossil fuel or nuclear power plants.[289] The relatively low temperatures result in relatively low thermal energy to electricity conversion efficiencies. However, since the fuel in this case is natural and renewable, low conversion efficiency is not as costly as it would be for fossil fuel. Achieving greater conversion efficiencies, though, will result in greater economic viability for geothermal power.

There are four basic types of geothermal power production plants: flash, binary, dry (or direct) steam, and flash/binary combined. The majority of geothermal plants draw pressurized hot fluid from deep wells, convert it to steam, and use the steam to drive turbines, thereby generating electricity. These types of plants are geothermal flash steam plants. Other types of geothermal plants transfer heat from hydrothermal resources to a working fluid via heat exchange. Each of these types is described in the following sections.

11.2.2.1 Flash Geothermal Power Plants

Flash GPPs are typically constructed at locations where the geothermal reservoir produces high temperature water between 175°C and 300°C.[289] When the hot, pressurized geothermal fluid arrives at the surface it can be flashed to steam. Water at standard pressure begins to boil at 100°C, but at higher pressures the boiling point is higher. Thus, when the pressure of saturated geothermal water is suddenly reduced some of the water flashes to steam (i.e., the energy released upon sudden pressure reduction causes some of the water to evaporate into steam). In a flash plant, the pressurized geothermal water is separated in a surface vessel (i.e., steam separator) into steam and hot water. The steam is delivered to the turbine, and the turbine powers a generator. The liquid is injected back into reservoir.

Flash-steam geothermal power plants are the most commonly used geothermal power generation systems, and they comprise a total of 63% of the installed capacity worldwide. This is primarily because most geothermal reservoirs are formed by liquid dominated hydrothermal systems. Furthermore, 59% of the flash GPPs are single-flash plants.[288]

A generic single-flash GPP may consist of production wells, wellhead/main separator(s), turbines, condensers, a gas removal system, a cooling tower and auxiliary equipment, such as fans and pumps. An illustration of the flash GPP process is provided in Figure 154.

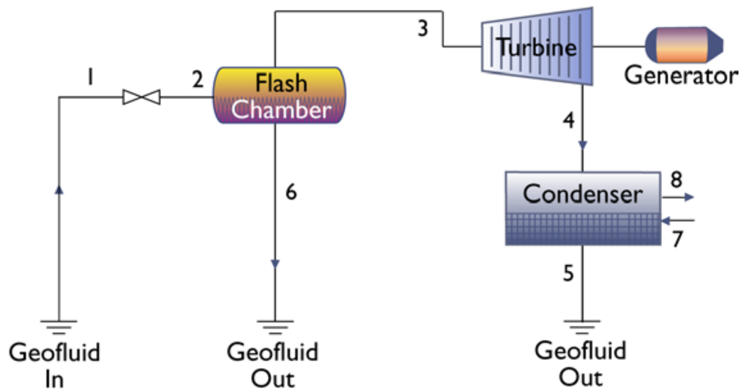

Figure 154. Example of a single-flash geothermal power plant.[290]

The geothermal fluid is flashed and separated into the steam and liquid phases in the flash chamber. Steam, which contains water vapor and NCGs, is directed to the turbine, while the liquid phase can be returned to the reservoir or put to other use. The steam, condensate, and NCGs flow through the turbine and then on to the condenser. The NCGs accumulate in the condenser and are removed by a gas extraction system. The remaining content is pumped to the cooling tower which reduces the temperature of the fluid to the cooling water temperature so it can be reused in the condenser. Circulation pumps are used to drive the liquid phase and fans draw air into the cooling tower.[288]

11.2.2.1.1 Gas Removal System

A steam jet ejector can be used to remove NCGs from the condenser. The ejector is relatively inexpensive since it has no valves, rotors, pistons or other moving parts. It is also simple to operate and maintain. However, it consumes a considerable amount of steam during operation. Multiple steam jet injectors can be used in series to increase the total compression since a single unit is limited in capacity.[288]

11.2.2.1.2 Hybrid Compression System

A liquid ring vacuum pump (LRVP) is a rotary-type compressor that can be used to compress and remove NCGs. It can be used on its own in low flow, low pressure systems. It can also be connected in series with a steam jet ejector, to provide additional compression of NCGs and increase the efficiency of removing these gases. This type of system is generally referred to as a hybrid system.[288]

11.2.2.1.3 Multistage Flash Geothermal Process

Multistage processes can be used to increase the capacity, efficiency, or both. In a multistage system, a condenser is typically used between the stages. By condensing the vapor prior to the next stage, the vapor load is reduced, which enables the use of smaller gas removal systems and thus reduces steam consumption. A condenser can be added to condense vapor from the final stage, which reduces the amount of waste vapor and suppresses noise. An example of a double-flash geothermal plant process is shown in Figure 155.

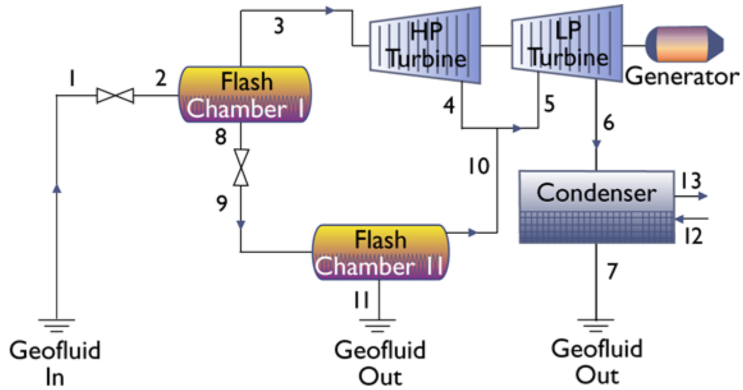

Figure 155. Example layout for a double-flash power plant. (HP – high pressure, LP – low pressure)[290]

11.2.2.1.4 Impact of Noncondensable Gas Fraction on Performance

A high fraction of NCGs results in a high rate of steam consumption by steam jet ejectors, which increases operating costs. Centrifugal compressors with overall efficiencies on order of 75% are capable of handling large quantities of NCGs, but are expensive to install. Higher NCG fractions also increase the amount of cooling water required in the condensers.[288]

11.2.2.2 Binary Geothermal Plants

Binary geothermal plants can utilize lower temperature to moderately hot geothermal fluids (e.g., 90°C to 150°C) by transferring its heat to a secondary fluid (hence the binary system), which has a lower boiling point.[289] Binary GPPs draw geothermal fluid from its source and pass it through a heat exchange with the second fluid that has a relatively low boiling point (typically a hydrocarbon fluid). Heating the secondary fluid past its boiling point vaporizes the fluid, and the vapor is subsequently used to power the turbines.

Binary geothermal plants have lower emissions than traditional geothermal systems and the geothermal fluid is physically separated from the working fluid during the heat exchange. These plants usually have zero emissions because they operate in a closed-loop system, where the working fluid is continuously cycled while the geothermal fluid is drawn up and through the heat exchange and then injected back to the source.

A binary GPP is characterized by high specific geothermal fluid consumption (i.e., mass per energy), low efficiencies, and large heat transfer surfaces for the heat exchanger and condensation system. Designs for binary GPPs can vary substantially, and optimization of the plant energy production and cost must be achieved on a site specific basis since standardization has not been achieved.[291]

11.2.2.2.1 Organic Rankine Cycle

The basic system used in binary plants is an organic Rankine cycle (ORC, see Figure 156). The general Rankine cycle is used in most power plants that convert heat to work. The organic Rankine cycle is used to allow the use of moderate temperature geothermal fluid. It is considered organic because the working fluid is a hydrocarbon. The most commonly used working fluids include isobutene and pentafluoropropane.

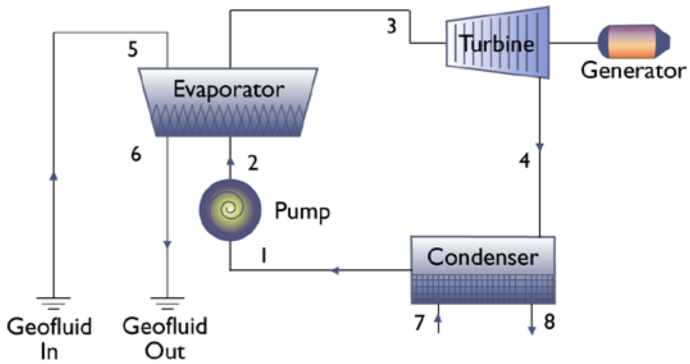

Figure 156. Diagram of a simple organic Rankine cycle geothermal plant.[290]

Potential variations of the ORC that can be used to increase efficiencies include the regenerative ORC, which is illustrated in Figure 157. This system proposes the use of an open feed organic heater (OFOH), which is a type of direct-contact heat exchanger in which the steam that is extracted is permitted to mix with the geothermal fluid.

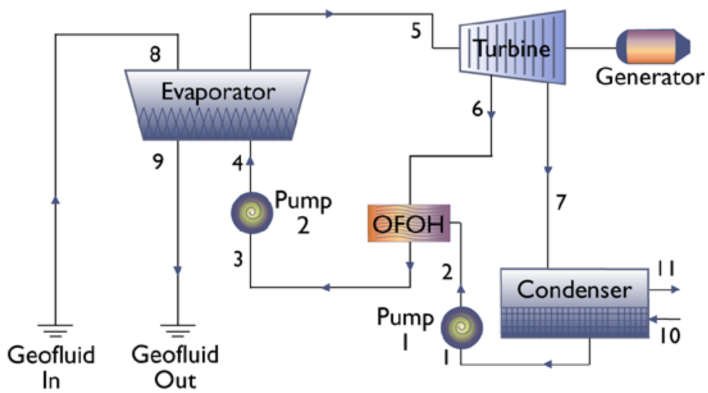

Figure 157. Organic Rankine cycle geothermal plant with regeneration.[290]

11.2.2.2.2 Binary Cycle Process for Geothermal Power Production

In binary plants (see Figure 158) operating on an ORC system, the geothermal fluid transfers thermal energy to the working fluid, which has a lower boiling point than water.[291] The geothermal fluid and the working fluid are kept physically separated, but exchange thermal energy in a heat exchanger. The working fluid expands into a gaseous vapor, and the force of the expansion, similar to the flash of water to steam in other geothermal systems, turns the turbines that power the generators. The geothermal water is injected back into the reservoir after completing the heat exchange.

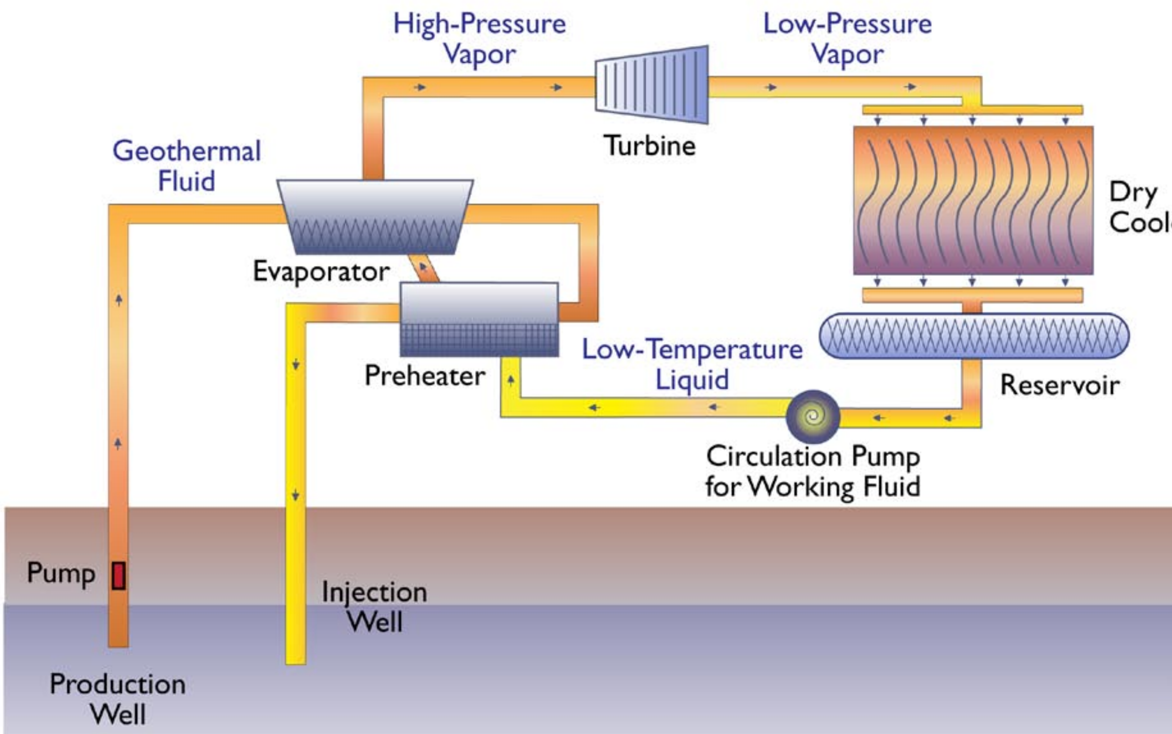

Figure 158. Example of a binary geothermal plant.[291]

11.2.2.2.3 Environmental, Durability, and Flexibility Advantages

There are no emissions from this process except for water vapor that exits the cooling towers when wet cooling is used, and there may be some loss of working fluid. Since higher temperature geothermal systems convert the geothermal fluid to vapor in order to power turbines, there are some emissions associated with the process. This is not the case in the closed-loop binary process, and thus there is no release of GHGs (e.g., CO_2 and CH_4) and no discharge of toxic elements (e.g., Hg and As).[291]

Another advantage of the binary GPPs is that the geothermal fluid does remain physically apart from the moving mechanical components of the plant (e.g., the turbine). Since the composition of the geothermal fluid can vary and certain contaminants could accumulate and cause excess wear and maintenance requirements if it was allowed throughout the system, the closed loop design ensures a longer life for the equipment. Furthermore, the working fluid is a known entity and the system can be designed with materials that are inherently resistant to any abnormal degradation caused by the working fluid.

Binary GPPs are able to operate using geothermal fluids that vary in temperature, pressure, and composition. As such, this enables their use at a number of sites that may have been uneconomical with other energy conversion processes.[279, 291] The large variation in geothermal fluid temperatures, pressures, and compositions, however, makes the design of the process and system units challenging.

11.2.2.2.4 Designing Binary Cycle Geothermal Systems

The design of binary plants is an area of ongoing research. The technology is not yet sufficiently advanced such that plants can be constructed with standard equipment. Thus, each installation has to be designed for the conditions at a given location, and each system is customized to specific geothermal fluid characteristics.[291]

For design purposes, the binary cycle process can be considered to have three subsystems: the heat recovery cycle (HRC), the recovery heat exchanger (RHE), and the cooling system (CS). As a subelement of the HRC, the RHE is looked at separately from the HRC to model thermodynamic and fluid dynamic processes that are specific to this unit. Figure 159 displays an approach to designing the binary cycle geothermal system elements.[291]

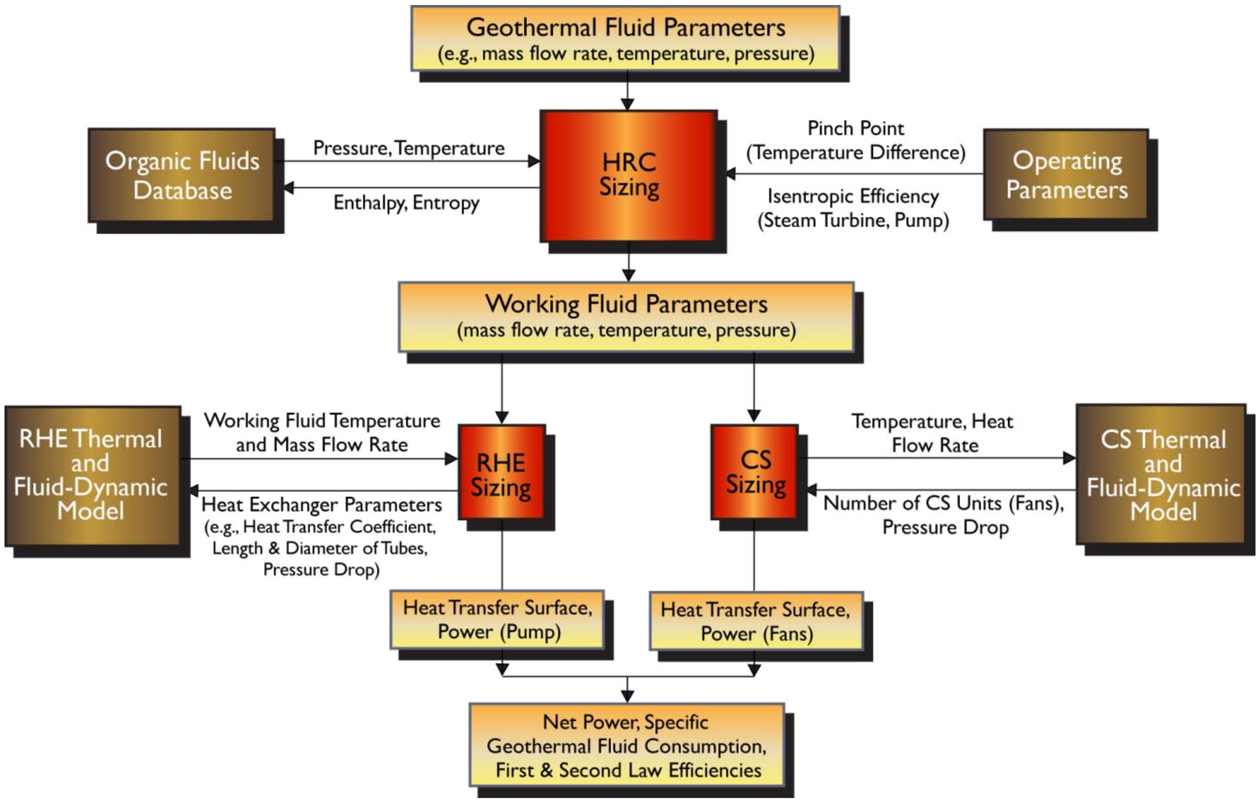

Figure 159. Approach to design of binary cycle geothermal system.[291]

11.2.2.2.5 Efforts to Improve Binary Cycle Geothermal Processes

Binary GPPs that utilize relatively low-temperature geothermal fluids have relatively low thermodynamic efficiencies. For instance, first law efficiencies are typically 5 to 10 percent, and second law efficiencies are typically 20 to 45 percent.[xciii] Work to increase these efficiencies has focused on the combination of the working fluid and heat recovery cycle.[291]

There have been a number of proposed designs to improve binary systems. Examples of proposed designs include a RHE with a cascade of evaporators and a multi-component working fluid (e.g., a Kalina cycle), a recovery cycle with both a high- and a low-pressure turbine, two or more pressure levels, and the use of supercritical cycles.[273, 291]

Providing temperature reduction to the process poses additional challenges. Water can be used to provide heat rejection, but at the expense of water consumption. If water is not sufficiently available, a dry cooling system can be used. However, because of the need for forced ventilation, the dry cooling system has a relatively high power consumption. These can consume 10 to 50 percent of the gross power and can contribute 30 to 35 percent of the total capital cost of the project.[291]

[xciii] First and Second Law efficiencies are calculated using basic thermodynamic principles.

11.2.2.3 Flash/Binary Combined Cycle Geothermal Power Plant

The flash vaporization and binary cycle processes can be combined to form a dual or combined cycle process for geothermal energy conversion. The combined cycle process involves the vaporization of the geothermal fluid in a flash chamber and the resulting steam is sent to power a back-pressure turbine, which releases the low-pressure steam to a binary portion of the process.[279] The low-pressure steam exchanges heat with a working fluid, thereby evaporating it to drive a turbine. A lower binary process receives the geothermal fluid that does not exit the flash chamber as steam and uses the heat to evaporate a working fluid thereby driving another turbine. An illustration of a flash/binary geothermal plant process is shown in Figure 160.

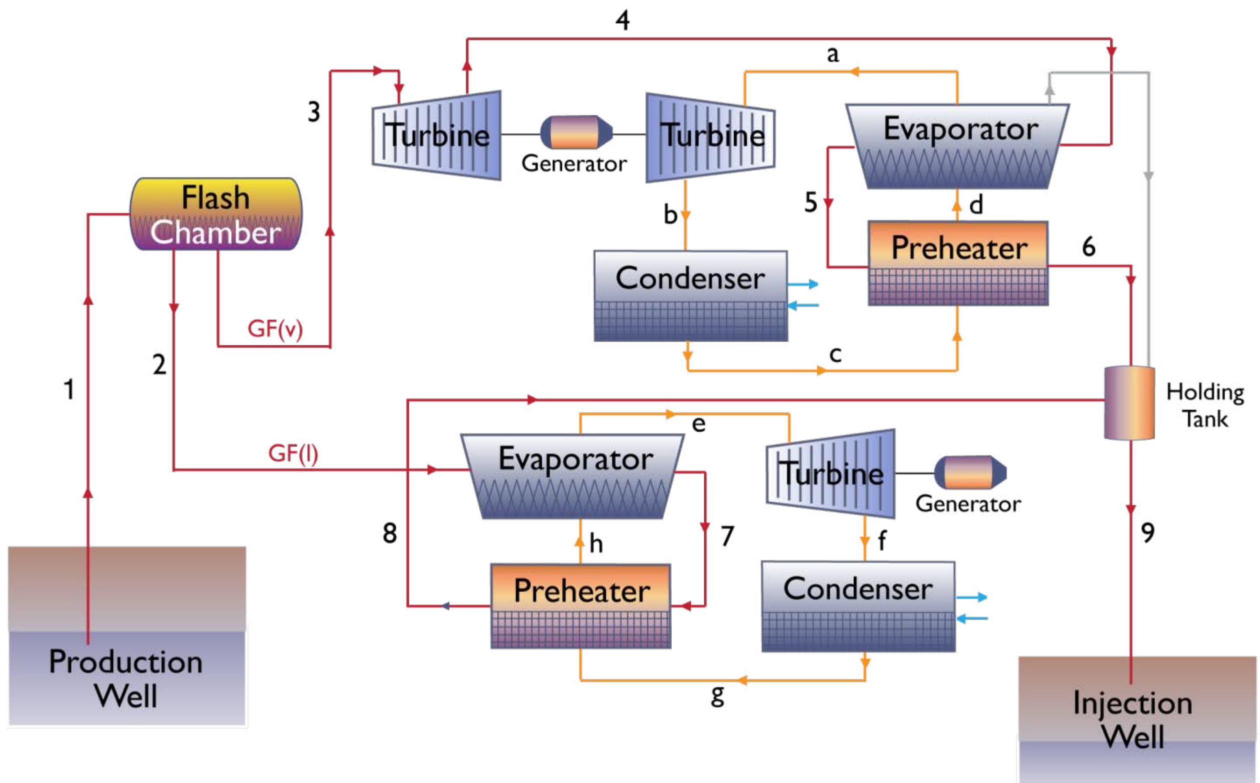

Figure 160. Example layout of a combined flash/binary geothermal power plant.[273]

This hybrid process draws upon the advantages of the two individual processes to reduce emissions and achieve a relatively high efficiency. It takes advantage of maximizing the use of process units and eliminates the need to remove NCGs.

11.2.2.4 Dry Steam Geothermal Power Plants

The oldest and simplest type of geothermal plant is the dry steam plant. Dry steam GPPs are installed at locations that offer high quality geothermal steam. The steam is collected directly from the geothermal reservoir to run the turbines that power the generator. No liquid/vapor separation is required by this type of plant because it is designed to only process steam. The emissions from this type of geothermal plant consist of excess steam and a small amount of NCGs.

11.2.3 Conversion to Thermal Utilities

In contrast to large-scale conversion to electricity, geothermal energy resources can be used to provide thermal utilities on a smaller scale. Facilities can be cooled and heated using a relatively simple or more sophisticated heat exchange system that harnesses the constancy of temperature beneath the earth's surface and the extreme heat or cold of the environment above the surface.

The temperature of the earth's crust near the surface is relatively uniform regardless of geographic location or climate above the surface. The temperature generally ranges between 50 to 60°F. At depths of 15 feet temperature fluctuations are 10°F or less.[292] These nearly constant temperatures can be used effectively as a natural heat exchanger to heat and cool facilities.

There are basically two types of systems that are used to convert geothermal energy into thermal utilities. The first is the active system, which uses artificial circulation devices (i.e., pumps) to circulate fluids in order to perform heat exchange. The second is the passive system, which relies on the natural phenomena based on density and buoyancy to exchange thermal energy. The passive system is less complex, but not as commonly used. Both of these systems are described in the following sections.

11.2.3.1 Active Systems

In active geothermal systems, heat pumps circulate a working fluid, usually water with some protective additives, between a piping system buried in the earth and connected to the building. The piping system exchanges heat to and from the earth depending on whether it is performing the function of cooling or heating. Basically, during warm seasons thermal energy is absorbed from the building and dissipated into the earth for cooling, and during cool seasons thermal energy is absorbed from the earth by the piping system fluid and is delivered to the building. These geothermal systems when used in conjunction with a well-insulated facility can serve as a highly efficient, low-cost method for providing heating and cooling.

11.2.3.1.1 Geothermal Heat Pumps

Geothermal heat pumps (GHPs) can be used across the US to heat or cool buildings. GHPs make geothermal energy accessible almost anywhere in the US because of the relatively constant temperature at shallow depths beneath the surface, and therefore deep geothermal wells do not need to be drilled. GHPs take advantage of soil and near-surface rocks, from 1.5 to 15 m (5 to 50 ft) deep, which have a nearly constant temperature and provide a heat source in the winter and a heat sink in the summer. They are often relatively expensive to install, but they can often result in significant payback.

A fluid (water or other working fluid) is circulated through a loop of piping that is run underground to create a heat exchanger. An indoor system extracts the energy from the fluid for heating or adds energy to the fluid for cooling replacing both a furnace and an air conditioner.[293] These piping systems are commonly buried in a continuous loop formation and can be designed both horizontally and vertically. These systems are advantageous because they can be installed anywhere, including under parking structures, landscaped ground, buildings, etc.[279]

Designing a heat pump involves evaluating several parameters. The coefficient of performance of a heat pump is the ratio between the acquired thermal energy in the condenser compared to the energy used for operating the compressor. The heat flow of the evaporator is the amount of thermal energy extracted from the working fluid. The heat flow of the condenser, however, is the amount of thermal energy gained for heating needs with the help of a heat pump. The compressor power indicates the amount of electricity is consumed to compress the working fluid.[294]

11.2.3.1.1.1 Closed Loop Systems

Closed loop systems use a piping network in which the working fluid circulates continuously. The sizing of the pipe is determined based on the amount of space that will utilize the thermal utilities, thermal conductivity of the ground, and other parameters. During construction, but prior to permanently burying the closed loop system, the pipes are purged to ensure no contamination and then pressurized to ensure there are no leaks.[295]

11.2.3.1.1.2 Open Loop Systems

Open loop systems are typically simpler than closed loop systems. Water from a below ground or an above-surface resource, such as a well, pond, lake, or municipal water system, is pumped out and passed through the heat pump heat exchanger and then discharged back to the source. Water temperatures can remain relatively constant throughout the year and thus such open loop systems are advantageous where permitted.[295]

Open loop systems are relatively inexpensive but require more maintenance to clean the components. Since the water is discharged after use, proper clearances to operate the system are required. In addition, chemical inhibitors are typically required to prevent degradation due to the contaminants that the system may encounter.[295]

11.2.3.1.2 Training and Certification

The International Ground Source Heat Pump Association (IGSHPA) provides installation standards and accredits designers and installers. The IGSHPA provides training and certification for designing and installing GHP systems.

11.2.3.2 Passive Systems

The simplest use of geothermal energy is through passive geothermal systems. Similar to active systems a series of pipes containing a working fluid, sometimes water, exchanges heat between the facility and the ground. The absence of a pump renders this a passive geothermal system. These systems have vertical pipes running from the foundation to several feet into the ground. Heat from the ground is drawn up into the building as a result of density changes according to temperature gradients.

11.2.3.3 Advantages and Disadvantages of Small-Scale Geothermal Heating and Cooling

There are numerous advantages and few drawbacks of geothermal heating and cooling systems. In addition to geothermal energy being a renewable resource, advantages of systems that use it include low operating cost, low maintenance, and low or no emissions. The Environmental Protection Agency considers geothermal systems the "most energy-efficient, environmentally clean, and cost-effective systems for temperature control." The main drawback is the relatively high capital cost required to install the piping system, which may require borehole drilling. However, this cost can be recovered in a relatively short period of time through savings in conventional energy costs. In addition, supplemental heating and cooling systems may be required for facilities that are not well insulated or installations that are located in extreme climates.

11.3 Next Generation Geothermal Energy Extraction

Technology developments in the past two decades have made it possible to access geothermal resources that were previously untapped. Primarily, the enhanced geothermal system is an engineered geothermal resource designed to facilitate the extraction of geothermal energy from naturally impermeable rock layers. The primary challenges facing this technology include drilling costs, water loss, fracture stimulation, and mapping methods.[274]

11.3.1 Enhanced Geothermal Systems

There is an abundance of geothermal reservoirs that simply lack key features to be viable as a resource for conventional geothermal power production systems: geothermal fluid and an interconnected pathway for movement of the fluid. However, such reservoirs may be useful by stimulating fracture, injecting water, and recapturing it after it absorbs the thermal energy. This concept continues to draw considerable research and development because of its great potential for economically producing power.

The EGS involves the creation of artificial permeability in hot rock and subsequently introducing water (or another working fluid) to extract the heat. An example of how EGS works is illustrated in Figure 161.

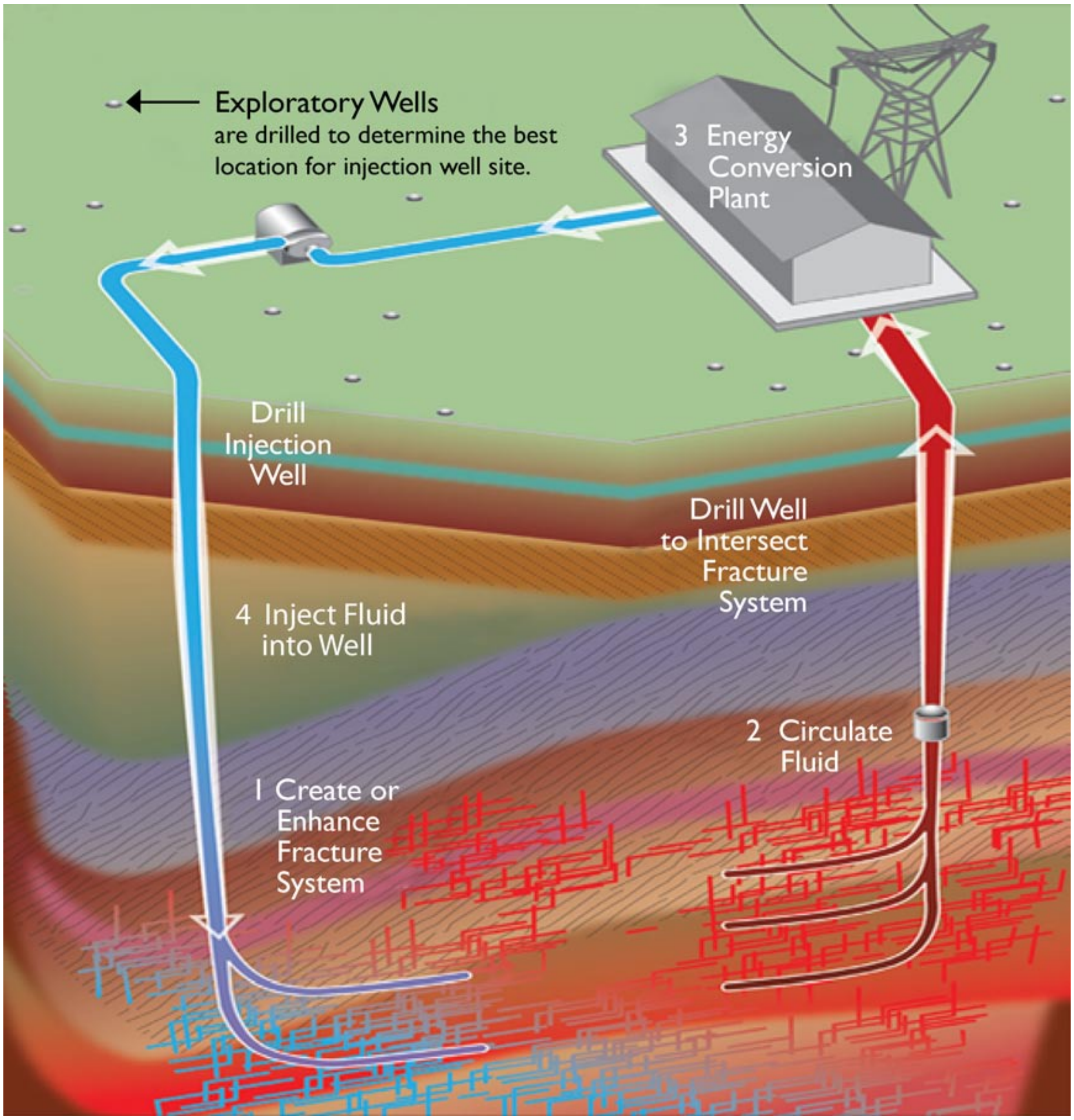

Figure 161. Simplified representation of an EGS.[274, 296]

11.3.1.1 Demonstration EGS Projects

While it may take several more decades to achieve the full potential of EGS, some of the concepts of EGS are currently being used. For example, the first large-scale, commercial EGS related project has been implemented at the Geysers geothermal power production facility. The facility expanded the capacity of their production wells by injecting treated wastewater into the geothermal reservoir.[279]

The Department of Energy's Geothermal Technologies Program is working with the US geothermal industry to make the EGS technology ready for industry use by 2015.[297] Key areas include site characterization, reservoir creation, reservoir validation, interwell connectivity, reservoir scale up, and reservoir sustainability. There are several EGS projects worldwide. A list of example EGS projects is provided in Table 54.

Table 54. Examples of worldwide EGS projects.[279]

Project	Location	Capacity	Status
Stoultz	France	1.5 MW	Operational
Landau	Germany	2.5 MW	Operational
Paralana	Australia	7 – 30 MW	In development: drilling
Cooper Basin	Australia	• 1 MW (showcase) • 250-500 MW	• Operational • Drilling stage
Desert Peak	Nevada	N/A	In planning

11.3.1.2 Costs Associated With EGS

There are significant capital costs associated with EGSs, because they require deep drilling (15 km) and rock fracturing. These precursor steps occur months or years before power is generated. Construction and equipment costs are also high. For instance, casing, pumps, and screens that can withstand elevated temperatures and pressures are expensive. Furthermore, all costs, including financial, environmental, and societal, should be considered completely.[298] For example, when assessing the power generation alternatives, costs associated with CO_2 effects, pollution, safety, should all be taken into consideration.

11.3.1.3 Disadvantages of EGS

EGS risks include geologic variability, the fractured reservoir may perform differently than expected, and the initiation of earthquakes due to injecting a fluid in some geologic systems. It has been estimated that 24 m^3/min of 300°C fluid is required to produce a megawatt of power. This quantity of fluid requires numerous, expensive, high capacity wells. Finally, once EGS wells are established, they fields have to be rotated in 20 or 30 year cycles. This allows expended reservoirs to regenerate their heat.[298]

11.3.1.4 Long-Term Prospective Capability of EGS

Despite the disadvantages, a 2006 study suggested that with moderate support, EGS has the potential to provide a significant portion of the nation's baseload capacity within the next 50 years.[299, 300] The American Recovery and Reinvestment Act included tax incentives and other provisions for renewable energy to support the development of EGS.[298]

11.3.1.5 Carbon Dioxide Working Fluid

Carbon dioxide has been evaluated as an alternative to the use of water for extracting heat from the geothermal reservoirs created in an EGS. High pressure, supercritical CO_2 could perform as the heat exchange fluid because of good thermophysical and chemical properties. This is an advantageous approach since in many areas water conservation is an important factor, and the loss of water in an EGS is a major challenge. Additionally, if there were CO_2 fluid losses during the process, it would have the default benefit of geologically storing CO_2, which is an area of high interest.

The use of water as the heat extraction fluid is also problematic since it readily dissolves minerals, especially at geothermal temperatures, and also precipitates them out. These characteristics of water can cause the undesired formation of a new water flow path in the case of dissolution, or the plugging of a flow path in the case of precipitation. CO_2, however, is not characteristically a good ionic solvent and therefore is expected to avoid these problems. Table 55 shows a summary comparison of CO_2 and water for use as working fluids in EGS.[301]

Table 55. Comparison of properties of CO_2 and water as fluids for EGS.[301]

Fluid Property	Carbon Dioxide	Water
Chemistry	Not an ionic solvent* • Poor solvent for rock minerals*	Powerful solvent for rock minerals • Potential for dissolution and precipitation
Fluid circulation in wellbores	• High compressibility* • High expansivity* • More buoyancy* • Lower parasitic power consumption to maintain circulation*	• Low compressibility • Moderate expansivity • Less buoyancy • Substantial power requirements for pumps to keep fluids circulating
Ease of flow in reservoir	• Lower viscosity* • Lower density	• Higher viscosity • Higher density*
Heat transmission	Lower specific heat	Higher specific heat*
Fluid losses	Can earn credits for storing greenhouse gases*	Costly, common obstacle to reservoir development

* Indicates favorable characteristic

11.4 Existing Geothermal Energy Facilities

An estimated 26 GW_e of geothermal power could be developed in the US by 2015, with direct use and heat pumps contributing another 20 GW of thermal energy.[302] By 2025 more than 100 GW of geothermal power could be in production, with direct use and heat pumps adding another 70 GW of thermal energy.[302]

For 2009, new projects represent a 26% growth rate in US. There were a total of 188 new projects across 15 states with the potential to generate as much as 7.875 GW_e of new electric power.[303] Table 56 shows other geothermal projects expected to be operating by 2015, and their generating capacities.[279, 304]

Table 56. Summary of near-term (by 2015) geothermal projects and their generation capacities expected in western US.[304, 305]

State	Capacity (MW)	Number of Sites
Alaska	20	3
Arizona	20	2
Colorado	20	9
California	2,400	25
Hawaii	70	3
Idaho	860	6
Nevada	1,500	63
New Mexico	80	6
Oregon	380	11
Utah	230	5
Washington	50	5
TOTAL	**5,630**	**138**

Existing geothermal electric power generation is located across nine states: California, Nevada, Utah, Hawaii, Idaho, Alaska, Oregon, Wyoming, and New Mexico. The total geothermal power capacity for the US and the capacity by state are shown in Figure 162. The fastest growing geothermal power states were Utah, New Mexico, Idaho, and Oregon.[304] In addition, Colorado, Louisiana, Mississippi and Texas are expected to add geothermal capacity in the near future.

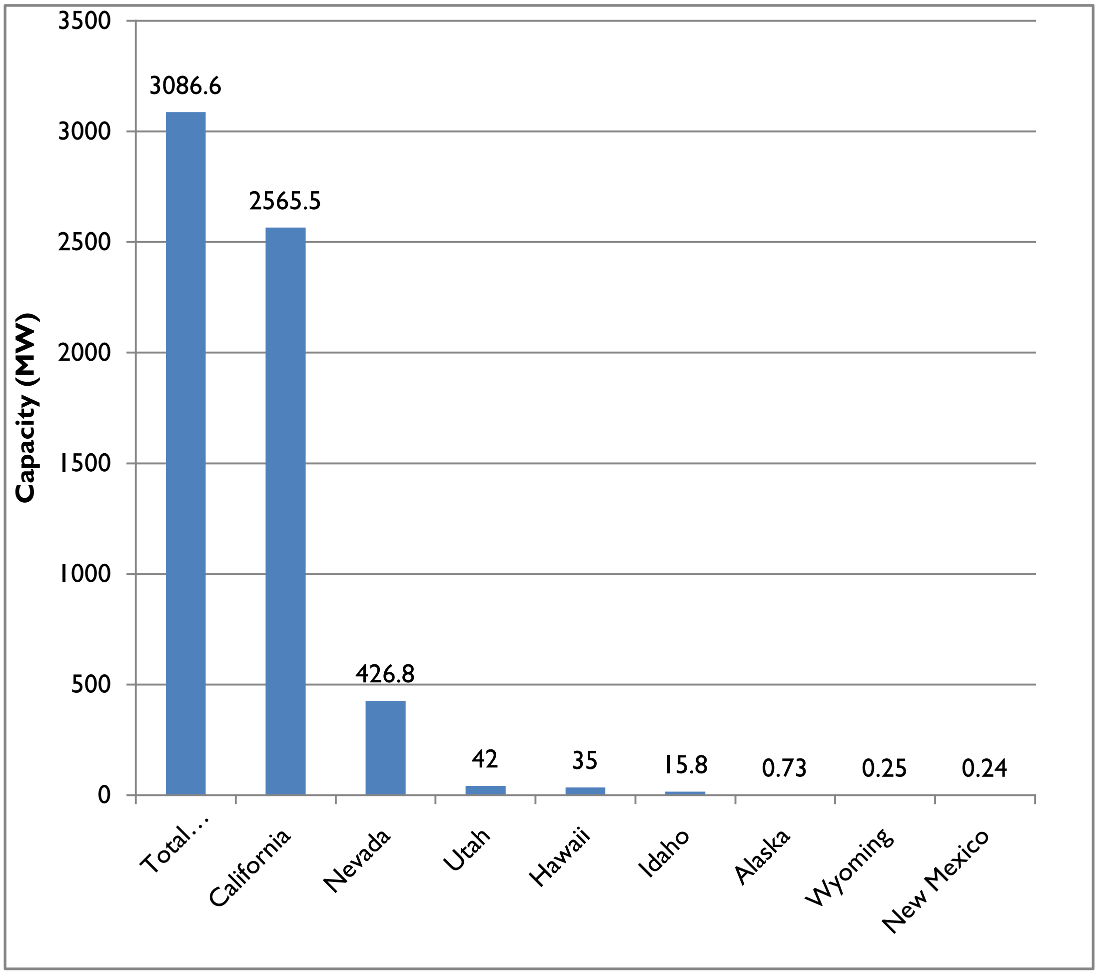

Figure 162. Capacity of operating geothermal projects by state.[306]

11.4.1 The Geysers in Northern California

The Geysers geothermal plant (see Figure 163) is perhaps the best example of how effective geothermal power can be. This plant represents the world's largest geothermal power plant complex. Since 1960, a total of twenty-three separate power plants have been built across the site.

Figure 163. The Geysers have provided geothermal power for decades through a number of reservoirs.[283]

11.4.2 Naval Air Warfare Center Weapons Division, China lake, CA

The China Lake Naval Air Station power grid contains a 270 MW geothermal plant that is capable of providing power to over 250,000 consumers.[307] A Geological survey of the Coso Hot Springs geothermal area on base during the early 1960's and test wells during the late 1960s indicated that the area would be an excellent place to develop a geothermal power plant (see Figure 164). A commercial contractor independently constructed the plant on Navy property and the first stage of the electric generation plant was opened in 1987. The total investment exceeded $650 million of private funds. The plant, which is privately owned and operated, now generates continuous power and sells it to the local power grid. It also saves China Lake 33% of its electrical energy costs.

Figure 164. The geothermal power plant at China Lake.[308]

11.4.3 Blue Mountain Faulkner 1 Geothermal Plant

The construction of a 49.5 MW geothermal power plant in Nevada, named Blue Mountain Faulkner 1, has been completed. Nevada Geothermal Power constructed a 21 mile power line interconnection to the Sierra Pacific Power Company (SPPC) power grid. This geothermal plant began operations in late 2009. Drilling to expand the geothermal resource to 56 MW was initiated in late 2010.[309][310]

11.5 Environmental Impact and Regulatory Issues

Geothermal projects must address regulatory, environmental, and construction issues with state and federal agencies and professional service providers.[276] The most common environmental issues that require assessment during the early stages of geothermal power plant development include:

- Air emissions
- Noise
- Land use
- Vegetation and wildlife
- Land subsidence
- Cultural factors
- Proper delivery system
- Adequate method to safely extract the geothermal heat/energy

11.5.1 Permits for Well Construction and Drilling

If a geothermal well is to be drilled, stringent well construction requirements will apply because geothermal drilling is more challenging than cold water drilling. Special equipment is required for protecting both the workers and the water resources. In addition to temperature differences, geothermal water often has a different chemistry than overlying cold water reservoirs. Therefore, both the hot and cold water reservoirs must be protected from cross contamination.[273, 276]

11.5.2 Land Use Rights (Permitting)

Land ownership and leasing issues must be fully addressed before geothermal projects can begin. The majority of geothermal projects operating today are on federally-owned land that has been leased to the developer. Before a project can begin it is necessary to establish an agreement that provides access to the property and water.[276, 279]

The US Department of the Interior's Bureau of Land Management (BLM) reviews and approves leases and permits to explore, develop, and produce geothermal energy on public land and certain other federal lands, including national forest lands. The agency is also responsible for ensuring that leaseholders' geothermal operations comply with BLM's regulations.

BLM is primarily responsible for leasing public and other federal lands for geothermal development. However, in many cases the DoD has the authority to develop their land by implementing geothermal projects. This authority has been granted through several public laws.[311]

- Public Law 95-356 (1978)
  - Granted authority to the secretary of each military department to develop any geothermal energy source on Department of Defense lands, excluding public lands administered by the Secretary of the Interior. The law allowed the military departments to contract "for the provision and operation of energy production facilities" for up to 30 years.
- Public Law 97-214 (1982)
  - Expanded lands available to the DoD for the purpose of developing and using geothermal resources to public lands set aside for military purposes

- In 1984, Public Law 98-407
  - Granted authority to the secretary of a military department to sell electricity produced from geothermal projects (alternative energy projects in general). Furthermore, the payment received from the sale can be applied to fund its supply of electricity.

11.5.3 Environmental Disposal Issues and Methods

There are several environmental issues that pertain to waste products and streams generated during geothermal energy production. Several of these are described briefly in the following sections.

11.5.3.1 Hydrogen Chloride Gas

Hydrogen chloride gas, which is very corrosive and toxic, is produced with steam in some vapor-dominated geothermal systems. Material selection is important when designing the geothermal system, especially if HCl is present. In many cases, the presence of this corrosive gas prevented the development of a geothermal system because of the probable corrosion problems. Recent corrosion mitigation innovations have enabled the exploitation of some of these geothermal resources.[274]

The dew point of HCl in geothermal systems is too high for the use of typical corrosion inhibitors. For instance, amine-based inhibitors are only applicable up to 200°C. One of the methods used to mitigate the harsh HCl environment is the deployment of caustic soda and high pH solutions to the geothermal wells and well heads. Solid neutralizers can also be used to convert acid to harmless salts.[274]

11.5.3.2 Geothermal Water

The geothermal water from a production facility is almost completely recycled back to the environment because it is not contaminated during the process. Typically it is sent back to the geothermal reservoir via injection wells. It can also be sent to evaporation/infiltration ponds or discharged to surface water.

However, geothermal water may contain minerals and other compounds that can degrade the local water quality if they are not properly handled prior to recycling. Discharging these minerals and compounds into surface water or injecting them into the ground may require permits from state agencies.[276, 279]

The heat in a vapor-dominated geothermal reservoir may still remain after 30 years of geothermal power production. Secondary recovery systems can be implemented at these sites. For example, a treated wastewater injection system was installed at the Geysers plant to send the treated wastewater into the geothermal reservoir. The wastewater absorbs the geothermal heat and can subsequently be used for power production. This is a useful method because the geothermal production can deplete the fluid from the reservoir before the thermal energy in the rock layer is depleted. This method has added considerable steam production and extended the useful life of the geothermal field.[274]

11.5.3.3 Mineral Issues

The porosity and permeability of the geothermal rock layer can be affected by the dissolution and precipitation of minerals. Minerals readily dissolve from the rocklayer when the fluid is not in chemical and thermal equilibrium with the minerals in the rock layer. Amorphous silica and calcite ($CaCO_3$) have a tendency to precipitate in the geothermal wells. The wellbores and surface equipment are prone to developing scale from the precipitation. Inhibitors can be injected to mitigate the precipitation by controlling the calcite further down in the well. These inhibitors to prevent scale buildup have been successful even in higher temperature geothermal fluids.

Injecting acids into the wells can mitigate the calcite precipitation. However, this can also expedite dissolution and thus minimize the effectiveness of the acid treatment further down the well. This can also accelerate the corrosion of the well materials. Chelating compounds can also be used to inactivate the ionic minerals. These compounds are not as active and can help neutralize a greater portion of the system.[312]

Preventing amorphous silica from precipitating is more difficult than it is for calcite. Acid treatment, specifically HF acid, is mostly used for preventing its precipitation, however, recent research suggests that chelating agents may also be effective. Overall, there are limited data on field level effects of these acid and chelating agents on the geothermal and environmental systems.[312]

Another method for controlling the calcite scaling is to keep the hot geothermal fluid in the liquid phase. This method employs electrical submersible pumps (ESP), which are common in the oil and gas industry, to keep the geothermal fluid pressurized and thus in the liquid phase. This prevents CO_2 from exsolving (or separating) from the calcium.[274]

11.6 Supplemental Funding and Cost Minimization

The release of the 2011 federal budget, which includes a 25% increase in geothermal technology funding through the Department of Energy, serves as the latest boost for the geothermal industry. The US is among the world leaders in geothermal energy production, and the industry, with its expected double digit year-over-year growth, will play a key role in maintaining our nation's place at the forefront of renewable energy development.

The 2011 budget specifically calls for $55 million for geothermal technology development that will go towards increasing energy independence, sustaining fossil fuel resources and creating jobs. In addition to the money, the budget also established Department of Energy funding that will be competed across the geothermal industry and other renewable energy sources. Some examples from the budget include:[313]

- $300 million for the Advanced Research Projects Agency – Energy (ARPA-E) to promote the development of advanced technologies, such as the enhanced geothermal systems, which could provide 800 GW of geothermal power across the US
- $500 million in credit subsidy to support $3B to $5B in loan guarantees for innovative energy efficiency and renewable energy projects
- The budget directs DOE to lead the federal efforts to double renewable energy generating capacity by 2012
- Tax credit and permitting initiatives pertinent to geothermal growth
  - Proposed an additional $5 billion to expand tax credits for new renewable manufacturing facilities
  - Funds for the Department of Interior to help expedite the permitting for geothermal and other renewable energy projects on public lands
  - With these new funds, the DOI hopes to be able complete the permitting process for 9 GW of new renewable power

12 EMERGING TIDAL, WAVE, AND OCEAN TECHNOLOGIES

Conventional, renewable hydropower has high construction and capital costs and therefore exhibits limited development. However, there has been much work to harvest the energy that is stored within tides, waves, and the temperature gradients of the ocean. Although progress is being made, many challenges remain. One of the most prominent problems is the transmission of the energy harvested from the location offshore to where it is needed onshore.[88] Tidal power, wave power, and ocean thermal energy conversion are described briefly in the following sections.

12.1 Tidal Power

Tidal power systems exploit the natural rise and fall of coastal waters caused by the interaction of the gravitational and kinematic forces of the sun, earth, and moon.[77, 314] The tide cycle is comparable to, but slightly offset from the solar day (i.e., 24 hours); the tidal day is 24.813 hours.[77] This difference results in two high tides[xciv] per day at an interval of approximately 12 hours and 25 minutes. Low tides, or ebb tides, follow high tides by 6 hours and 12 minutes. The difference in the solar and tidal day causes the peak in available tidal power at a particular point to occur fifty minutes later from one day to the next.[315]

The magnitude of tides also depends on the 29.53 day rotation periods of the moon about the earth, the earth's daily rotation, and the orientation of the earth on its path around the sun. Two types of tides are commonly produced: spring and neap. Spring tides are tides of the maximum amplitude and occur when the sun, moon, and earth align.[77] Spring tides occur twice per month.[315] Neap tides are minimum amplitude tides that occur when the angle between the moon, earth, and sun is equal to 90°.[77]

The overall effect of tidal forces on the ocean level is relatively small. The ocean typically has a tidal range equal to one meter between its high and low tides. This value increases to two meters at continental shelves, and some estuaries and deep, narrow bays have exhibited tidal ranges up to 15 m.[77] These are caused by tidal and reflected waves: tidal waves are produced on the open sea, while reflected waves are caused by an interaction of two wave types that form at the sides of estuaries. Tides are ultimately subjected to and limited by the frictional losses encountered from water moving over the sea bed. The world's largest tidal range is 10.8 m and is located at the Bay of Fundy in Canada.[77]

Energy can be produced from tides as the water rises and falls with the aid of a basin or dam.[77] Current versions of this technology consist of a semi-permeable barrage[xcv] (or barrier) built across an estuary to allow floodwaters to fill a basin in a series of sluices.[86] There are four general modes utilized for power generation: ebb generation, flood generation, two way operation, or flood pumping.[315]

In ebb, or low tide, generation, the basin or estuary water level is heightened to allow the coming high tide water to pass through the sluice gates without turbine operation. This water is stored in the basin once the sluice gates are closed. As the tides recede on the other side of the estuary or basin, during the ebb tide, the sluice gates are opened and the water is allowed to flow over the turbines from the estuary to the ocean where the water is at a lower level (see Figure 165). This action of the water causes the turbines to spin and generate electricity. Power is produced twice during the ebb-tide period.[315]

[xciv] High tides may also be referred to as flood tides

[xcv] Low dam that has one-way gates (sluices) that allow the incoming flood tide to pass into the inlet; when the tide turns, the flood waters flow out of the inlet and through large turbines that are built into the barrage. These turbines are used to produce electricity.

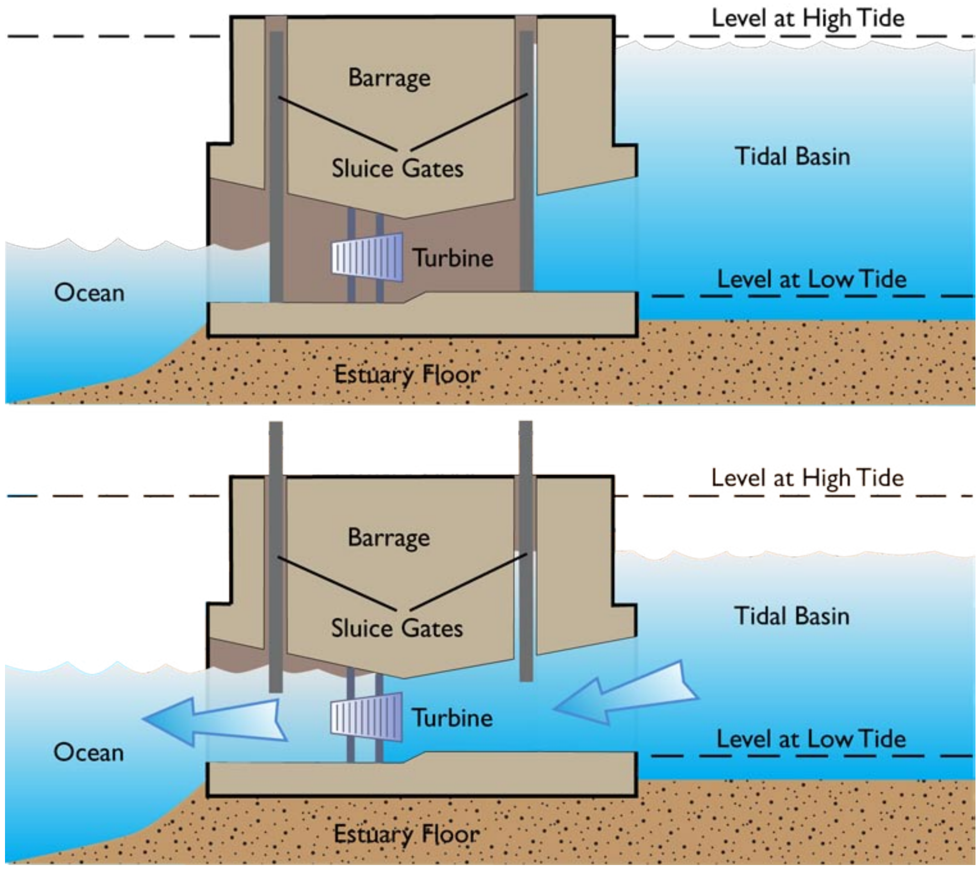

Figure 165. Tidal power generation using a barrage system.

During the flood tide, the turbine is run as the water fills up the basin or estuary. However, as the water recesses, the sluice gates are kept open and the turbines turned off. Flood tide generation is the opposite of ebb tide generation. As with ebb generation, flood tides also produce power during two periods; however, both periods occur during high tide. In addition to ebb and flood tide generation, some barrages operate with two way generation. This method takes advantage of both the high and low tides using a double pitched turbine. As a result, there are four periods of power production during the tidal cycle as opposed to two. Although there are greater opportunities for power production with this method, the cost of the turbines is significantly higher and the efficiencies are much lower because the turbine blades cannot be synchronized for two way operation. In addition, the tidal phases are not fully completed in terms of the filling and emptying of the basins prior to the next tidal cycle.[315]

Because these types of systems produce low electricity yields, it is envisioned that in the future, water will be pumped into the estuary or basin on the flood tide and later used for energy production.[95] This will increase the basin height further in comparison to that which can be achieved by the tidal range.[315] This pumping uses outside energy, supplied from grid connections to operate the pumps during times of low electricity demand.[95, 315] This however allows for greater electricity production during times of high demand. The amount of energy expended to pump the water is fully regained. The energy produced as a result of the elevated basin height is much greater than that produced from the tides alone.[315]

Regardless of the potential associated with tidal power, many issues still have yet to be solved. The potential impacts of tidal power include changes in water levels, sedimentation in basins leading to decreased basin volumes, less mixing in the waters above the basin, land drainage issues, ecosystem changes, and locks for watercraft travel.[77]

The oldest and largest tidal plant is located in La Rance France and has been successfully producing electricity since 1968. This plant requires very little maintenance and only two operators. Currently, tidal plants are less popular as they are expensive and have long construction periods. In addition, they produce power less than half of the time and are greatly affected by the seasons and cycles of the moon which affect the amount of energy produced. The potential for tidal energy is limited within the US, which has only a few sites where it could be produced economically; much of the potential lies in France, England, Canada, and Russia. In the US, tidal power has potential at about 20 locations which have good inlets and large enough tidal ranges to produce energy economically. The tidal range is approximately one foot at these locations.[88]

In addition to the tidal power barrages, which utilize the potential energy caused by differences in heights between the high and low tides, other systems utilize the kinetic energy in the ebb and flood flow to drive turbines. These include tidal turbines (see Figure 166) and tidal fences (see Figure 167).[314] These tidal systems, that make use of the tidal currents, have been cited as having the fewest environmental impacts, while also having increased reliability and predictability with lower capital investments. It has been estimated that there is approximately 3,000 GW of tidal energy available to be harvested.[77, 314, 315]

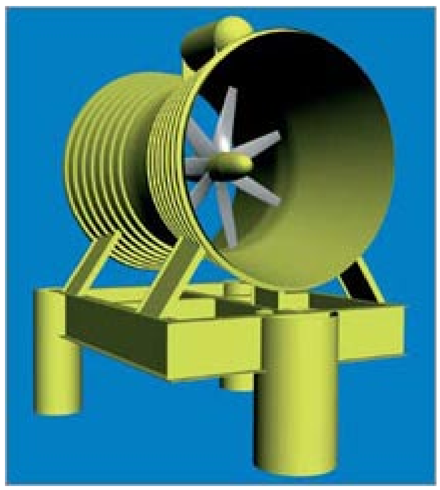

Figure 166. Illustration of a tidal turbine.[316]

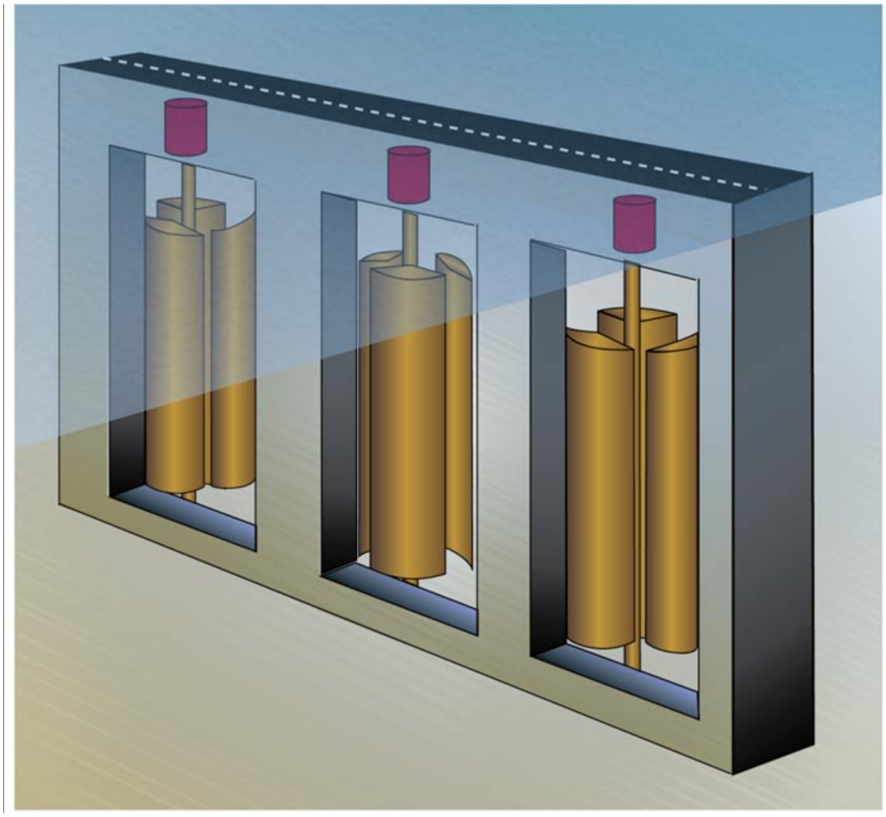

Figure 167. Illustration of a tidal fence.[317]

Small tidal energy systems are available, such as the 60 kW tidal generator at Coast Guard Station Eastport, Maine. The tide at this station rises and falls more than 20 feet. The turbine, which is shown prior to launch in Figure 168, has a cross-flow design. This tidal generator is the first to supply a federal facility with tidal power.

Figure 168. Tidal power generator prior to deployment at Coast Guard Station Eastport.[318]

Tidal turbines are built in arrays underwater as turbines are on a wind farm. They function best when the current is between 4 to 5.5 miles per hour (mph). Tidal turbines are ideally located close to shore, where water depths are 65.5 to 98.5 feet.[319] Tidal fences can be built across small channels and straits. Because seawater has a greater density than air, it carries much more energy and as a result enables the harvesting of significant quantities of energy in comparison to wind turbines.[316]

12.2 Wave Power

Wave power is the method developed to harvest the energy transmitted to waves by winds moving across the surface of water, specifically the oceans. Although these systems could provide large quantities of renewable energy in theory, they have considerable developmental issues that must be solved.[77, 95] In the US, the west coast is the best resource for wave power.[88]

There are several methods by which wave energy is harvested. One method uses a wave to push and pull air through a pipe. As the air moves into and out of the pipe it spins a turbine located within to produce electricity. This method has been demonstrated in Norway. The demonstration tower was built into a cliff and electricity was produced for $0.04 per kWh using this method. The significant disadvantage is that the noise from the turbines could be heard for miles. The second method uses a narrow channel to bend waves, increasing their power and size. These waves are used to spin turbines directly.[88]

There are three main systems for the harvesting of wave power: fixed, floating, and oscillating. Fixed wave power devices mount to the seabed or shore and provide maintenance advantages in comparison to the other types. However, the availability of sites for the installation of this type of device is limited. Floating devices and oscillating water columns generate electricity from the harmonic motion of the water using a floating part assembly.[95] Most challenging however is developing systems that can withstand the severe and corrosive marine environments.[320]

12.2.1 Types of Wave Energy Converters

Wave energy conversion can be classified into two types: offshore or onshore. These are described briefly in the following sections.

12.2.1.1 Offshore Systems

Offshore wave energy systems are typically situated at locations in which the water is more than 131 feet deep.[321] Common offshore wave energy converters are listed below. Others include the Wave Dragon, Archimedes Wave Swing, and PowerBuoy™.

12.2.1.1.1 Salter Duck

The Salter Duck is the best known wave energy converter. Originally developed by Salter in 1974, the Salter Duck consists of a long central core to which duck sections are mounted (see Figure 169). These duck sections are asymmetric and cam-shaped. They are designed to extract energy through a semi-rotary motion that is induced by waves. Each duck has a large gyroscope that is placed inside its nose and used to drive a hydraulic pump that powers a generator to create electricity. This pump is designed to be maintenance free for 25 years.[77, 322, 323]

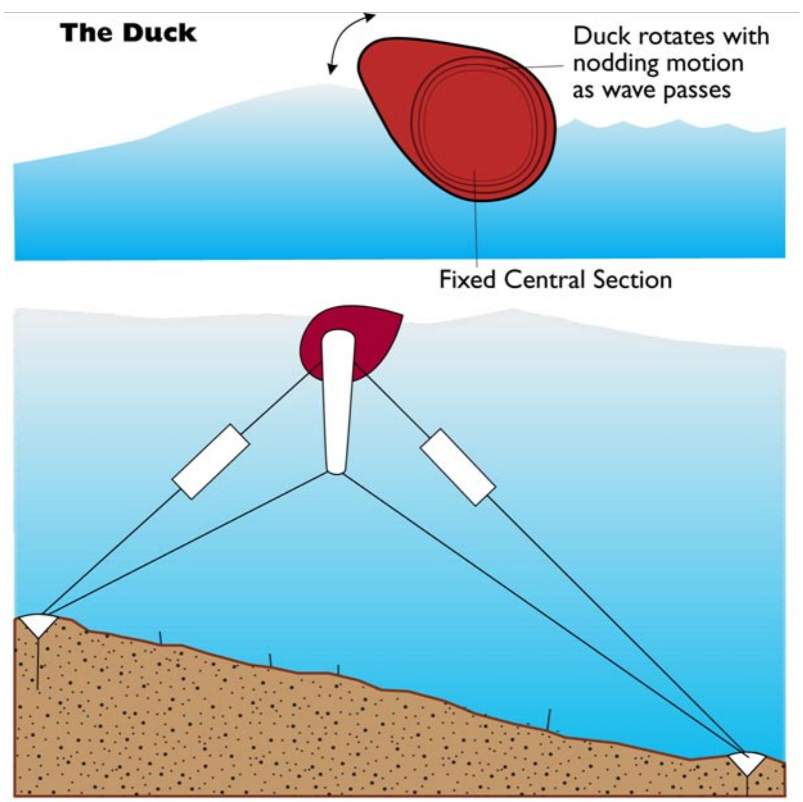

Figure 169. Schematic of the Salter Duck wave energy conversion device.[324]

12.2.1.1.2 Pelamis

The Pelamis is a type of wave energy converter that is currently available commercially. It is a semi-submerged structure that is 120 m in length and 3.5 m in diameter. The Pelamis is composed of cylindrical sections that are hinged together so that they can articulate. A hydraulic ram, which pumps high pressure oil through hydraulic motors, is used to resist the motion of these articulating joints. These motors drive generators that ultimately produce electricity. A mooring system of floats and weights is used to hold the Pelamis in position while also allowing it to swing with oncoming waves.[322] Figure 170 shows the Pelamis as installed off the coast of Spain.

Figure 170. The Pelamis wave energy converter.[325]

12.2.1.2 Onshore Fixed Systems

Onshore wave energy converters are built along shorelines to extract the energy in breaking waves.[321] Typical onshore wave energy converters are described briefly in the following sections.

12.2.1.2.1 Oscillating Water Columns

One promising oscillating water column (OWC) was designed by the National Engineering Laboratory. Their system is a concrete structure that is mounted to the sea bed; the motions of the waves cause the column of water to rise and fall, which in turn caused air to flow through the turbines and generate electricity (see Figure 171).[77]

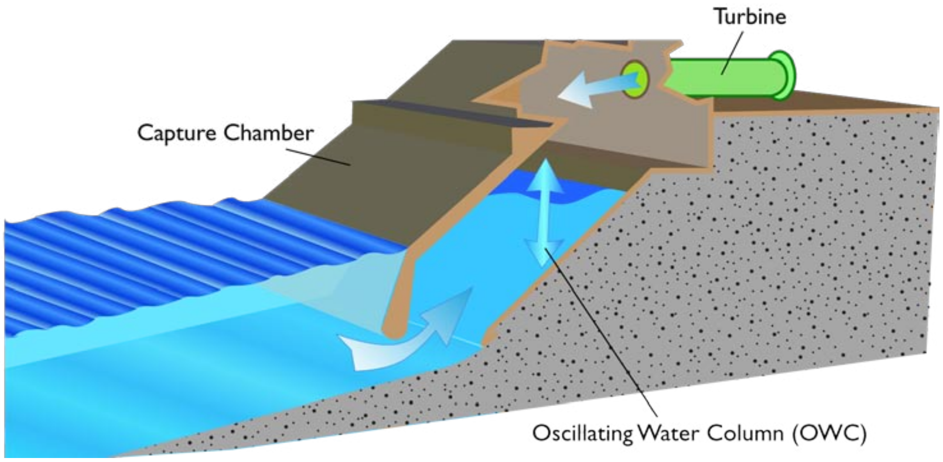

Figure 171. Schematic of an oscillating water column.

Another type of oscillating water column is the Belfast Buoy. This buoy is made of glass-fiber reinforced polyester resins and consists of a vertical axis air turbine that rotates in the same direction irrespective of the direction of air flow.[77]

12.2.1.2.2 Tapered Channel System

The tapered channel (TAPCHAN) system operates using a concept similar to that of traditional hydropower facilities. As shown in Figure 172, this system consists of a tapered channel that feeds water into a reservoir that is constructed onshore, above sea level. As the waves hit the channel, the amplitude of the waves are increased as they move into the reservoir. This kinetic energy within the wave is converted to potential energy as it is stored in the reservoir and no longer in motion. Energy is produced from this water with the use of a turbine-generator set. As in a traditional hydropower plant, the water is fed from the reservoir to the turbine using a pipe. TAPCHAN systems are best suited for regions with consistent wave production and with tidal ranges less than 1 m.[322]

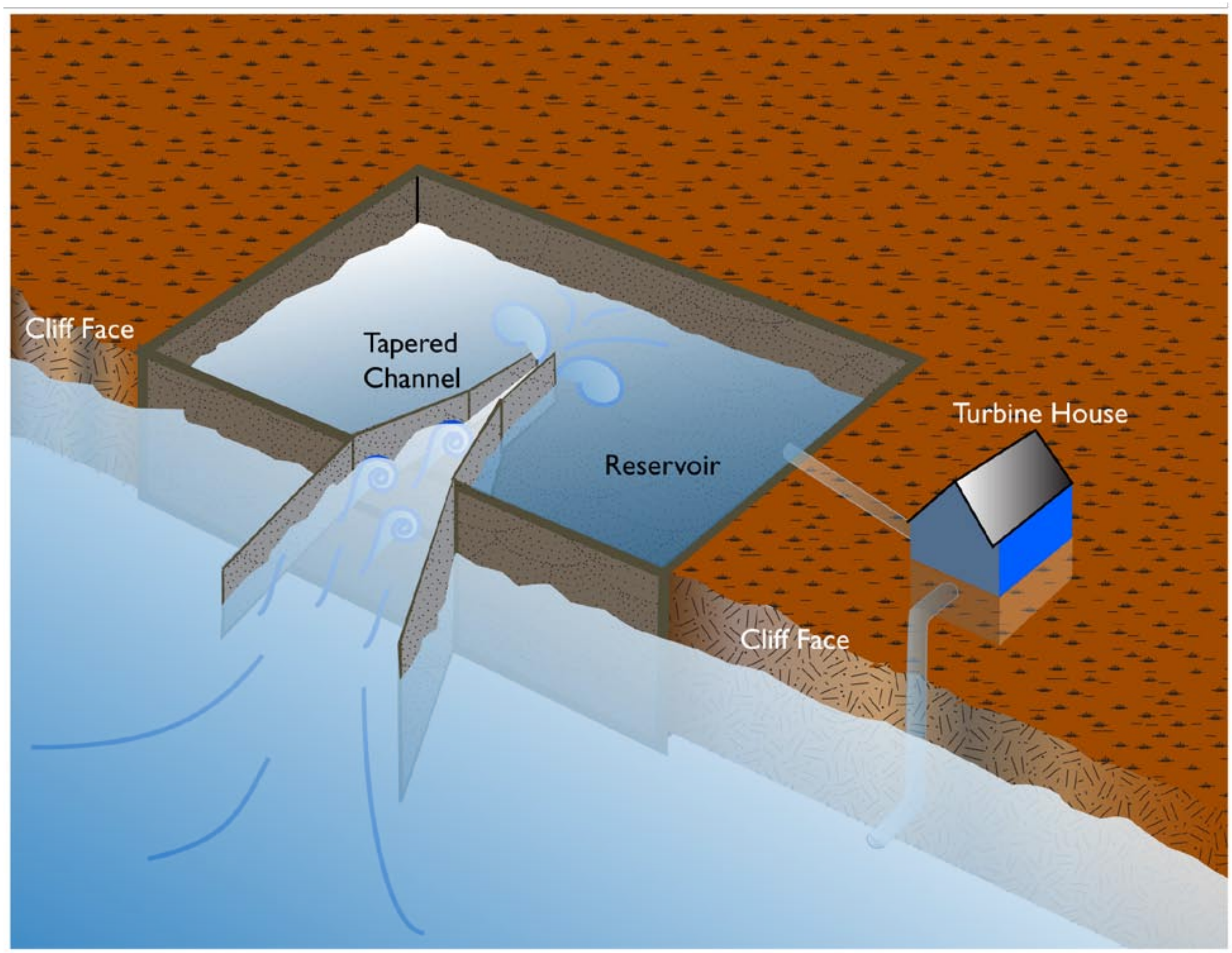

Figure 172. The Tapered Channel wave energy production device.

12.2.1.2.3 WaveRoller

The WaveRoller is another onshore wave energy converter that consists of plates that are anchored to the bottom of the sea. As waves move across the plates, they pivot back and forth; the kinetic energy produced is collected by a pump. This energy is later converted to electricity using a generator.[322]

12.2.2 Economics of Wave Power

The cost of wave power technologies depend strongly upon several factors. These include the system, water depth, distance from shore, and the characteristics of the ocean floor. Additional project assumptions must be made prior to cost estimate determinations.

One study performed a detailed economic evaluation to determine the potential for wave energy development in the US coastal areas. The cost estimate for electricity was determined to be $0.09 to $0.11 per kWh including tax incentives. This estimate was for electricity from the commercial facilities in the offshore regions of California, Hawaii, Massachusetts, and Oregon. Currently, these facilities require extensive capital with the costs having a high degree of uncertainty. For the facilities in the states mentioned, the capital investment costs were between $4,000 and $15,000 per kW. Therefore it is necessary for significant breakthroughs to make the technology cost competitive.[326]

12.3 Ocean Thermal Energy Conversion

Ocean thermal energy conversion (OTEC) exploits the temperature gradient between the surface of the ocean and the deep, cold water in order to produce baseload electrical energy.[77, 327] This temperature difference provides a thermal driving force to operate a heat engine and produce electricity. The warm water at the surface of the ocean is converted into steam under pressure. Alternatively, it can be used to heat another fluid, converting it into a vapor. The steam or vapor spins a turbine to produce electricity. The colder water from deeper within the ocean is brought to the surface using robust pumps. This water cools the steam or vapor, thereby turning it back to its liquid form.[77, 88] Since oceans are natural collectors of solar energy, no additional or special storage systems are required for the utilization of ocean thermal energy. Additionally, due to their large size, OTEC systems have great potential for competition with other power generation methods.[77]

The earliest ocean thermal energy system was developed in the 1920s off the coast of Cuba. This plant was 22 kW in size and had an efficiency less than 1%. It operated using an open Rankine cycle, in which the higher temperature water was passed directly to a low pressure evaporator to provide steam to power the turbine. This OTEC plant was then followed by a French experiment 20 years later that was eventually discontinued due to its lack of success. Interest renewed in this area during the 1960s in the US with the interest changing to the use of a closed Rankine cycle. Several large-scale investigations were performed that showed a net cycle efficiency between 2.1% to 2.4%. However, following this investigation, a joint project between the state of Hawaii, Lockheed Missiles and Space Company, and Billingham Corporation was initiated to develop a mini-OTEC plant. This plant was placed into operation in 1979 off the coast of Hawaii producing 18 kW. This plant established that the problems that were raised during the feasibility studies were surmountable.[77]

Aside from the engineering challenge of creating conduits and robust pumps for pumping seawater from extreme depths, a couple of factors that affect the economic feasibility of OTEC systems are biofouling and corrosion. Biofouling increases the pumping requirements as a direct result of the clogging of pipes and valves as well as the drag and weight of the platform hull. In addition, it decreases the heat transfer capacity of the heat exchangers, a critical subsystem in OTEC plants. Corrosion also affects much of the OTEC plant leading to large downtimes and high maintenance and replacement costs.[328]

Heat exchangers are used for the evaporation and condensation of the working fluid. Their material of construction is based upon the working fluid, the cost of materials, and the availability. Because the heat exchanger is such a critical element to an OTEC plant, it is often necessary to design much of the system around the material selected for the heat exchanger. Corrosion largely affects the heat exchanger because of the seawater's corrosivity and the heat exchanger design itself (i.e., thin-walled tubes and large surface areas). There is some experience with these environments and similar systems.[328]

OTEC technologies require a minimum temperature difference of 38°F between the warm and cold water to operate. Therefore, this technology is limited to tropical regions where temperature differences of 40°F exist. Aside from the temperature difference requirement, if offshore, the transportation of electricity poses extensive challenges. It has been estimated that it will be approximately 15 to 20 years before this technology is available to produce energy economically.[88]

12.3.1 OTEC Technologies

The two major OTEC technologies used today are closed-cycle and open-cycle. Each technology is described below.

12.3.1.1 Closed-Cycle OTEC

In closed-cycle OTEC systems, a low boiling point fluid is utilized in conjunction with cold and warm seawater. The warm seawater, from the surface, is used to heat the heat transfer fluid, converting it to a vapor using a heat exchanger. The vapor is subsequently used to rotate a turbine and ultimately produce useable energy. Cold seawater is then used to condense the vapor, returning it to its original liquid state. This fluid is then recycled through the system.[329]

12.3.1.2 Open-Cycle OTEC

Open-cycle OTEC plants also utilize the warm and cold seawater to generate electricity as with the closed-cycle system. However, no additional fluid is required. First, the warm seawater is pumped into a low-pressure container where it is allowed to boil, leaving the salt behind. The produced low pressure steam is then used to spin a turbine-generator set to produce electricity. This steam is then condensed back to a liquid using the cold, deep-ocean water.[329]

PART IV:

ENERGY STORAGE, TRANSMISSION, DISTRIBUTION AND METERING

13 ENERGY STORAGE

The term energy storage refers the method of accumulating useable energy over time and saving it for use at a later time. This is typically done during low energy demand periods, and the energy is later distributed during peak demand periods. Energy storage technologies do not generate electricity, but they can be used to deliver electricity to the electric grid or an end-user on an as-needed basis. Energy storage systems can also be used to improve power quality by correcting voltage sags, flicker, and surges, or correct for frequency imbalances. Energy storage devices are also used as uninterruptible power supplies (UPS), since they are capable of providing electricity during short utility outages. There are several energy storage systems that perform similar tasks in the end. This section will briefly describe the most common systems and the technologies involved. A summary of energy storage technologies is provided in Figure 173.

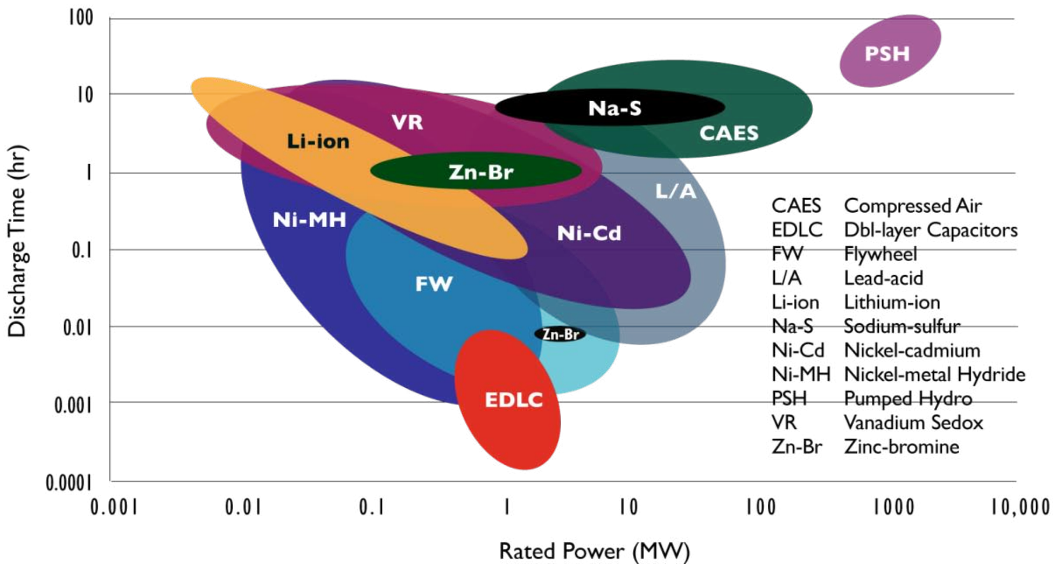

Figure 173. Summary of energy storage technologies.[330]

13.1 Electrochemical Energy Storage

Electrochemical energy storage systems use chemical methods to store and redistribute energy. This section will focus on primary and secondary batteries, as well as fuel cells for energy storage systems.

13.1.1 Batteries

The term battery, used to describe a unit of artillery working together, was used by Benjamin Franklin to describe a set of Leyden jars, which are devices that store electrical charge and were the precursor to the capacitor.[331] The fundamental unit of a battery is an electrochemical cell (also known as a galvanic or voltaic cell), which converts chemical energy to electrical energy through chemical reactions that cause electrons to move from one electrode to another. A galvanic cell has two electrodes, an anode (negative terminal) and a cathode (positive terminal), which are connected through an electrically conductive medium, or electrolyte, and an electrically conductive path. When the electrodes are electrically connected, electrons are generated via an oxidation-reduction reaction and flow across the conductive pathway from the anode to the cathode, while ions migrate through the electrolyte. Batteries can store chemical energy when the conductive path is not connected, otherwise they will disseminate the stored chemical energy.

The increasing number of electronic devices being used by deployed forces puts a greater emphasis on developing longer lasting, lightweight batteries. Many efforts are focused on more efficient batteries, which have a higher energy density. Energy density refers to the ratio of power a battery can supply relative to its own weight. There are many variations in battery design and deciding on the proper battery for a given application depends on the nature of use and the environment in which the battery will be operated. Discharge temperature, rate of discharge, ventilation, mobility, weight, and repeatable use, are among the main design considerations for batteries. Batteries can essentially be placed in one of two categories: primary and secondary.

13.1.1.1 Primary Batteries

Primary batteries, also known as disposable batteries, generate power with an irreversible reaction, and thus it is not practical to recharge them. Once the initial reactants have been depleted, the battery is no longer useful for power applications, however many still have some value and can be recycled.

13.1.1.1.1 Alkaline Batteries

Alkaline batteries are one common type of disposable battery and have remained popular because they typically offer higher power densities than rechargeable batteries. Their high power capacity is due to their high electrochemical efficiency and makes them favorable for long duration discharge.[332] However, they are not well-suited for all applications and provide poor performance under high drain applications over 75 ohms.

Alkaline batteries typically have zinc (Zn) and manganese dioxide (MnO_2) electrodes and are named for their electrolyte, which is an alkaline compound (e.g., potassium hydroxide). Zinc and manganese dioxide react through the potassium hydroxide electrolyte to form zinc oxide and a manganese oxide (Mn_2O_3).[333]

13.1.1.1.2 Zinc-Carbon Batteries

Based on the Leclanche cell, zinc-carbon batteries offer the cheapest primary battery design but weak performance.[334] They are comprised of a zinc anode, which also serves as the battery case; a carbon rod that serves as the cathode and is surrounded by manganese dioxide and carbon black; and a paste of ammonium chloride and zinc chloride, which serves as the electrolyte.[335] They are considered to have a good shelf life.

13.1.1.1.3 Mercuric-Oxide Batteries

Mercury has been used as an additive in batteries for well more than a hundred years, and it is still used today despite the known environmental effects. The use of metallic mercury as an additive by US manufacturers has diminished dramatically over the past several decades primarily due to federal law, but other mercury-based compounds are still used in regulated fashion. Alkaline button cell batteries are permitted to contain up to 25 mg of Hg. Other types of button cell batteries, such as zinc-air and silver oxide, contain small amounts of mercury (i.e., average content less than 25 mg).[336]

In mercuric-oxide batteries, the cathode is zinc, the electrolyte is potassium hydroxide and the mercuric oxide (HgO) serves as the anode. The Mercury-Containing Battery Management Act of 1996 prohibits the sale of the button cell form of mercuric-oxide batteries, and the larger variety of these batteries are regulated and restricted to military and medical use.[336] These batteries are carefully managed and recycled.

13.1.1.1.4 Zinc-Air Batteries

Atmospheric oxygen can be used as the oxidizing agent for electrochemical cells. The use of an abundant and widely available resource for the oxidizing agent or cathode reactant allows zinc-air batteries greater zinc anode capacity and therefore other attractive performance properties. For example, zinc-air batteries have five times the anode capacity compared to conventional zinc-anode batteries. Zinc-air batteries use zinc for the anode, air as the cathode reactant and potassium hydroxide as the electrolyte. Advantages of zinc-air batteries include high energy density, constant discharge, good shelf-life, and low operating cost.[337]

13.1.1.2 Secondary Batteries

The ability to recharge a battery or reverse the chemical reaction in the cell by supplying electrical energy to the cell is the defining characteristic of secondary batteries. Rechargeable batteries do not have an infinite life cycle and ultimately will begin to lose their ability to hold a charge for a number of reasons, such as dissipation of the active materials, loss of electrolyte, and internal corrosion.

13.1.1.2.1 Lead Acid Batteries

The lead-acid battery is a rechargeable wet cell battery suitable for applications where weight is not as critical of a factor. Their construction includes a liquid filled container, which must remain upright and well ventilated to release volatile hydrogen gas: a product of overcharging. Lead plates serve as the electrodes, and the electrolyte is a sulfuric acid (H_2SO_4) solution.

Although lead-acid batteries possess a poor energy-to-weight ratio they can provide a high power-to-weight ratio and are relatively cheap to manufacture, thus making them the optimal choice for many applications. Even as the oldest form of rechargeable battery, they are still the most popular choice for automobiles and other vehicles that need to provide high current to a device, such as an electric starter.

13.1.1.2.2 Lithium-Ion Batteries

With a higher energy-to-volume ratio, sealed dry cell batteries are well-suited for portable power applications. There are several different material combinations that can be used for the chemical reaction in dry cell batteries. Nickel cadmium (NiCd) and nickel metal hydride (NiMH) are of the most well-known battery types with lithium-ion (Li-ion) currently being the most popular and fastest growing.

Li-ion batteries contain a lithium ion which travels between the anode and cathode when discharging. When electricity is added to the cell the ion moves in the reverse direction, from cathode to anode, thereby charging the battery. The electrodes of a lithium-ion battery are made of lightweight lithium and carbon. Lithium is a highly reactive element that stores a large amount of energy in its atomic bonds. Thus, a high energy density is obtainable with Li-ion batteries. The voltage, capacity, life, and safety of a lithium-ion battery can change dramatically depending on the choice of material used for the anode, cathode, and electrolyte. This design flexibility is favorable, but can also make them dangerous if they are not implemented correctly. As higher charge densities are achieved in Li-ion batteries safety concerns and related manufacturing costs increase. Li-ion batteries are very popular choice for portable electronics because they have an excellent energy-to-weight ratio, do not maintain memory, and have a slow self-discharge when not in use.

13.1.1.2.3 Nickel-Cadmium Batteries

Nickel cadmium batteries are capable of producing large surge currents, which is ideal for devices that require a large current (e.g., power tools). The use of cadmium, a toxic heavy metal, however, makes them an environmental hazard and requires special disposal. NiCd batteries primarily compete with alkaline batteries. While they cannot match the charge capacity of alkaline batteries, they do offer the advantage of being rechargeable.

13.1.1.2.4 Nickel Metal Hydride Batteries

The nickel metal hydride battery uses a hydrogen-absorbing alloy for the negative electrode instead of cadmium. They can have up to three times the energy density of a similarly sized NiCd battery and have been a popular battery choice for hybrid vehicles. In comparison to the Li-ion battery, NiMH batteries have a lower charge density and therefore offer inferior performance in many portable electronic devices. Additionally, their high self discharge rate makes them impractical for many slow discharge devices, such as clocks or remotes. They are better suited for high-rate discharge than alkaline batteries due to their lower internal resistance. For instance, in digital cameras, NIMH batteries can sustain a constant voltage at high current discharge for a longer period of time and of course maintain the added benefit of being rechargeable. NiMH batteries tend to have the quickest rate of self discharge and are a poor option for long-term energy storage.

13.1.2 Fuel Cells

A fuel cell (FC) is a device that converts chemical energy from a fuel source to electrical energy via electrochemical reactions in the presence of a catalyst. An electric current is generated as electrons are freed in a half-cell reaction at one electrode, conducted through an external circuit from which electric power is drawn, and finally combined at the opposing electrode in the other half-cell reaction. In the meantime, ions are migrating across an electrolyte to participate in the reactions.

Much like batteries, with no moving parts fuel cells can silently and without vibration provide power. Since there is no mechanical wear, the expected life of a fuel cell is long. The primary difference between a fuel cell and a battery is the battery is a closed electrochemical system in which the reactants can be completely consumed and thus the output power eventually can be depleted. FCs have a continuous supply of reactants, and thus can operate without being recharged. While the fuel source can vary, the typical reactants are hydrogen and an oxidant, which is most often oxygen. While a hydrogen source must be provided, in most cases oxygen can be drawn from the air. The cellular aspect of these power devices is derived from their modular nature.[338]

Fuel cells on their own are not energy storage systems, they can be combined with electrolyzers and batteries to form an energy storage system. For instance, direct current from solar photovoltaics can be used to power an electrolysis reaction that separates water into hydrogen and oxygen. These products can be stored under pressurized conditions and used at a later time as reactants in a fuel cell. The fuel cell, therefore, can provide electrical power as needed. Such a system can have a specific energy as high as 1 kWh/kg.[339]

Fuel cells are typically organized according to the type of electrolyte used. Some of the most common types of fuel cells will be discussed in the following sections. A summary of fuel cell technologies is presented in Table 57.

Table 57. Comparison of fuel cell technologies.[340]

Fuel Cell Type	Common Electrolyte	Operating Temperature (°C)	System Output (kW)	Electrical Efficiency, %	Combined Heat and Power (CHP) Efficiency, %	Applications	Advantages
Polymer Electrolyte Membrane	Solid organic polymer poly-perfluorosulfonic acid	50 – 100	<1 – 250	53-58 (transportation) 25-35 (stationary)	70-90 (low grade waste heat)	• Backup power • Portable power • Small DG • Transportation • Specialty Vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up
Alkaline	Aqueous solution of potassium hydroxide soaked in a matrix	90 – 100	10 – 100	60	>80 (low grade waste heat)	• Military • Space	• Cathode reaction faster in alkaline electrolyte, leads to higher performance • Can use a variety of catalysts
Phosphoric Acid	Liquid phosphoric acid soaked in a matrix	150 – 200	50 – 1000 (250kW module typical)	>40	>85	• DG	• Higher overall efficiency with CHP • Increased tolerance to impurities in hydrogen
Molten Carbonate	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600 – 700	50 – 1000 (250kW module typical)	45-47	>80	• Electric utility • Large DG	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP
Solid Oxide	Yttria stabilized zirconia	600 – 1000	<1 – 3000	35-43	<90	• Auxiliary power • Electric utility • Large DG	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte reduces electrolyte management problems • Suitable for CHP • Hybrid/GT cycle

13.1.2.1 Solid Oxide

Solid oxide fuel cells (SOFCs) use a solid ceramic material, yttria stabilized zirconia, for the electrolyte. These FCs must operate at high temperatures in order to readily conduct ions via the ceramic electrolyte. Due to the high operating temperatures, however, expensive catalysts are not required and hydrocarbon fuels can be used directly.

13.1.2.2 Alkaline

Alkaline fuel cells (AFCs) contain an aqueous solution of potassium hydroxide (KOH), which serves as the electrolyte. Potassium hydroxide is used because it is the most conductive alkaline hydroxide. These types of FCs are susceptible to contamination. A small amount of carbon dioxide in either of the reagent streams (i.e., hydrogen or oxygen) will result in carbonation of the potassium hydroxide. Ultimately, such a contamination would result in the formation of particulates which deposit in the porous electrode. Thus, AFCs require pure hydrogen and oxygen, and therefore are primarily used in space applications.[338]

13.1.2.3 Molten Carbonate

Molten carbonate fuel cells (MCFCs) utilize a liquid solution of lithium, sodium, or potassium carbonates for the electrolytic medium. This is a hot corrosive liquid, and thus these FCs are primarily used for stationary applications. Due to the high operating temperature of the fuel cell, natural gas can be used as the hydrogen source. Steam is also generated because of this high operating temperature, which can be harnessed for an auxiliary source of power.[338]

13.1.2.4 Phosphoric Acid

Phosphoric acid fuel cells (PAFCs) utilize concentrated phosphoric acid as the electrolyte because it is a good ionic conductor at high temperatures. Since the electrolyte is a hot corrosive liquid, PAFCs are well-suited only for stationary applications.

13.1.2.5 Polymer Electrolyte Membrane

Polymer electrolyte membrane (PEM) fuel cells, also known as proton exchange membrane fuel cells, rely on a specialized fluoropolymer membrane material that has sulfonic acid groups. The sulfonic groups facilitate ionic conduction under hydrated conditions. The operating temperature for PEMFCs is relatively cool (i.e., 70°C). An illustration of a PEMFC is provided in Figure 174.

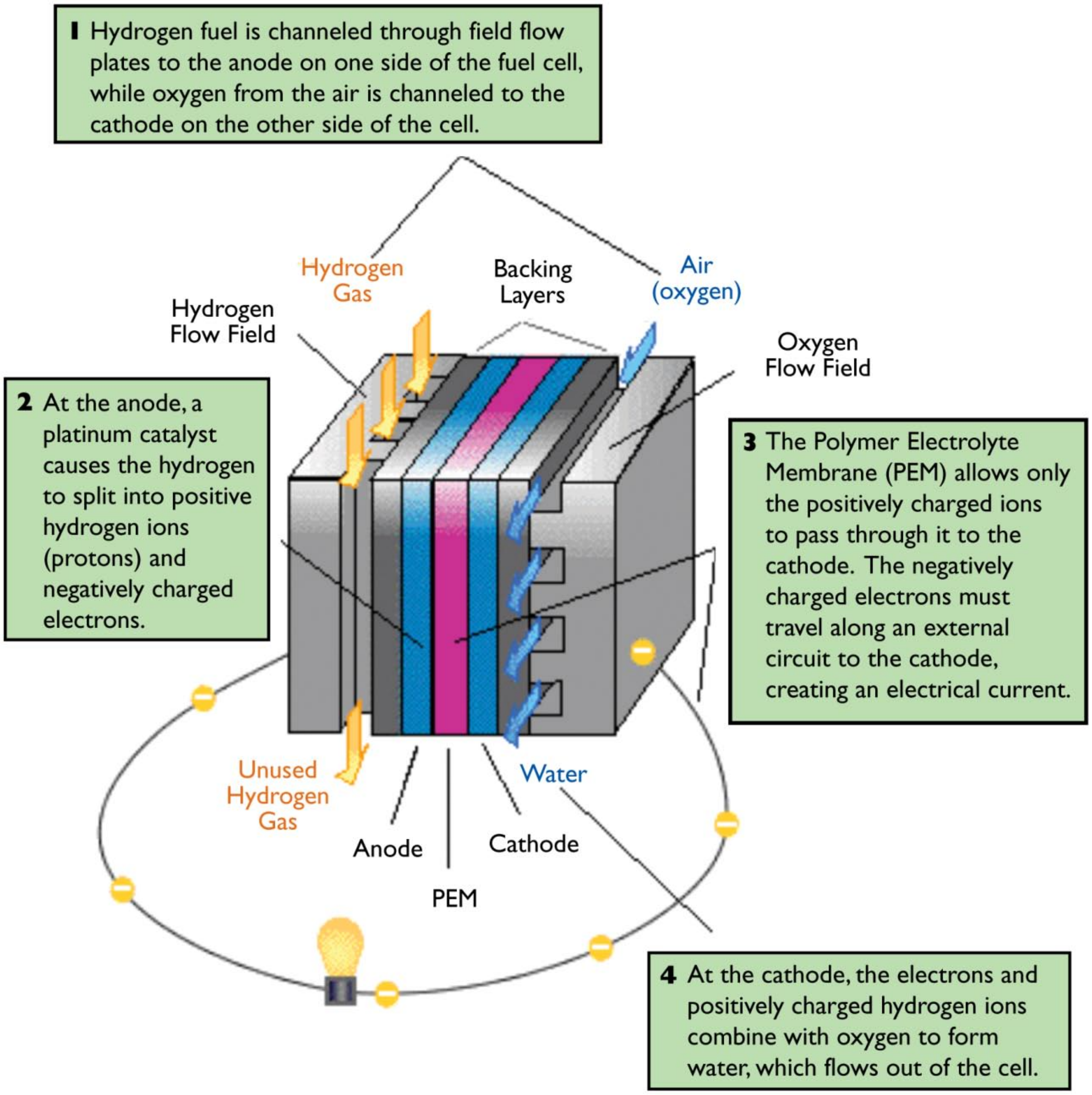

Figure 174. Diagram of a PEM fuel cell.[341]

13.1.2.5.1 Direct Methanol

Direct methanol fuel cells (DMFCs) are a subset of PEMFCs. These FCs utilize the same electrolyte material, but use a different fuel source (i.e., methanol), and thus a different catalyst (i.e., platinum/ruthenium alloy rather than carbon-platinum).

13.2 Electromagnetic Energy Storage

Electromagnetic energy storage systems rely on electrical and magnetic principles to store and redistribute energy. This section focuses on supercapacitor and superconductor based systems, which are the most common electromagnetic storage systems.

13.2.1 Supercapacitors

Supercapacitors are electrical storage devices that operate as large versions of common electrical capacitors. They are sometimes referred to as ultracapacitors. Supercapacitors are different than batteries because capacitors store energy in an electrostatic field as opposed to batteries, which store energy in a chemical form. For instance, when a supercapacitor is charged, there is no chemical reaction; rather the energy is stored as a charge or concentration of electrons on the surface of a material.

Supercapacitors are capable of rapid charging and discharging cycles and they can be recharged hundreds of thousands of times, unlike conventional batteries, which last for only a few hundred or thousand recharge cycles. However, the power stored in supercapacitors is only available for a short duration, and their self-discharge rate is much higher than batteries.

Common applications of supercapacitors include starters for diesel trucks and railroad locomotives, transient load leveling in electric and hybrid-electric vehicles, and energy capture from braking. In power systems, they are commonly used to bridge power sources for uninterruptible power supplies.[342]

13.2.2 Superconducting Magnetic Energy

Many materials exhibit a traditional electrical resistance behavior above some critical temperature (T_c), and superconductivity below that temperature. For most materials however, this critical temperature is very near absolute zero. As the material's temperature approaches this critical value, the material becomes less resistive, until it finally exhibits a complete disappearance of electrical resistance upon reaching T_c. Materials in the superconductive state conduct electricity perfectly, or without resistance.[343]

Superconducting magnetic energy storage (SMES) systems store energy in the magnetic field created by the flow of direct current through a large coil of superconducting material that has been cooled. Power is available almost instantaneously from SMES systems, and very high power output is provided for a brief period of time. There are no moving parts. However, the energy content of SMES systems is small and short-lived, and the cryogenics (super-cooling technology) can be a challenge. Thus SMES systems are used for power quality problems and short-term power losses. They have also been used for electricity-grid support, preventing voltage collapses, minimizing voltage instability, and reducing system outages.[344]

13.3 Mechanical Energy Storage

Systems that are designed to store kinetic energy generally include some type of rapidly rotating mechanical component. These systems are favorable in situations where rapid absorption and discharge of the energy is required. The majority of these systems are too expensive for use on the utility scale, but research into designing future systems with advanced materials (e.g., carbon nanotubes, carbon fiber) is underway.

13.3.1 Flywheels

A flywheel is a rapidly-spinning cylinder or disc suspended in a vacuum-sealed container that stores kinetic energy. Their design is similar to a spinning tire that is being propelled and thus contains its own energy potential. Flywheels are fairly common because they are a critical component in a number of modern mechanical systems. For example, flywheels are used to enhance the performance of internal combustion engines and electric motors in many vehicles. In energy storage systems, similar to supercapacitors, flywheels have applications as uninterruptable power sources and load stabilizers during peak usage times.

Most flywheel energy storage systems (FES) use electricity to accelerate or decelerate the flywheel, but devices that use mechanical energy to harness the wheel's rotational energy are also being developed. A flywheel can be combined with a device that operates either as an electric motor that accelerates the flywheel to store energy or as a generator that produces electricity from the energy stored in the flywheel. The faster the flywheel spins, the more energy it retains. Energy can be drawn off as needed by decreasing the speed of the flywheel. Advantages of FES include low space and maintenance requirements, durability and resistance to fluctuating temperatures.[345, 346, 347]

13.3.2 Pumped Hydro

Pumped hydro facilities pump water from a lower elevation to a reservoir at higher elevation. The pumps used to fill the higher supply reservoir use off-peak electricity to move the water. When electricity is needed during periods of high demand, the water is released from the upper reservoir and passes through hydraulic turbines that generate electricity to meet the demand.

Due to its unique setup with the two reservoirs, pumped hydropower can be used to store electrical energy for extended periods of time in large quantities. This fact makes it an ideal for use in conjunction with peak and intermittent load power plants to level out their electrical production and establish power plants that are baseload. For example, pumped hydro has been used in this manner with larger coal and nuclear plants to increase their efficiency. It can also be used in an emergency to provide temporary power when a plant goes offline unexpectedly.[348]

13.3.3 Compressed Air Energy Storage

Compressed air energy storage (CAES, sometimes referred to as compressed gas energy storage) involves a hybrid storage and power production system. Electricity is used when demand is low to power a motor which drives compressors and forces air into an underground storage reservoir, such as a rock cavern or abandoned mine. When the demand for electric power spikes the process is reversed, and compressed air is returned to the surface. This air is heated by natural gas in combustors and run through high-pressure and low-pressure expanders to power a generator and produce electricity.

In traditional gas turbines, the air that drives the turbine is compressed and heated using natural gas. Thus, compressed air energy storage requires less gas to produce power because the air entering the system has already been compressed.[349, 350]

13.4 Thermal Energy Storage

Thermal energy storage encompasses any technology which uses thermal energy stored in a reservoir for later use. For power production, thermal energy storage can be used to capture cheaper and cleaner energy that is produced during off-peak hours. This can allow for greater contribution from renewable sources, such as wind and solar, which do not always supply consistent power when it is most needed.

13.4.1 Heat Transfer Fluids

In solar collector technology, heat is captured from solar collectors and stored for energy production overnight or at a later time. It can be stored for upwards of 24 hours. There is a need for advanced heat transfer fluids. Synthetic heat-transfer oils are considered traditional working fluids for thermal energy storage. More recently, nanofluids have been developed to improve the efficiency of heat transfer in solar fields. Therminol VP-1 is the heat-transfer fluid of choice in parabolic trough solar fields. It is thermally stable to about 400°C and has a low freezing point of 12°C.

13.4.1.1 Molten Salts

An ideal heat transfer fluid will have a low freezing point as well as a high working temperature. Nitrate salts have been characterized and tested for use in trough power plants. New formulations have freezing points around 100°C and these molten salts are being considered for future power storage applications. The downside to nitrate salts is their potential corrosive properties. Research efforts are currently exploring non-nitrate molten salt fluids and other less corrosive substances for heat-transfer fluids.

There are three basic types of molten salt physical chemistry and application. These include molten carbonate fuel cells (MCFC), thermal electromechanical batteries (TB) and high temperature secondary batteries (HTSB). Each contains the basic components of a battery cell: semiconductor electrodes, a molten ionic conductor as the electrolyte, and necessary structural components. An MCFC uses two gas (oxygen and hydrogen) electrodes and a molten alkali carbonate electrolyte to create a complex electrochemical reaction which produces a stream of electrons. The TB uses oxidizable and reducible reagents separated by molten salt electrolyte to produce electron flow through an oxidation/reduction reaction. The HTSB functions similar to the TB. However, to provide a charge and recharge cycle, it requires an additional constituent or separator of anode and oxidant ions within the molten salt.[351]

13.4.1.2 High Heat Capacity Fluids

In addition to high heat transfers fluids, materials research is investigating cheaper high heat capacity storage fluids. By achieving greater heat capacity, less fluid can be used to achieve the same amount of heat energy storage. A decrease in storage fluid volume could reduce overall system costs.

13.4.2 Water-Based Thermal Energy Storage

Water based thermal energy storage exists for two main reasons: water has a relatively high volumetric heat capacity and is a plentiful resource. Furthermore, water-based energy storage systems can generally be separated into two major categories: ice and steam.

13.4.2.1 Ice Storage

Ice storage for daytime cooling is one of the most commonly used forms of thermal energy storage. This technology takes advantage of off-peak energy production. In a common energy system, inefficient energy generation is typically reduced or brought off-line overnight, making energy cheaper to produce. time of use (TOU) rates, or real time pricing (RTP) rates allow for large buildings or campuses to reduce their daytime cooling costs. In this design, ice is produced for cooling for 16 to 18 hours, and this stored capacity is used to cool for six to eight hours a day. Equipment can be sized 40 to 50% smaller than traditional energy equipment. This design trait helps to create competitive capital investment costs. Ice produced from off-peak electricity can also be used to cool the intake on a gas turbine generator and thereby increase generation capacity during peak demand.

13.4.2.2 Steam Accumulator

Steam can also be collected similar to ice for use as thermal energy storage in a steam accumulator. Although archaic in many ways, steam power is relatively efficient and is particularly valuable to certain industries and applications which require large peak loads, such as textiles processing, brewing, and the rubber industries. With adequate storage, trains and railway systems, might be able to run entirely from renewable sources, such as wind or solar. One problem with using steam is to manage peak loads and response times from steam systems. Steam accumulators are essentially large, insulated pressure vessels which allow for more efficient management of steam powered systems by collecting the steam generated by a boiler and controlling the release of the steam as it is needed. Although a short-term storage method, this regulation of steam flow allows equipment to run more efficiently and avoid aggressive cycling which reduces equipment life. Steam accumulators also provide faster equipment response times to steam powered plants thereby increasing productivity.

14 ENERGY DISTRIBUTION, TRANSMISSION, AND ADVANCED METERING

Often when considering the implementation of renewable energy power generation, several potential power transmission and distribution challenges must be addressed. For example, one of the foremost challenges encountered is integrating a new power source with an existing electrical grid. If there is an existing grid that can be used, it must be determined if the new power generation can be handled by the existing grid and transmission and distribution equipment. Furthermore, if new transmission lines are required, the capital cost may be prohibitive to implementing the project. This may especially be the case for remote and distributed generation projects, depending on the distance between the generation point and the consumption point. How transitioning from nonrenewable power generation to renewable generation may affect the power reliability and security at DoD installations must also be addressed.

14.1 Current Grid Structure

To evaluate the impact that implementing renewable energy sources on operations at DoD installations, it is important to have a good understanding of the current power grid and its capabilities. The current grid structure, which is illustrated in Figure 45, provides electricity from numerous renewable and nonrenewable energy sources to more than 308 million people in the US through the current grid.[352] More than 3,741 TWh of electricity can be used annually by homes and businesses.[353] This mammoth sum of electricity is transported over more than 180,000 miles of transmission lines, divided up over 30,000 transmission paths through 14,000 transmission substations.[354] These transmission lines are maintained and operated by more than 3,000 separate utility companies, which makes any effort to increase capacity or improve efficiency very challenging. Given the size, complexity, age (i.e., first constructed in late 19th century) and decentralized nature of the US power grid, it can be inferred that the existing power grid might not be set up to maximize the use of new renewable energy sources.

14.2 Grid Challenges with Renewable Energy

The existing grid continues to meet the current US power demand, as well as current DoD needs. However, as the DoD increases its dependency on renewable energy sources, challenges with the existing grid arise. In some cases, it is not sufficient for handling additional amounts of electricity being generated by new and existing renewable energy sources. Moreover, if an energy source is being replaced with a new renewable energy source, the existing grid structure must also be upgraded or replaced.

According to a 2009 Electric Transmission Study performed by the DOE, transmission systems are rarely, if ever, constructed unless they are needed to meet an existing demand. This is because of the high cost and long lead times associated with construction of transmission lines.[355] This can hamper the development of renewable projects, because to maximize the cost saving impact of renewable energy projects, the renewable plant will thus need to be constructed near an existing transmission system. Renewable energy sources, such as wind and solar power, require large quantities of land, and for the DoD in particular they often must be located in remote areas to mitigate issues such as radar interference. These remote areas lack the necessary transmission lines to get the electricity into the grid, where it can be used by DoD Installations.

To help the DoD meet the renewable energy usage goals detailed in *Section 4.2.2.1*, improvements would be need to be made to the existing grid structure to allow for the efficient and cost-effective use of locally generated renewable energy at DoD Installations. The excess costs of long distance transmission lines for renewable energy has rendered some renewable energy projects economically unfeasible when compared to nonrenewable power generation sources using the life cycle cost criteria detailed in Chapter 16. In order to increase the use of renewable energy sources while keeping life cycle costs down and ensuring energy security, new technologies and ways to integrate and deliver renewable energy are needed.

14.3 Smart Grid

One such method of integrating renewable energy is through the use of a smart grid approach. According to SmartGrid.gov, a smart grid is "an automated electric power system that monitors and controls grid activities, ensuring the two-way flow of electricity and information between power plants and consumers."[356] Using advances in digital sensing, control systems, metering, communication and improvements in grid design, the smart grid approach provides a more efficient and more reliable flow of electricity to meet consumer demand in real time. According to the DOE, there are five technology areas that enable the development of a smarter power grid: [357]

- Integrated Communications
- Sensing and Measurement
- Advanced Components
- Advanced Control Methods
- Improved Interface and Decision Support

Each of these areas is described in more detail in the following sections.

14.3.1 Integrated Communications

The ability to monitor the state of the power grid in real time requires a robust communications network to transfer data between the grid, power suppliers (e.g., local utilities), and consumers (e.g., DoD installation). Through the use of communications technologies such as broadband over power line, 802.11 Wireless Internet, code division multiple access (CDMA) cellular communication, and very small aperture terminal satellite communication. Grid automation systems have been developed to recognize current operating conditions and problems and adjust energy output and flow paths to maintain a varying power demand in the face of system obstacles. Examples of automation systems include substation automation (SA), distribution automation (DA), and supervisory control and data acquisition (SCADA). Expanded integration of communications between control systems and sensing devices throughout the smart grid will further improve energy reliability and help alleviate congestion as the devices provide a greater amount of real time information at faster speeds.

14.3.2 Sensing and Measurement

Enabling real time data acquisition and electricity measurement requires a new level of sensing and metering approaches and technologies. The EPAct set forth the requirement for installation of advanced electricity meters in all federal buildings by October 1, 2012 (see *Section 4.2.1.3*).[358]

14.3.2.1 Advanced Meters

The term advanced energy meter refers to a device that can measure, record, and remotely communicate energy usage data as required by the EPAct.[358] Advanced meters are used to measure the usage of electricity, gas, and water. They commonly contain alarm systems, system diagnostic functions. The recording intervals can be adjusted, and the meters can perform two-way communication over wired or wireless communication networks. An advanced electricity meter is shown in Figure 175.

Figure 175. Advanced electricity meter installed at Naval Air Station Kingsville.[359]

14.3.2.2 Advanced Metering System

An advanced metering system (AMS)[xcvi] measures energy usage on time-based intervals, and communicates, manages, and distributes the data to users. Data inquiries can be made on an on-demand or scheduled basis. Advanced metering infrastructure (AMI) includes hardware, such as the meters, communication devices, and network storage. It also includes software for data management, access, and distribution. This infrastructure enables the creation of a network between advanced meters and users to allow them to access and assess data as energy is used, as illustrated in Figure 176.[358]

[xcvi] Advanced metering applies to water, gas, and electricity measurement.

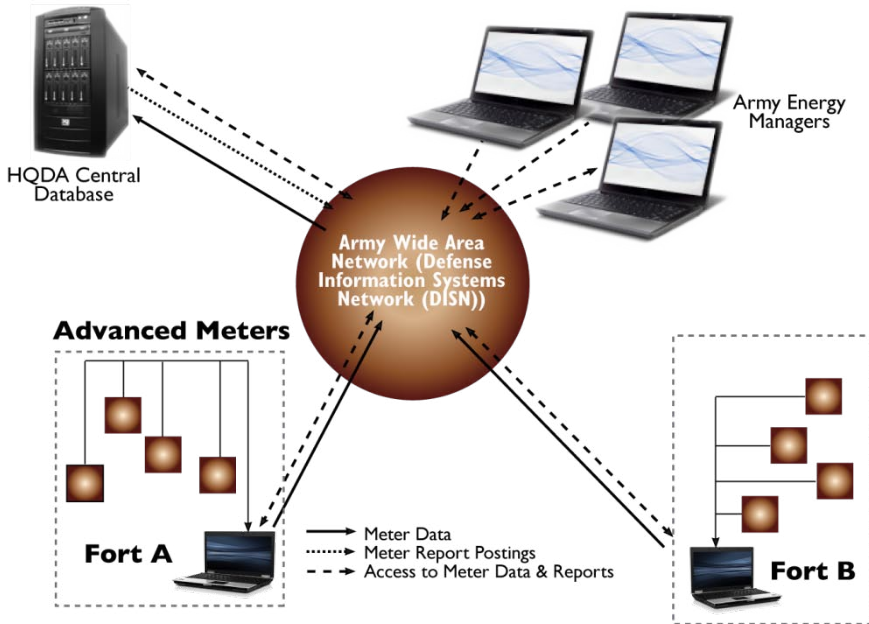

Figure 176. Illustration of an advanced metering system.[360]

14.3.2.3 Metering Applications and Approaches

Energy metering has a wide range of applications in the Federal Government. Within an AMS, an advanced meter can be used simply to record data. It can also be used to perform the following functions:[361]

- Measure total energy consumption
- Quantify usage during hours of operation
- Measure peak energy demand
- Provide a survey of a system's energy load
- Monitor and control the energy load within a facility
- Schedule energy loads to minimize costs during peak demand times

With each application, there are metering approaches that can be customized to meet the needs of a project. These include one-time measurement, run-time measurement, short-term monitoring, and long term monitoring. Only long-term monitoring, however, is sufficient to satisfy the advanced metering requirements set forth in EPAct 2005.

14.3.2.3.1 One-Time Measurement

The one-time measurement method is used to determine an instantaneous or discrete value of energy usage.[xcvii] It is typically used to establish a baseline of energy use. This method can be applied to a system or unit of equipment to determine level of usage and periodically re-measured to evaluate changes in efficiency or performance, for instance. It is a low-cost method that is does not determine actual use over time, and therefore is not as accurate for determining energy use compared to other methods.[361]

[xcvii] One-Time measurements don't meet the metering requirements detailed in Section 103 of the EPAct.

14.3.2.3.2 Run-Time Measurement

Run-time measurements are traditionally used to measure the operational time of equipment and electrical systems. Run-time measurements are traditionally applied at the system or subsystem level to record the amount of time a system is operating or running.[361] However, run-time measurements usually have to be paired with one-time or spot measurements to plot energy usage over operating time of a system. Spot measurements are used because they give a measurement of instantaneous energy usage.[362]

14.3.2.3.3 Short-Term Monitoring

Short-term measurements document both the amount of energy used and the hours of operation on a subsystem, system, or whole building level. This approach is commonly used to assess system performance and/or validate results of energy efficiency projects.[362] When employing a short-term monitoring approach, which typically is applied for less than one year, several mobile data logging devices equipped with various current flow, voltage, and pressure sensor are set up to autonomously gather data over a wide-range or user-define time intervals.[361]

14.3.2.3.4 Long-Term Monitoring

Long-term monitoring is very similar to short-term monitoring, however it mainly focuses on the whole building for a much longer time period (e.g., up to the life of the building). The majority of the sensors and data acquisition systems in long-term monitoring efforts are in fixed positions, sending data via internet connection to a main computing system. This is the only method that can satisfy metering requirements from the EPAct 2005.

14.3.2.3.5 Summary of Metering Methods

For more information on energy metering and best practices refer to the *Metering Best Practices: Guide to Achieving Utility Resource Efficiency*, published by the Department of Energy Federal Energy Management Program.[363] Table 58 presents a summary of the metering methods, including advantages and disadvantages.

Table 58. Applications, advantages, and disadvantages of measurement approaches.[358]

Measurement Approach	Applications	Advantages	Disadvantages
Run-Time	Measuring time-based usage of equipment	Low-cost	Very few uses
		Very easy to use	Measures only hours of operation
		No interference with utility operation	Data must be gathered from system manually
			Requires additional calculations to maximize usefulness
Short-Term	Validate results of energy efficiency projects	Able to measure energy used and hours of operation	More expensive
	Assess system performance	Remote data recovery	Limited accuracy
			Few applications
Long-Term	Systems susceptible to weather and occupancy variation	Able to measure energy used and hours of operation	Most Expensive
		Most Accurate	Most difficult to install
		Able to record and measure data variances	
		Remote data recovery	

14.3.3 Advanced Components

Ensuring a constant, reliable flow of electricity is one of the main purposes of transitioning to a smarter power grid. Improving grid reliability requires the use of cutting edge components and energy resources. These new components include advanced wiring, power flow controlling devices, solid state transfer switches, voltage compensators, advanced energy storage technologies, and a distributed generation power source (i.e., as opposed to a centralized power generation, see *Sections 6.6*, *7.3.1* and *7.3.2*), commonly known as a distributed energy resource. Many of these components have helped lead to the development of a power distribution concept known as a microgrid (see *Section 14.3.6*).

14.3.4 Advanced Controls

Advanced controls are an integral part of creating a responsive power grid that can act autonomously to varying line conditions. The distributed control technologies employed in smart grids monitor grid parameters in real time using the sensing, metering, and communications technologies described in previous sections. Control technologies, such as dynamic distributed power control devices, can regulate the current flowing through transmission lines at any given time, maximizing line utilization while meeting demand. Other control technologies can evaluate current line conditions and shutdown lines to preserve vital system assets, similar to how a surge protector protects a singular electrical outlet.

Analytical tools are also used to provide system control in a smart grid. Existing tools can measure various operating parameters (e.g., voltage, congestion, frequency) and predict the impact that the loss of any piece of equipment will have to the grid.[364] From this predictive modeling, response plans can be optimized to accommodate anticipated system disturbances.

14.3.5 Improved Interface and Decision Support

Decision support technologies can further improve the effectiveness of advanced controls. Computer hardware and software possess the ability to show multiple levels of operation-relevant information (e.g., congestion, voltage, line impedance, usage time, demand, etc.), identifying real-time problem areas based on real-time data. In addition, decision support software can assist system managers through the representation of this information in a simplified manner, improving the ability of system operators to ensure continuity and quality of the grid. This information can also enable faster activation of the controls to protect the power grid from experiencing the type of failures that can cause massive blackouts.

14.3.6 DoD Smart Grid Projects

Since passage of the 2005 EPAct, the DoD has been aggressively pursuing improvements in energy efficiency and developing a smarter energy grid through the use of advanced metering. The Air Force currently has advanced metering efforts at Ellsworth, Elmendorf, and Minot Air Force Base that employ a wireless network to collect data from electricity, natural gas, and water meters and the information on a web-based software program. In addition, Vandenburg AFB has successfully replaced over 400 utility meters with remotely-accessible smart meters, helping reduce annual energy consumption by 19% in 2009.[365] The Navy Facilities Command Engineering Services Command is implementing more than 14,000 advanced electricity meters at over 100 installations by 2013 under the auspices of the Navy's Advanced Metering Infrastructure Program.[366]

As part of the Army Metering Program, the Army developed the Metering Data Management System (MDMS) to acquire and report various types of data (e.g., energy usage data intensity, demand, usage trends, etc.) from advanced meters at Army installations as illustrated in Figure 176. The data and reports generated by the MDMS are accessible through the Army Corps of Engineers Engineering Knowledge Online (EKO) website and the MDMS Enterprise Portal.[367] In 2010, two pilot Metering Data Management Systems were installed at Fort Carson and Fort Stewart with the rest of the metered installations coming online by October 2012, as the Army works to meet the 2005 EPAct deadline for metering all federal buildings.[368]

14.4 Microgrid

A microgrid is an integrated system of interconnected loads and DERs that can operate in parallel to an existing grid structure, augment the existing grid, or operate completely separate from the grid.[369] Microgrids operate on a multi-tiered structure that enables continuity of operations in the event of any service disruption from the local utility. The different tiers can vary greatly in size from application to application. Tier size is usually based on the voltages needed to maintain critical operations within an area (see Figure 177). This multi-tiered structure also results in increased energy efficiency, greater grid reliability, and an improved ability to handle demand spikes. Within each microgrid, there are three main components, the distribution grid, DERs, and energy storage devices.

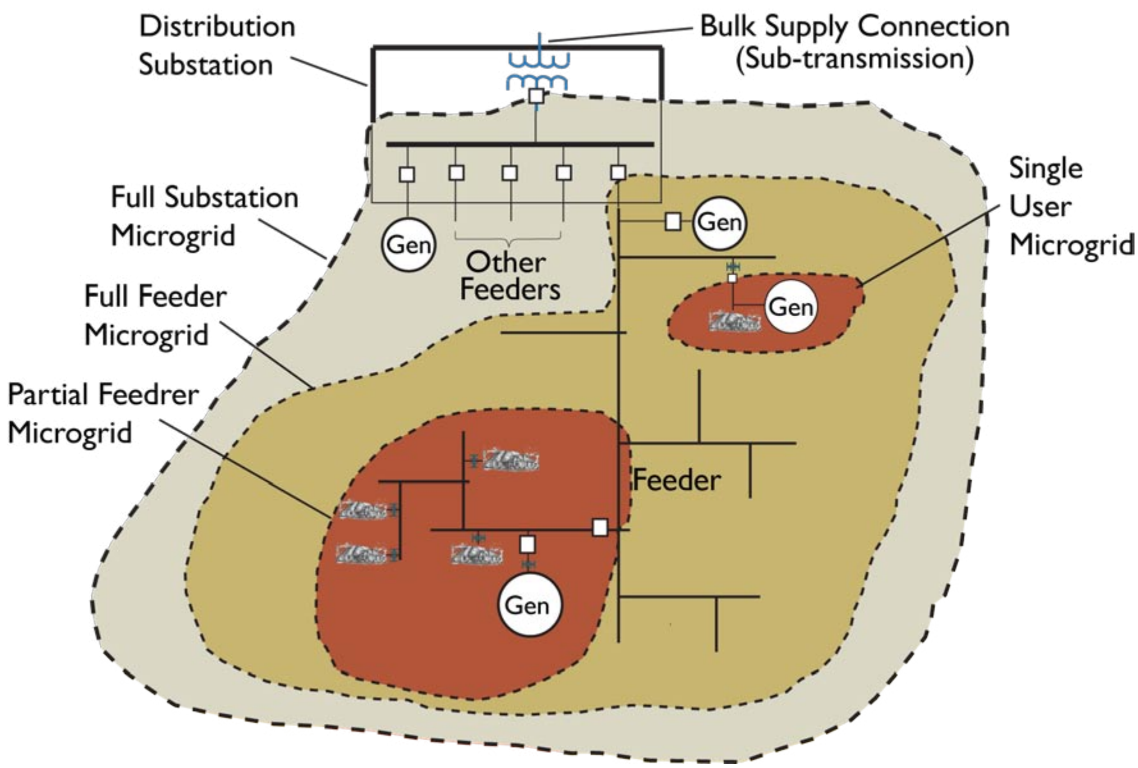

Figure 177. Example of multi-tiered microgrid structure.[370]

14.4.1 Distribution System

Within a microgrid, the individual tiers can be connected with looped transmission frameworks in a building-block manner. Each block (tier) will interconnect the DERs, load points (e.g., buildings), and energy storage devices within the tier and connect them to the next higher tier. Once the tiers are fully integrated, they are usually connected through feeder lines to a central supply point with the local power grid. Advanced control systems are used to regulate the flow of electricity between the tiers as well as close off the connection with a higher tier in the event of a reduction or complete loss of power. Based on the application, the supply point can be as big as a distribution substation (4 kV to 34 kV) and as small as a diesel generator.[371]

14.4.2 Distributed Energy Resources

Distributed energy resources are decentralized power sources used to provide electricity to specific areas of the microgrid. In current microgrid constructs, DERs rely on renewable and nonrenewable energy sources, such as wind turbines, solar cells, fuel cells, microturbines, reciprocating engines (diesel generators), combustion turbines, and cogeneration systems, to provide a reliable source of electricity to the individual grid tier.[372] This is an area where renewable energy sources can have the greatest positive impact on the DoD's efforts to reduce dependence on electricity from nonrenewable sources. Most microgrids to date employ nonrenewable sources (e.g., diesel generators, fuel cells, combustion turbines) as the primary power source and use renewable energy sources to augment the primary power source and provide emergency power if the primary system fails. However, the advances in renewable energy efficiency present them as viable primary energy sources, similar to how microgrids are employed in forward deployed areas.

14.4.3 Energy Storage

Within a microgrid's power distribution system, electricity is stored in batteries near the load source (e.g., building or installation) and near the DER. These batteries provide stability and additional capacity to the microgrid when there is a fluctuation in electricity provided from the local utility. The energy storage systems within each microgrid tier are structured to meet the power needs of each tier given the event of a DER failure. Energy storage systems can be electrochemical, thermal, mechanical, and electromagnetic. More information on the types of energy storage technologies employed in microgrids can be found in *Chapter 13*. An example of a microgrid concept for the DoD is presented in Figure 178.

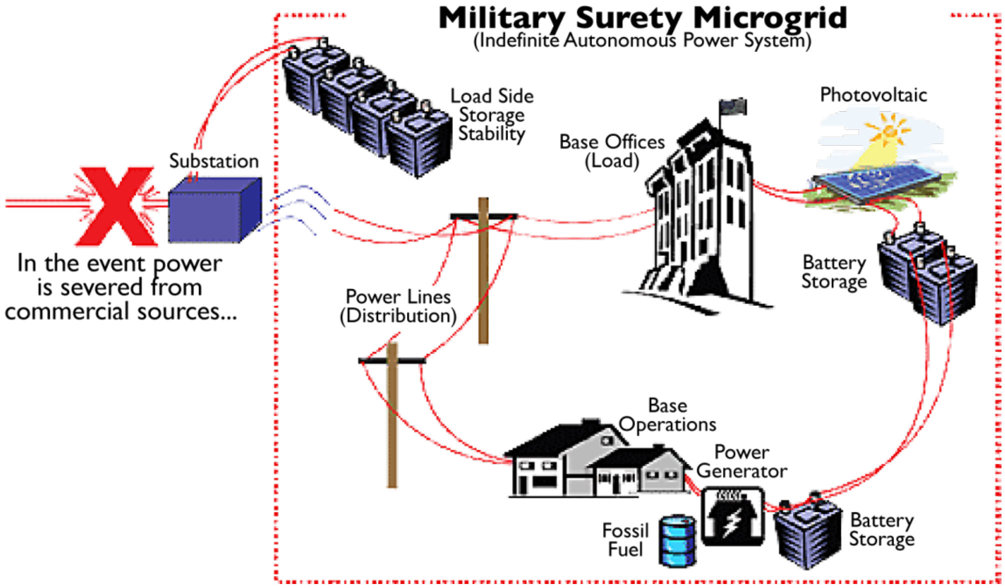

Figure 178. DoD microgrid concept.[373]

14.4.4 DoD Microgrid Projects

Microgrids that employ renewable and nonrenewable energy sources in tandem have been successful in small applications in forward deployed areas. The DoD has been assessing the potential for implementation within their facilities using a scaled up version of what is currently used in the field. Using a microgrid design (see Figure 178) developed by the DOE for energy surety, several microgrid test sites are operational or in development at many DoD installations (see Table 59).

Table 59. DOE/DoD microgrid test sites.[374]

Service	Location
Army	Fort Sill
	Fort Bliss
	Fort Carson
	Fort Belvoir
	Fort Devens (99th Air Guard)
Navy/Marine Corps	Naval Surface Warfare Center – Indian Head
	Camp Smith
Air Force	Maxwell AFB
	Vandenburg AFB
	Kirtland AFB
	Schreiver AFB

The first Army energy surety microgrid test site at Fort Sill, OK, was constructed by the Army Corps of Engineers to demonstrate the viability of microgrids to ensure a reliable energy supply using mostly renewable energy on a larger scale. From this test site, the Army will be able to evaluate the ability of the microgrid design to efficiently link renewable and nonrenewable DERs. The DoD and DOE are also working on the development of a sample microgrid called the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS).[375] This sample microgrid takes the existing microgrid design developed by the DOE and places additional focus on the vulnerability of the microgrid to cyber attack. Starting out with small-scale microgrids similar to those currently used in forward deployed areas, the goal of the SPIDERS Joint Capability Technology Demonstration (JCTD) is to develop and demonstrate a large-scale microgrid design that can be implemented DoD-wide.[376] SPIDERS is also focused on the use of renewable energy with its design, further helping the DoD meet the renewable energy requirements set forth in the EISA.

PART V:

MAKING SMART DECISIONS

15 FINANCING AND CONTRACTING CONSIDERATIONS

In order for the DoD to achieve its goal of producing or procuring 25% of the facility energy it consumes from renewable resources by 2025 (see *Section 4.2.2*), the department must be aggressive and use a variety of production and procurement options that are available. It is not economically feasible to simply construct enough renewable energy power plants to support this objective. Thus, the DoD is using several procurement options as described in the following sections.

15.1 Power Purchase Agreement

The power purchase agreement is one of the most common mechanisms that are used to procure renewable energy in the private sector, and it has some significant advantages for the DoD. In such an agreement, the DoD can purchase renewable energy or power from a private entity that owns the renewable energy production facility. The facility can be existing or can be constructed; it can be located off-site or on Federal land. In some cases, the private entity will secure a long-term PPA that enables them to invest in the capital construction, operation, and maintenance of a new renewable power generation facility. The private entity will retain ownership of the constructed energy facility and equipment, while providing power to the purchaser at the agreed upon price. There are several advantages to PPAs and a few disadvantages as listed in Table 60.

Table 60. Advantages and disadvantages of PPAs.[377]

Advantages	Disadvantages
No capital costs	Capital and O&M costs rolled into price of electricity
Private entity eligible for tax incentives	Required to purchase power according to contract terms
No O&M Costs	Not much experience with PPAs in the DoD
Long-term price stability and predictability	May require site access by non-government entities
Minimal risk to DoD	Some transaction costs
Improved energy security	Must coordinate delivery issues with local utility provider

PPA projects that are located on Federal land are eligible for double credit toward renewable energy goals (see *Section 4.2.1.6*). Figure 179 illustrates an example of the participants and their respective roles that may be involved in a PPA.

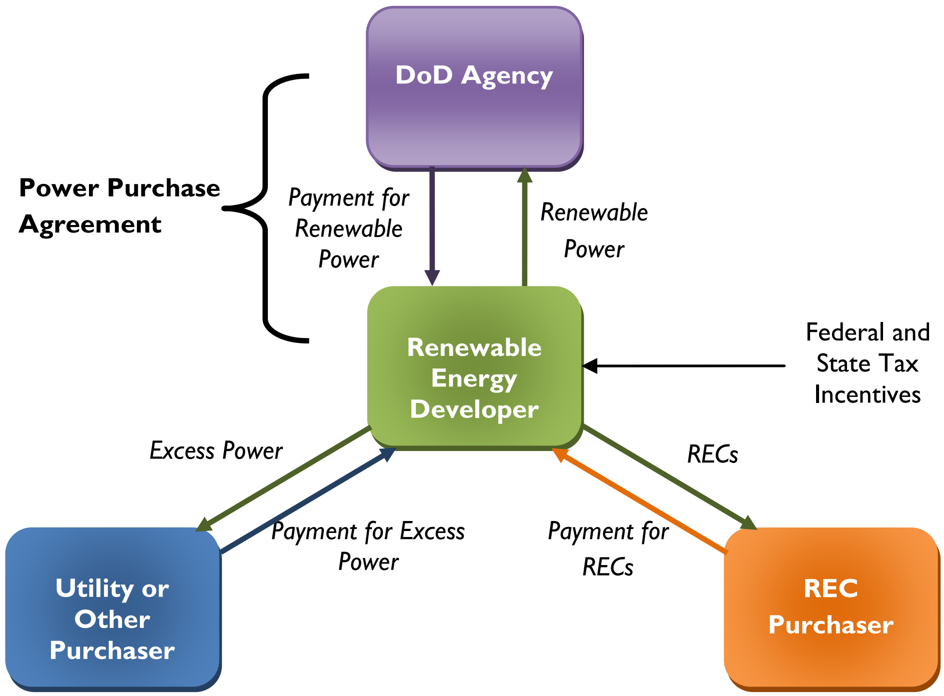

Figure 179. Example of a PPA and potential participants.[377]

Examples of DoD PPAs include the Fort Carson (see *Section 8.7.1*) and Nellis AFB (see *Section 8.7.2*) solar arrays. The Nellis PPA involved an indefinite length PPA with a one year termination clause. It also leased the land to the renewable developer for 20 years, and allowed RECs to be sold to the local utility. The Fort Carson PPA involved a 17 year contract with a 3 year option. It also leased the land to the renewable developer for 20 years and allowed RECs to be sold to the local utility.[377]

There are three states in which solar PV PPAs are not permitted due to a state or other legislative barrier, and at least 18 states in which these PPAs are authorized or being used. These are listed in Table 61. For the states not listed, the status of PPA authorization is not known.

Table 61. List of states where solar PV PPAs are authorized or not permitted.[378]

Authorized or In Use	Not Currently Permitted
Arizona (limited to certain sectors)	Florida
California	Georgia
Colorado	North Carolina
Connecticut	
Hawaii	
Illinois	
Maryland	
Massachusetts	
Michigan	
Nevada	
New Jersey	
New Mexico	
New York	
Ohio	
Oregon	
Pennsylvania	
Utah (limited to certain sectors)	
Virginia	

The Federal Energy Management Program offers resources to aid the evaluation, planning, and implementation of PPAs, including a step-by-step walkthrough of considerations and milestones for PPAs. Table 62 lists several of these resources.

Table 62. Resources for PPA information.

Resource	Where To Find It
Detailed PPA Presentation	http://www1.eere.energy.gov/femp/pdfs/afo_ppa_pres.pdf
On-Demand Training	http://apps1.eere.energy.gov/femp/training/course_detail_ondemand.cfm/CourseId=44
Sample PPA Documents	http://www1.eere.energy.gov/femp/financing/ppa_sampledocs.html
Case Study	http://www1.eere.energy.gov/femp/pdfs/pfs_mesatoparray.pdf

15.2 Utility Energy Service Contract

The utility energy service contract allows the DoD to implement facility energy improvement projects with minimal initial or long-term investment. These improvements may include energy efficiency, renewable energy, or water efficiency projects. Under a UESC, the utility provider to a DoD site covers the capital costs of the project and is repaid through energy savings that are attained after commissioning until the contract end-date. After the contract end-date the DoD realizes the cost avoidance from the energy project. UESCs can be used in conjunction with appropriations or without any appropriations. Figure 180 provides an example of how cost savings can be achieved through a UESC. Table 63 lists some of the advantages and disadvantages of a UESC.

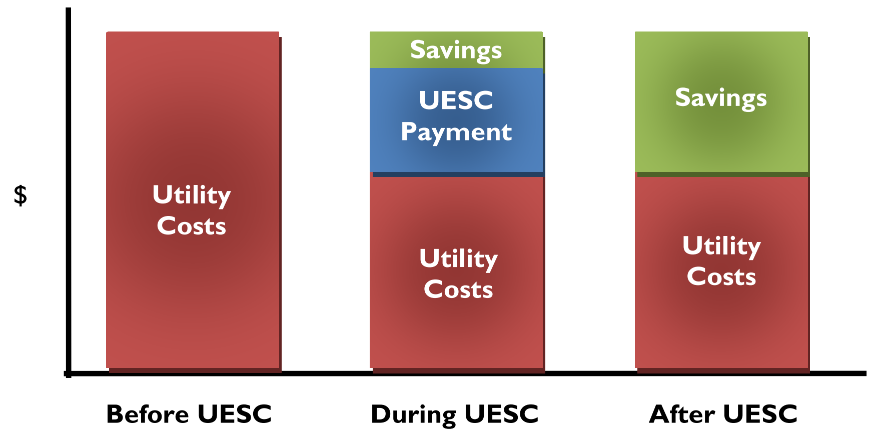

Figure 180. Illustration of UESC financing and cost avoidance through energy savings projects.[379]

Table 63. Advantages and disadvantages of a UESC.

Advantages	Disadvantages
No capital costs	Not all utilities participate
Minimal net cost	Risk to DoD for under-performance of project
Streamlined procurement process	Utility experience with specific projects may vary
May use in conjunction with Congressional appropriations	
Renewable energy or energy efficiency projects	
Project scale can vary substantially	
Multiple projects can be rolled into one UESC	

There is more experience with UESCs than PPAs, and as such, there are many resources available, including case studies, lessons learned, a working group, and other publications. Some of these resources are listed in Table 64.

Table 64. Resources for UESC information.

Resource	Where To Find It
UESC Enabling Documents	http://www1.eere.energy.gov/femp/pdfs/uesc_enabling_documents09.pdf
Types of UESCs	http://www1.eere.energy.gov/femp/financing/uescs_types.html
Federal Utility Partnership Working Group	http://www1.eere.energy.gov/femp/financing/uescs_fupwg.html
Model Agreement (DoD) and Explanation	http://www1.eere.energy.gov/femp/pdfs/modelagreement.pdf http://www1.eere.energy.gov/femp/pdfs/civexplan.pdf
Lessons Learned	http://www1.eere.energy.gov/femp/pdfs/uescs_lessons_learned.pdf
Case Studies	http://www1.eere.energy.gov/femp/financing/uesc_case_studies.html

15.3 Energy Savings Performance Contract

An energy savings performance contract is similar to a UESC, except that an energy service company is involved. The ESCO performs an energy audit and identifies energy savings projects. The ESPC allows the DoD to implement such projects without capital costs or appropriation funding. The ESCO facilitates financing of the project and is repaid through utility savings. ESPCs may involve energy efficiency, renewable energy, or water conservation projects.

The ESCO designs and constructs or installs the energy project; it also guarantees that the savings from the project will sufficiently cover the costs over the term of the contract. Energy savings are measured and verified annually. At the contract end-date, any further cost savings go to the DoD component. Contracts up to 25 years are allowed. (The basic concept of the UESC as illustrated in Figure 180 applies to the ESPC; the primary difference is the use of an ESPC instead of the local utility.)

The DOE administers indefinite-delivery, indefinite quantity (IDIQ) ESPCs that are set up to facilitate energy projects at any Federally-owned facility in the world. This allows for a very streamlined and efficient method for implementing an ESPC project. Several advantages and disadvantages are listed in Table 65.

Table 65. Advantages and disadvantages of ESPCs.[377, 380]

Advantages	Disadvantages
No capital costs	ESCO must own equipment/plant to be eligible for tax incentives
No Congressional appropriations required	Not amenable to fixed price contracts due to energy variables
Up to 25 year contract length – good for renewable projects	Complex contracting mechanism
Guaranteed performance	Long-term contracts require more effort up-front
O&M costs can be included in contract	Must own facility (leased facilities not eligible)
No DoD O&M personnel required	
Allows for sale of excess energy	
Well-established project implementation process	

Similar to UESCs, but unlike PPAs, there is significant government and some DoD experience with ESPCs. The DOE offers numerous resources for facilitating ESPCs. Some of these are listed in Table 66.

Table 66. Resources for ESPC information.

Resource	Where To Find It
ESCO Guides	http://www1.eere.energy.gov/femp/financing/espcs_resources.html
ESCOs with DOE IDIQ Contracts	http://www1.eere.energy.gov/femp/financing/espcs_doeescos.html
Qualified ESCOs	http://www1.eere.energy.gov/femp/pdfs/doe_ql.pdf
Case Studies	http://www1.eere.energy.gov/femp/financing/espcs_casestudies.html
Training	http://www1.eere.energy.gov/femp/financing/espcs_training.html

15.4 Enhanced Use Lease

The enhanced use lease is an administrative mechanism that enables DoD components to capitalize on underutilized, non-excess real property assets (e.g., land, unused buildings, etc.), by leasing the assets to private entities. The leased property can be used for various purposes including the following:

- Office space, aircraft and hangar facilities
- Warehouses and industrial facilities
- Laboratories and R&D facilities
- Medical facilities
- Energy projects
- Hotels and temporary lodging

According to USC Title 10 Section 2667, the DoD has the authority to enter into EULs and retain leasing proceeds. More specifically, it has the authority to use proceeds from EULs without further congressional action.[381] For real property to be eligible for lease, it must:

- Be under control of the Secretary of the respective Service department
- Not be needed for public use during the lease period
- Not be excess property (i.e., property that is not required to meet the agency's needs or responsibilities).

Essentially, this means that for the real property asset to be eligible, it is not anticipated that it will be needed during the lease period, but the Service may need it at some time during the future or needs to retain ownership of the asset for a mission-related purpose.[382]

There are additional requirements that relate to the terms of the lease. Essentially, the lease requires invocation of a fair market value, must be competed, and must be reported to Congress among other requirements. DoD components can receive cash or in-kind consideration for compensation on leased properties. Types of in-kind consideration that may be accepted include:

- Maintenance, repair, improvement, or restoration of facilities
- Construction of new facilities
- Provision of facilities
- Provision of payment of utility services
- Provision of real property maintenance services
- Provision of other appropriate services to occur on leased property

Energy EULs recently have been growing in popularity since they provide a way to implement renewable energy projects on underutilized DoD real property. Each military Service has a component that facilitates and manages EULs: the Air Force Real Property Agency; Army Corps of Engineers, Baltimore District; and the Naval Facilities Engineering Command. Examples of energy projects include:

- Solar
- Wind
- Biomass

- Geothermal
- Coal Gasification
- Cogeneration
- Central Utility Plants

The major disadvantage to the energy EUL is that the energy generated is not necessarily for use by the military base, and thus may not be credited toward the renewable energy goal. This is because the developer is paying the DoD for use of the land. For their energy project to be profitable, they must be able to recoup the cost of their lease as well as any other capital or development costs by selling the energy to an external source. However, a EUL-PPA hybrid agreement could be established, such that the military base can also take advantage of the energy generation. Examples of in-kind consideration that can help meet energy goals include:

- Development of energy infrastructure for on-base use
- Free energy from the project
- Energy grid modernization
- Power for the DoD site during grid outages

Another way to enable EULs to contribute toward DoD energy goals is to reinvest the compensation received on the lease in energy projects for the installation. Some of the advantages and disadvantages of energy EULs are listed in Table 67.

Table 67. Advantages and disadvantages of EULs.

Advantages	Disadvantages
Compensation for underutilized assets	Energy is not necessarily used by military site (i.e., does not count toward goals)
Project size limited only by asset size and market demand	
Encourages development of energy infrastructure	
Compensation can be reinvested for base energy projects	

15.5 Summary of Energy Project Contracting and Financing Options

Table 68 presents a comparison of the various contracting options available to the DoD for energy projects. The comparison is notional and is not meant to be comprehensive, however, it is intended to be a quick reference tool to compare the options.

Table 68. Comparison of contracting options.[377, 383]

	UESC	ESPC	PPA	EUL (Energy)
Description	Utility finances and implements energy project at DoD facility; DoD pays for project out of resultant energy/utility savings	ESCO develops, constructs/installs, and finances energy project at DoD facility; DoD pays for project out of resultant energy/utility savings	Developer implements energy project on DoD property; developer is repaid by DoD purchase of energy generated over period of agreement	DoD can lease non-excess, underutilized real property for the purpose of energy projects and is compensated with cash or in-kind consideration
Authorization	42 USC 8256, 10 USC 2913, 10 USC 2855 48 CFR 41 48 CFR 16	42 USC 8287, 10 CFR 436	10 USC 2922a FAR Part 41	10 USC 2667
Period of Performance	Up to 25 years	Up to 25 years	Up to 30 years (with Secretary of Defense approval)	Varies
Competition	Not required, sole source to utility, utility can compete subcontracts	Required	May be required	Required
Contracting Party	Utility	ESCO	Developer or Utility	Developer
Guaranteed Performance	Negotiable	Yes	No, but developer has inherent incentive to maximize performance	Negotiable
Measurement and Verification	M&V and annual audit negotiable	M&V and annual audit required	None required	None required
Operations and Maintenance	Negotiable	Typically included	Typically included	
Ownership	DoD typically retains ownership	DoD typically retains ownership; ESCO may retain ownership to receive tax incentives	Developer retains ownership	DoD retains ownership of real property asset
Potential Combinations	PPA, EUL	PPA, EUL	UESC, ESPC, EUL (PPA requires a land use agreement)	UESC, ESPC, PPA
Financing Combinations	May be combined with appropriations, may use financing for paying utility bills	May be combined with appropriations	May be combined with appropriations	None

15.6 Renewable Energy Certificates

When there are no practical options to directly purchase or produce renewable energy, an organization can purchase renewable energy certificates, which are sometimes referred to as renewable energy credits. A REC represents one MWh of energy generated from a renewable resource, which is provided to the power grid. The total RECs purchased does not necessarily need to be equivalent with the amount of power used by the purchaser.[384]

The REC system works when a renewable power generation plant provides electricity directly to the common power grid. The renewable power provider sells a REC for each MWh that it produces. The purchaser of the REC can then claim the use of an amount of power from renewable resources based on the number of RECs purchased. This process is depicted in Figure 181. Since the renewable power is provided to the common grid, once a REC is sold, no other entity can claim the environmental benefits from the renewable power, except for the REC purchaser.

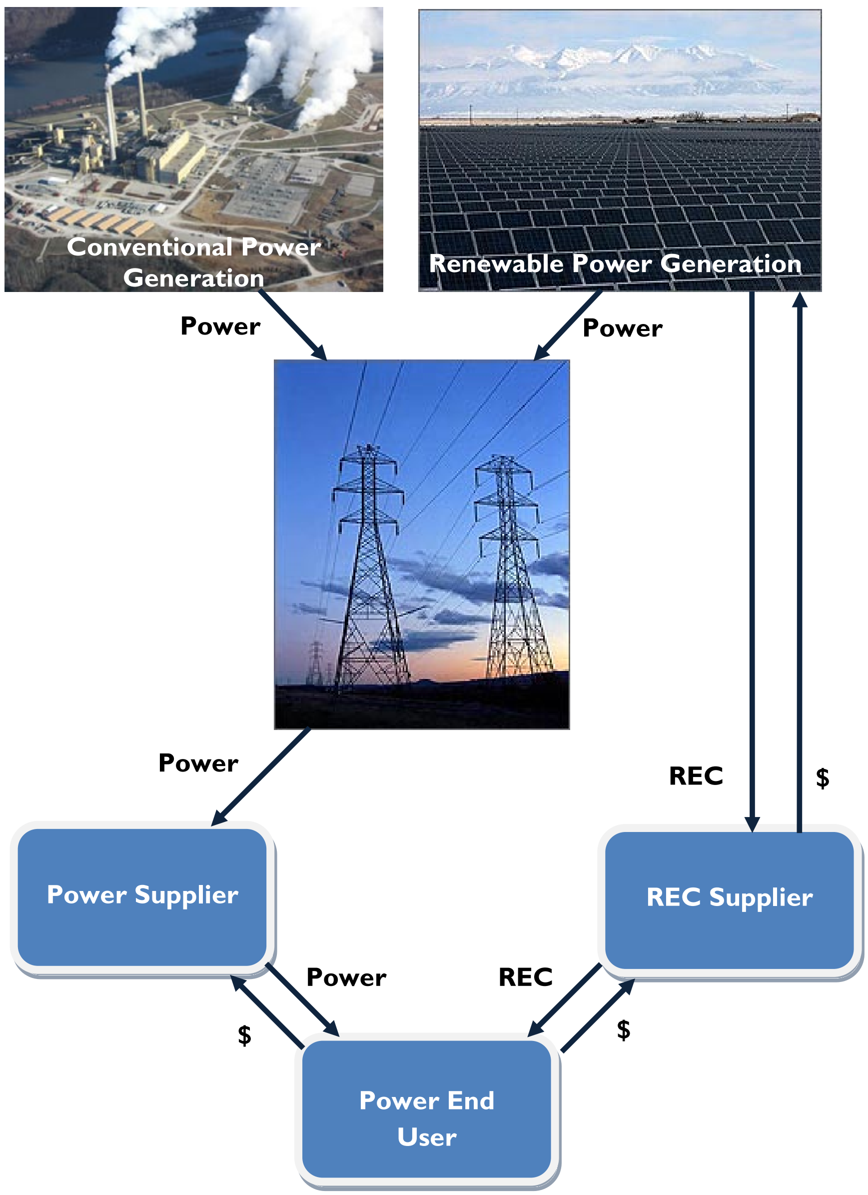

Figure 181. Illustration of the REC system.[384, 385, 386, 387]

The renewable energy certificate typically includes an identification number, the type of renewable energy produced, the date when it was produced, the date when the generation plant was built, the location of the plant, and the amount of GHG emissions if any were produced. Once the REC owner makes an environmental claim based on the identification number of the REC, that REC can no longer be sold and the REC is essentially retired.[388]

15.7 Impact of Energy Prices

While some forms of energy have greater price volatility than others, almost all forms have some variability in pricing. Nuclear and hydroelectric have the least amount of fluctuation in pricing. Some of the factors that influence price volatility include, supply, demand, new legislation, and technological developments.

15.7.1 Effect of Crude Oil Prices on Biofuel Viability

The price of crude oil has a direct and almost immediate impact on the viability of biofuels. In general, when crude oil prices are low, biofuels are less viable because of their relatively higher cost. However, when crude oil prices are high, biofuels become much more economical.

15.7.2 Impact of Natural Gas Stability

Over the long-term, the supply of natural gas is expected to be stable, and thus the price is also expected to be relatively stable. This stability favors natural gas over coal for new power plants, partly because of the uncertainty regarding the potential for stricter regulations on coal mining and combustion. Furthermore, combined-cycle power plants are more favorable than nuclear plants, in lieu of the natural gas stability. However, since natural gas is a fossil fuel, it may face expensive requirements for carbon capture and storage.[389]

16 ECONOMIC ANALYSIS OF ENERGY PROJECTS

As alternative energy sources are identified for potential use at DoD installations, the economic impact of employing these sources must be assessed. Using life cycle cost (LCC) tools, DoD installation managers can assess the present and future costs associated with the implementation of an alternative energy source. Life cycle costs are defined as:

> The sum of present values of investment costs, capital costs, installation costs, energy costs, operating costs, maintenance costs, and disposal costs over the life time of a project.[390]

Because LCC analysis looks at all costs from construction to disposal, LCC analysis is the standard method of evaluation for all Federal Energy Management Program energy-saving investments.[391] These results from an analysis of LCC are even more significant in cases where several alternatives may meet the required performance level but other variable costs might be different.

16.1 Guidance for Life Cycle Cost Analysis

Understanding the criteria that the federal government looks at when assessing the financial risk associated with energy related projects is of vital importance as LCC analysis is required by federal law for all energy-related projects. The methodologies and procedures for LCC analysis of energy related projects in federal buildings are defined in Title X of the Code of Federal Regulations, Part 436 (10 CFR 436), Subpart A. To provide further guidance on how to perform all aspects of LCC analysis for federal energy projects, the National Institute of Standards and Technology (NIST) developed the *Life-Cycle Costing Manual for the Federal Energy Management Program* (also known as NIST Handbook 135). An annual supplement to NIST Handbook 135 entitled: *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis* is published every April, updating the real discount rate and corresponding discount factors for all energy and non-energy costs associated with LCC analysis. Additional guidance on LCC analysis of facility energy projects can be found in *P-442: Economic Analysis Handbook*, developed by the Naval Facilities Engineering Command.

In addition, the Office of Management and Budget has published Circular A-94: *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* to provide further guidance on how to perform LCC analysis. The rules in OMB Circular A-94 apply only to non-energy, non-fuel related analysis, however they still provide a good background on how to perform generic life cycle cost analysis.

16.2 Performing Life Cycle Cost Analysis

When choosing between the current state and any alternatives in an energy-saving project, the present value[xcviii] of life cycle costs is calculated. The alternative that is the most cost effective is usually chosen. According to 10 CFR 436 Subpart A, a project is deemed cost effective when the candidate project meets the evaluation criteria contained in Table 69.[391]

[xcviii] All costs in LCC analysis must be calculated in the present value

Table 69. Important criteria for LCC analysis under FEMP.

Criteria	Description
Evaluation Method	Life cycle cost analysis
Discounting Approach	Present value from base date
Cost Measurement Basis	Constant dollars from base date
Cash Flows	End of year or when incurred
Evaluation Criteria	Lowest LCC Greatest net savings Highest savings-to-investment ratio (or SIR >1) Internal rate of return > FEMP discount rate
Base Date	Beginning of study period
Service Date	Date when a system goes into operation
Study Period	Planning/construction period added to maximum service life[xcix]
Discount Rate	Determined annually by DOE
Energy Prices	Local energy prices at site used to calculate energy costs by energy type
Cost Escalation	DOE-projected differential

16.2.1 Calculating Life Cycle Costs

When performing LCC analysis, it is imperative that all aspects of the project are accounted for (see Table 69). This goes beyond the basic financial information. Project constraints, non-monetary considerations (environmental impact, available resources, available energy sources), and operational assumptions need to be documented and their impact on any project costs must be assessed. In addition, the base and service dates for the project timeline must be properly defined.

16.2.1.1 Base Date and Service Date

The base date is the first day of the project and is more importantly, the point in time to which all costs related to the project must be discounted.[390] Setting the incorrect base date can lead to financial inaccuracy as the incorrect discount rates can potentially be applied to their respective project costs. The service date is the date when a system goes into operation.

16.2.1.2 Present Value Factor

To bring all future costs being considered during an LCC analysis to the present value, each of the costs are multiplied by a present value factor. The two types of present value factors used in LCC analysis are the uniform present value (UPV) and single present value (SPV) factor. A UPV factor is used to bring any recurring costs into the present value without having to first calculate the future sum of the projected costs. All that is needed instead is the first annual amount and the relevant UPV factor.**Error! Bookmark not defined.** Single present value factors are used to bring non-recurring future costs to the present value. UPV and SPV factors are mostly used for non-fuel related costs. In addition the UPV's and SPVs, there is a modified UPV that takes fuel price escalation and inflation rates into account[c].

When calculating energy-related recurring costs, there are two sets of modified UPV factors that can be used, one that is calculated using discount rates (usually 3.0%) set by the DOE, and the other using discount rates (1.9%, 2.7%) set by the Office of Management and Budget. The DOE-based modified UPV

[xcix] Recommended study period for renewable energy projects is 20 years.

[c] Further explanation and guidance of how and where to use certain types of UPVs and SPVs can be found in Part 1: Tables for Federal Life Cycle Analysis of the annual NIST publication *"Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis"* (NISTIR 85-3273-XX).

factor (FEMP UPV*) should be used for all DOE/FEMP LCC analyses[ci] and the OMB modified UPV factor is be used to calculate energy costs for efforts where energy conservation is not the main focus.

16.2.1.3 Life Cycle Cost Equation

The basic life cycle cost equation is provided in Equation 12.

$$LCC = \sum_{y=0}^{N} \frac{C_y}{(1+d)^y}$$

Equation 12

Where

C_y – sum of all costs that occur in year y

N – number of years in study period

d – discount rate for adjusting cash flows to present value[391]

This formula, however, requires the costs for each year to be summed. When applying the LCC formula to building-related energy efforts, the formula in Equation 12 can be simplified as shown in Equation 13.[392]

$$LCC = I + O\&M + E + R - S$$

Equation 13

Where

I – investment cost

O&M – operations and maintenance costs

E – energy costs

R – replacement costs

S – salvage value of equipment

16.2.1.3.1 Investment Costs

Investment costs include any and all costs related to the acquisition and installation of equipment used in an energy savings project. This includes planning costs, design costs, construction costs, and installation costs. However, investment costs do not include sunk costs as sunk costs were committed to or incurred before this effort was started.[391]

16.2.1.3.2 Operations and Maintenance Costs

Operations and maintenance costs are any material and labor costs incurred during regular operation and maintenance of equipment used in the production of energy from renewable resources.[392] O&M costs do not reflect any costs incurred in the acquisition of energy sources (electricity, fuel, oil) for power as those costs are tied to overall energy costs.

16.2.1.3.3 Energy Costs

The calculation of potential energy costs is one of the most difficult parts to execute when performing an LCC analysis, because energy costs are based on a significant amount of assumptions, considerations, escalation rates, and energy rates that have to be projected up to 25 years[cii] in the future. 10 CFR 436 requires several considerations when calculating energy costs, including:

[ci] DoD alternative energy related LCC analyses fall under this category

[cii] 10 CFR 436 mandates that the maximum study period for LCC analysis of an energy project is 25 years

- Using local energy pricing schedules
- Using DOE energy price escalation rates unless they have been provided by the local utility company
- Quantifying the amount of energy used or saved by energy type instead of using resource energy data.[393]

In addition, summer and winter energy rate changes, time-of-use energy rates, block rate schedules, and energy demand rates must be factored into the estimation of an annual energy cost.[391] Further guidance on these considerations can be found in Section 4.6.1: "Estimating Energy Costs" of *NIST Handbook 135*.

16.2.1.3.4 Replacement Costs and Salvage Value

Replacement costs are any future costs that are incurred to replace the components of or an entire system that is used in an energy-saving project.[392] The salvage value refers to value of any component or system employed in an energy-savings project at the end of the study period.

16.2.1.4 Example 1: Comparing two renewable energy power source options

A DoD installation located in the northeastern US is looking at transitioning to a biomass-fed steam boiler system to generate electricity (3.75 GWh) throughout several facilities. They are presented with the first option (Project X), which is a steam system that contains two boilers, each with 10,000 lb/hr steam capacity. The second option (Project Y) is to install a larger boiler that contains a 25,000 lb/hr steam capacity. For this example, Project X will be considered at the base case and Project Y will be the alternative. Project X has an initial investment cost of $1,500,000, with annual operations and maintenance costs of $270,000, annual energy costs of $300,000 (3,750,000 kWh @ $0.08/kWh). There will be an additional $50,000 cost for scheduled equipment replacement during years 5, 10, and 15 of operation. Once the 20 year study period has ended, the assets in Project X will have a salvage value of $200,000. Project Y has an initial investment cost of $1,200,000, with annual operations and maintenance costs of $200,000, annual energy costs of $250,000 (3,750,000 kWh @ $0.067/kWh). There will be an additional $100,000 cost for scheduled equipment replacement during years 7 and 14 of operation. At the end of the study period, the assets in Project Y will have a salvage value of $110,000. The life cycle costs for Project X and Y are shown in Table 70 and Table 71.

Table 70. Life cycle costs for Project X.

	Base Cost	Year of Occurrence	Discount Factor	Present Value
Initial Investment	$1,500,000	Base Date	N/A	$1,500,000
O&M Costs	$270,000	Annual	14.88[ciii]	$4,017,600
Energy Costs	$300,000	Annual	15.62[civ]	$4,686,000
Replacement Costs	$75,000	5	0.863[cv]	$64,725
		10	0.744	$55,800
		15	0.642	$48,150
Salvage Value	$200,000	20	0.554[cv]	$110,800
			Total	**$10,483,075**

Table 71. Life cycle costs for Project Y.

[ciii] Uniform Present Value (UPV) Factor based on 3.0% DOE Discount Rate
[civ] FEMP Modified Uniform Present Value (FEMP UPV) for electricity in the northeast (Census Region 1)
[cv] Single Present Value (SPV) Factor based on 3.0% DOE Discount Rate

	Base Cost	Year of Occurrence	Discount Factor	Present Value
Initial Investment	$1,300,000	Base Date	N/A	$1,300,000
Operations/Maintenance	$200,000	Annual	14.88	$2,976,000
Energy Costs	$250,000	Annual	13.41	$3,352,500
Replacement Costs	$100,000	7	0.813	$81,300
		14	0.661	$66,100
Salvage Value	$110,000	20	0.554	$60,940
			Total	$7,836,840

Based on the LCC calculations, using the steam system that contains the larger boiler is the more cost-effective option as it has a significantly lower overall life cycle cost.

16.2.2 Calculating Additional Analysis Criteria

Certain federal funding sources have different addition criteria requirements that must be met to approve funding for energy-improvement projects. For example, in cases where several project alternatives are competing for limited funding, the FEMP LCC rules set forth in 10 CFR 436 require the use of savings-to-investment Ratio (SIR) or adjusted internal rate of return (AIRR) as a method of ranking each alternative. In addition, energy savings performance contracts require the calculation of a simple payback period as an additional measure of economic performance in project assessments. When evaluating mutually exclusive alternatives, net savings (NS) can be calculated and used interchangeably with data calculated using standard LCC methods. A detailed breakout of how these criteria are used when assessing prospective renewable energy projects can be found in Table 72.

Table 72. Economic evaluation criteria for renewable energy projects.

Decision Type	LCC	NS	SIR	AIRR	Payback
Accept/Reject	Yes (Lowest LCC)	Yes (NS > 0)	Yes (SIR > 1)	Yes (AIRR > Discount Rate)	No
System Selection	Yes (Lowest LCC)	Yes (Highest NS)	No	No	No
Project Priority	No	No	Yes	Yes	No

16.2.2.1 Net Savings

Net savings is a measurement of the variation between the LCC of the current state and an alternative option over a set period of time. This method is very important in cases where the benefits of greatest concern are overall cost savings. The basic NS formula is presented in Equation 14

$$NS = LCC_{current} - LCC_{alternative}$$ **Equation 14**

Once individual cost variables are added, the equation becomes as shown in Equation 15

$$NS = [\Delta E + \Delta O\&M] - [\Delta I_0 + \Delta R - \Delta S]$$ **Equation 15**

Where:

ΔE – Energy cost savings between the current state and the alternative

$\Delta O\&M$ – Difference in operations and maintenance costs

ΔI_0 – Additional investment cost relative to the current state

ΔR – Difference in replacement costs

ΔS – Difference in salvage value

In Example 1, Project X was shown to have a total LCC of $10,483,075 and Project Y had a total LCC of $7,836,840. Using Equation 15, the NS can be calculated for this example. The results are presented in Table 73.[391]

Table 73. Net savings calculation for example 1.

$LCC_{Current}$	$LCC_{Alternative}$	Net Savings
$10,483,075	$7,836,840	$2,646,235

When comparing the alternative to the current state, the calculated NS in Table 73 is found to be significantly greater than zero, which infers that Project Y is more cost effective than Project X. It should be noted that the same conclusion was made by calculating life cycle costs and net savings. In this manner, NS or LCC calculations can be used as both will return the same result when comparing the current state to alternate efforts.[391] If multiple alternatives are being compared against the current state, the option with the highest NS (or lowest LCC value) is usually the project that is selected.

16.2.2.1.1 Savings to Investment Ratio

When choosing between similar cost-effective renewable energy alternatives, additional measures of assessing these alternatives are required. One such method of ranking alternatives is to compare the total saving versus the total investment[cvi]. This method is referred to as the savings-to-investment ratio. Any renewable energy project that has a calculated SIR of over 1.0 is usually considered to be cost-effective in comparison to the current state. However, the current state and alternative must have the same base date, study period, and discount rate or else they cannot be compared accurately.[391]

The generic formula for SIR is presented in Equation 16. Table 74 contains the calculated differences between the LCC factors of Project X and Project Y in Example 1. Using these values, the SIR can be calculated using Equation 16.[391]

$$SIR = \frac{[\Delta E + \Delta O \& M]}{[\Delta I_0 + \Delta R - \Delta S]}$$ **Equation 16**

Table 74. Savings to investment information for example 1.

Unit	Difference
ΔE	$1,333,500
ΔO&M	$1,041,600
ΔI	$200,000
ΔR	$21,275
ΔS	$49,860

The resultant SIR represents an average return on investment of $13.86 for every $1 invested above and beyond the required minimum return on investment set forth by the DOE discount rate (3.0% for this example).

16.2.2.2 Adjusted Internal Rate of Return

As stated earlier, some projects require the calculation of additional measures of relative cost-effectiveness. Similar to the minimum acceptable rate of return (MARR), the adjusted internal rate of

[cvi] SIR is required as part of 10 CFR 436

return measures the percent yield of an investment over a set period of time. AIRR is a useful measure of ranking independent investment alternatives. When comparing AIRR and MARR, if the AIRR is greater than the MARR, then the investment is considered to be cost effective in comparison to the current state. Conversely, if the MARR is greater than the AIRR, then the investment is not cost effective. In most LCC analyses, the MARR value is the FEMP discount rate. The simple formula for calculating AIRR is presented in Equation 17.

$$AIRR = (1+r)(SIR)^{\frac{1}{N}} - 1$$

Equation 17

Where

R – MARR

Using the SIR calculated in the previous section and additional information provided in the LCC section, we calculate the AIRR of Project Y (using Equation 17) to be 17.47 %.[391]

In this example, Project Y had the lowest LCC, an NS of over two million dollars, an SIR of 13.86:1, and an AIRR of over 17%, which suggests that Project Y was the more cost effective solution. However, it is important to note that the project with the lowest LCC will not always yield the highest SIR or AIRR when ranked against other alternatives. While LCC is the most important economic factor when deciding to accept or reject a renewable energy project because it does not need to be compared to a current state, SIR and AIRR require a current state of which their relative values are to be ranked. However, when comparing projects that are in competition for a limited funding source, SIR and AIRR are used to rank the respective projects (assuming they have low life cycle costs).

16.2.2.3 Payback Period

In addition to savings-to-investment ratio and adjusted internal rate of return, the amount of time required recoup investment costs is commonly used as a method to rank similar investment options. Referred to as Simple Payback (SPB) or Discounted Payback (DPB), these measures determine whether an investment will be able to pay for itself. If the calculated payback period is found to be less than the service life of the renewable energy project, then the project is thought to be cost effective. However, it is important to note that both SPB and DPB are relative values as they both are calculated in respect to the current state. When calculating SPB and DPB, the year, y, has to be found for which Equation 18 is true.

$$\sum_{t=1}^{y} \frac{[\Delta E_t + \Delta O\,\&\,M - R_t + S_t]}{(1+d)^t} \geq \Delta I_0$$

Equation 18

Where

ΔE_t – Energy cost savings in year t

$\Delta O\&M_t$ – difference in operations and maintenance costs in year t

ΔR_t – difference in replacement costs in year t

ΔS_t – difference in salvage/residual costs in year t

d – FEMP discount rate[cvii]

Both SPB and DPB can be calculated using Equation 19.[391] The difference between SPB and DPB is that SPB does not take discounted cash flows or price escalations into account when calculating the payback period. For this reason, SPB is the more popular method for calculating payback period as the

[cvii] When calculating a simple payback period, this value will be zero

calculations are simpler to perform. When calculating the payback period for a project with no one time operations/maintenance or replacement costs, SPB can be calculated using Equation 19.

$$SPB = \frac{\Delta I_0}{\left[\Delta E + \Delta(O \& M)\right]}$$ **Equation 19**

This method provides a good instrument for assessing projects that are already deemed as cost effective. However, DPB is the preferred method of calculating a payback period because it provides a more accurate estimate of the payback period.

16.2.3 Life Cycle Cost Calculation and Analysis Tools

Accurate evaluation of the cost-effectiveness of renewable energy projects can be very difficult. Given the wide range of renewable energy technologies that are available to the DoD, there are several different expenses that need to taken into account within the five larger cost categories (investment, energy, operations and maintenance, replacement, salvage). The DOE and NIST have developed several analysis tools and energy information databases to ensure accurate calculation of these costs. One such program, called the Building Life-Cycle Cost (BLCC) Program was designed specifically to calculate LCCs for federal, state, and local government facility energy reduction projects. BLCC contains several modules (see Table 75) to evaluate the cost-effectiveness of not only building-related (macro) energy projects, but system and component level (micro) energy and non-energy related projects.

Table 75. BLCC analysis modules.[394]

Module	Description
FEMP Analysis of Energy Project	Analyzes Energy conservation, water conservation, and renewable energy projects based on FEMP rules set forth in 10 CFR 436
Federal Analysis of Financed Projects	Analyzes federally funded energy projects funded via ESPC or UESC
Office of Management and Budget Analysis	Provides analysis for projects that are subject to OMB Circular A-94 for non-energy related federal construction efforts
MILCON Analysis for Energy Project	Analysis of energy/water saving or renewable energy project constructed by the DoD
MILCON Analysis for ECIP	Analysis for energy/water saving projects by the ECIP
MILCON Analysis for Non-Energy Project	Analysis of DoD construction projects that do not include energy/water saving efforts

Through the use of these modules, the BLCC program can employ the proper discount rates, price escalation rates, utility rates, and any other application-specific data that could. Since its development, BLCC has proven to be an useful tool in the evaluation of any and all costs and benefits associated with energy saving and renewable energy projects. In addition to calculating life cycle costs, the BLCC program also generates, net savings, savings-to-investment ratio, adjusted internal rate of return, and payback period data (see Figure 182).

Comparative Analysis Report

File

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$1,500	$3,000	-$1,500
Future Costs:			
Energy Consumption Costs	$13,647	$9,326	$4,322
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$0	$0
Recurring and Non-Recurring OM&R Costs	$746	$1,668	-$922
Capital Replacements	$446	$0	$446
Residual Value at End of Study Period	-$289	-$481	$193
Subtotal (for Future Cost Items)	$14,551	$10,512	$4,039
Total PV Life-Cycle Cost	$16,051	$13,512	$2,539

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	$3,400
- Increased Total Investment	$861
Net Savings	$2,539

Savings-to-Investment Ratio (SIR)

SIR = 3.95

Adjusted Internal Rate of Return

AIRR = 12.88%

Payback Period

Estimated Years to Payback (from beginning of Service Period)

Simple Payback occurs in year 6

Discounted Payback occurs in year 6

Figure 182. Sample report from BLCC program.

16.3 Case Study: Solar Water Heating System on US Coast Guard Base

The following is the summary of a case study in an April 2005 DOE Federal Energy Management Program report entitled *Guidance on Life-Cycle Cost Analysis Required by Executive Order 13123*.[395] The full case study can be found in Appendix B of the aforementioned report.

The US Coast Guard (USCG) wanted to assess the feasibility of installing a water heating system that employed solar energy to heat the water used in 280 residences on an installation in Hawaii. The current system, which employs electrical resistance to provide heat, requires 10% of the heater tanks to be replaced annually (starting one year from the base date). Instead of replacing the tanks with original equipment (OE), the USCG was looking into replacing the tanks with a solar-powered heating system that would be operational within one year. The overall investment cost for the solar-powered tanks is $1,000,000, with the USCG paying 25% of the cost upfront and financing the remaining amount over ten years through an energy services contract with a local utility company. The study period for this LCC analysis is 21 years (20 year study period + 1 year construction and implementation), with a discount rate of 4.8% (discounted from the end of each year), and an energy price of $0.05 per kWh. Additional LCC information for the current system and solar alternative can be found in Table 76 and Table 77.

Table 76. Life cycle cost information for existing heating system.

Description	Amount	Recurrence
Energy use	2.975 GWh	Annual
Initial Investment Costs	0	One Time
Replacement Costs (Year 6,11,16)	$23,750.00	One Time
Operations & Maintenance Costs*	$32,220.00	Annual

* Tank renewals begin after one year and end with 9 years left in the study period

Table 77. Life cycle cost information for solar water heating system.

Description	Amount	Recurrence
Energy use		
Before implementation	2,975,000 kWh	Annual
After Implementation	560,000 kWh	Annual
Initial Investment Costs	$250,000.00	One Time
Contract Costs	$114,306	Annually (10 years)
Replacement Costs (Total)	$313,980	
Year 11	$295,400	One Time
Year 16	$18,580	One Time
Operations & Maintenance Costs	$10,000	Annually
Contract Administrative Cost	$1,000	Annually (10 years)
Contract Oversight cost	$3,500	One Time

The information provided in Table 76 was entered into the BLCC software and the resultant life cycle cost for the current water heating system was estimated to be $2,704,931 over the study period.

Implementation of the solar water heating system resulted in an over 80% annual reduction in energy usage to provide a comparable amount of heated water. The life cycle cost for the solar alternative as calculated using the BLCC software was $2,004,931. The net savings between the current heating system and the solar alternative was $700,000 over the life of the project. Based on these LCC calculations and the reduction in energy consumption, the solar-powered water heaters were chosen over simply replacing the existing electric resistance water heaters. Additional economic decision factors (SIR, AIRR, payback period) could not be calculated for the solar alternative because part of the chosen alternative was funded through an energy services contract.

16.4 Case Study – Savannah River Cofiring Facility

The following is the summary of a case study in a June 2004 DOE Federal Energy Management Program Federal Technology Alert entitled *Biomass Cofiring in Coal-Fired Boilers*.[396] The full case study can be found in the aforementioned report.

The Savannah River Site (SRS) is a DOE facility for handling and processing nuclear materials located in South Carolina. Since its construction in the 1950's, SRS has been powered by a coal-fired steam plant. The existing coal fired steam plant used 11,145 tons of coal per year, at an annual cost of $550,000 per year. As a result of operations at SRS, over 300 tons of paper and cardboard were generated annually. This waste was either sent to a landfill or in the case on recently unclassified documents, was incinerated in a burn pit located at SRS. The annual cost of disposing the paper waste generated at SRS was over $160,000 per year. Additional current state costs can be found in Table 78.

Table 78. Current state costs at SRS.

Description	Amount	Recurrence
Coal Consumption	11,145 Tons	Annual
Paper Waste generated	350 Tons	Annual
Initial Investment Costs	$0	One Time
Energy Costs	$550,000	Annual
Landfill Costs	$77,280	Annual
Incinerator Costs	$83,050	Annual

In the early 2000s, the Site Facilities Department embarked on an effort to reduce coal consumption at SRS. This effort centered on the implementation of a system that co-fired a process engineered fuel (PEF) made of paper and woody biomass in addition to coal in the existing steam boilers. Through the use of PEF, the Site Facilities Department hoped to reduce coal consumption by 20% in addition to eliminating the costs associated with disposing of the paper waste. The 20% reduction in coal consumption would equate to $110,000 in cost avoidance in addition to the reducing potentially harmful emissions.

Table 79. Life cycle costs for co-fired plant at SRS.

Description	Amount	Recurrence
Coal Consumption	8,905 Tons	Annual
Initial Investment Costs	$850,000	One Time
Energy Costs	$438,000	Annual
PEF Processing Costs	$30,000	Annual
Landill Costs	$0	Annual
Incinerator Costs	$0	Annual

The life cycle costs detailed in Table 79 would save more than $1.1 million over ten years, returned an SIR of 2.3, and had an AIRR of more than 11%. In addition, the initial investment required to implement the co-fired plant at SRS could be paid back in less than four years. Based on these results and the calculated reduction in CO_2 and SO_2 emissions, the biomass co-fired plant was chosen for implementation instead of staying with the current system.

16.5 Levelized Cost of Energy

Levelized cost of energy, which is sometimes referred to as the levelized cost of electricity, is another method that can be used to assess the viability of an energy project. It is generally a good method for comparing two or more energy project alternatives since it takes into account the total costs of building and operating a system, time value of money, and the life of the system. Thus, it is particularly useful to compare different scales of energy production, operation times, and investment amounts.

Most basically the LCOE can be described by the formula shown in Equation 20.[397]

$$LCOE = \frac{Total\ Life\ Cycle\ Cost}{Total\ Lifetime\ Energy\ Production} \quad \text{Equation 20}$$

The LCOE has also been described as the value of each unit of energy produced to cover all costs associated with the project as well as a certain margin, typically profit.[398] For instance, each MWh of energy produced has a standard cost that when all units of energy produced over the lifetime of the plant are summed, the total is equal to the total life cycle cost. LCOE can be calculated using Equation 21.[399]

$$LCOE = \frac{LCC}{\sum_{n=1}^{N} \frac{Q_n}{(1+d)^n}}$$ **Equation 21**

Where

N – analysis period

n – year

Q_n – energy output or energy saved in year n

d – discount rate

The LCOE takes into account capital costs, fuel costs, fixed O&M costs, variable O&M costs, and financing costs, and assumes a utilization rate.[400] Deviations from the assumed fuel costs can significantly impact the actual levelized costs. Solar and wind power, however, typically do not involve fuel costs. The LCOE is also sensitive to variations in the input factors, such as discount rate, O&M costs, and anticipated life. An example of this sensitivity is shown in Table 80.

Table 80. Variability of LCOE for three Solar PV scenarios.[397]

	Case 1	Case 2	Case 3
Annual Degradation	1.0%	0.5%	0.3%
System Life	15	25	40
Annual O&M, $/kWh	$0.030	$0.010	$0.005
Discount Rate	9%	7%	5%
LCOE $/kWh	$0.23	$0.13	$0.09

Levelized costs of energy for various types of energy plants are displayed in Table 81. Since these values can vary depending on the region of implementation, Table 82 presents a range of levelized costs that account for the minimum and maximum estimated costs.

Table 81. Estimated average levelized costs of new plants entering service in 2016.[401]

Plant Type	Capacity Factor	Levelized Capital Cost	Fixed O&M	Variable O&M (Including Fuel)	Transmission Investment	Total System Levelized Cost
	$/MWh (2009)					
Conventional Coal	85	65.3	3.9	24.3	1.2	94.8
Advanced Coal	85	74.6	7.9	25.7	1.2	109.4
Advanced Coal with CCS	85	92.7	9.2	33.1	1.2	136.2
Natural Gas-Fired						
Conventional Combined Cycle (CC)	87	17.5	1.9	45.6	1.2	66.1
Advanced CC	87	17.9	1.9	42.1	1.2	63.1
Advanced CC with CCS	87	34.6	3.9	49.6	1.2	89.3
Conventional Combustion Turbine	30	45.8	3.7	71.5	3.5	124.5
Advanced Combustion Turbine	30	31.6	5.5	62.9	3.5	103.5
Advanced Nuclear	90	90.1	11.1	11.7	1.0	113.9
Wind	34	83.9	9.6	0	3.5	97.0
Wind – Offshore	34	209.3	28.1	0	5.9	243.2
Solar PV	25	194.6	12.1	0	4.0	210.7
Solar Thermal	18	259.4	46.6	0	5.8	311.8
Geothermal	92	79.3	11.9	9.5	1.0	101.7
Biomass	83	55.3	13.7	42.3	1.3	112.5
Hydro	52	74.5	3.8	6.3	1.9	86.4

Table 82. Regional variation in levelized costs of new plants entering service in 2016.[401]

Plant Type	Total System Levelized Costs ($/MWh, 2009)
Conventional Coal	85.5 – 110.8
Advanced Coal	100.7 – 122.1
Advanced Coal with CCS	126.3 – 154.5
Natural Gas-Fired	
Conventional Combined Cycle (CC)	60.0 – 74.1
Advanced CC	56.9 – 70.5
Advanced CC with CCS	80.8 – 140.0
Conventional Combustion Turbine	99.2 – 144.2
Advanced Combustion Turbine	87.1 – 118.2
Advanced Nuclear	109.7 – 121.4
Wind	81.9 – 115.0
Wind – Offshore	186.7 – 349.4
Solar PV	158.7 – 323.9
Solar Thermal	191.7 – 641.6
Geothermal	91.8 – 115.7
Biomass	99.5 – 133.4
Hydro	58.5 – 121.4

17 ENERGY PROJECT CHALLENGES AND LESSONS LEARNED

Energy legislation and policies enacted since the dawn of the 21st century have required the DoD to invest in cost-effective, efficient renewable energy at their facilities. The installation and integration of solar, biomass, wind, and geothermal energy sources on or near DoD installations has not been without significant technological, programmatic, and financial challenges. While several of these challenges are technology-specific, the vast majority of the challenges faced when implementing renewable energy projects were programmatic and financial. The following sections provide information on some of the specific challenges faced while attempting to meet energy goals as well as some of the lessons learned.

17.1 Programmatic Challenges and Lessons Learned

There are several programmatic challenges that an installation can face when implementing renewable energy projects. The greatest challenge for any renewable energy project is to make sure that the project does not in any way impede the primary mission of the DoD installation.

If there is a potential conflict between having power generated from renewable energy and performing mission needs, then a clear and concise evaluation of how these conflicts can be mitigated is needed and what (if any) accommodations need to be made. According to a December 2009 GAO Report, OSD has yet to provide guidance on when it is appropriate to make accommodations that can balance the renewable energy project with mission objectives.[402] Developing guidance on making such accommodations will enable DoD installation managers to maximize the potential for developing RE projects while ensuring no negative impact on mission performance.

17.1.1 Account for Land Needs in Project Planning

When evaluating the feasibility of certain renewable energy resources, it is essential to ensure that the proposed technology is designed to minimize its impact on the installation's physical footprint while maximizing its potential to generate renewable energy. If a renewable energy project interferes with current or future land needs, it will most likely be rejected or at a minimum need to be redesigned.

17.1.2 Plan for Maintenance

As the use of renewable energy systems increases throughout the DoD, there is an increased maintenance burden on the services. Maintaining utilities is not a core competency of the services, and thus operations and maintenance (O&M) funding for these systems is hard to obtain. O&M funding is predominantly for weapon systems.[23] Lack of maintenance funding and resources can lead to reduced system performance, potentially eliminating the quantitative benefits of using renewable energy.

To mitigate the increased maintenance burden placed on the services by renewable energy systems, it would be advantageous for the services to contract the maintenance operations to the organization that developed the system. As stated earlier, the DoD does not possess the core competencies required to maintain these systems, so these systems have a better chance of operating as designed by organizations that do possess the proper maintenance competencies.

To reduce the impact of maintenance issues after system installation, greater emphasis should be placed on system and component quality. One important factor is the quality record of the construction contractor, which should be taken into consideration during the project solicitation process.[403] Moreover, detailed feasibility assessments of proposed technologies, in addition to placing a greater emphasis on overall system quality and technical maturity instead of simply focusing on initial project costs, will help reduce the impact of future operations and maintenance-related issues on system performance and costs.

17.1.3 Understand Potential Funding Options

There are several types of funding sources available to installations looking to implement renewable energy projects (see *Chapter 15*). However, many funding sources have fairly restrictive payback timelines, limiting the types and sizes of the renewable sources as they may not be able to meet the payback period. In addition, the timeline from initial energy assessment to construction has to be fairly short because most project funds have to be obligated within 1 to 2 years.[404] Also, projects that attempt to use ECIP funding require a greater upfront investment compared to privately funded projects. This is because state and federal tax incentives for renewable power projects are not applicable to the DoD.[405] In addition, ESPCs for renewable energy projects traditionally have been an underutilized mechanism because the ESCOs have lacked the requisite working knowledge of renewable energy technologies.[405]

The negative impact of these challenges can be significantly reduced through proper planning and preparation. During the design phase, it is imperative that the input of all parties that are impacted by a renewable energy project is solicited and then taken into account when finalizing the design. For example, stakeholders typically include:

- Contracting representatives
- Energy managers and program managers
- Design engineers
- Contractors and construction firms
- Local government
- Utility companies
- Base commanders

In several of the projects researched for this handbook, the management teams that included representatives from all involved parties incurred fewer problems during system implementation. Most of the potential problems were already identified and mitigated during the design process.

17.1.4 Securing Energy Generation

The susceptibility of renewable energy systems to weather and maintenance-related reductions in electricity generation presents significant energy security issues. As DoD facilities shift toward becoming net-zero with a great dependence on renewable energy, additional measures must be enacted to ensure that any loss of generation will not jeopardize base critical operations. These measures can include building decentralized renewable energy sources (i.e., distributed generation) for system redundancy and employing smaller renewable or nonrenewable power sources to meet demand spikes or mitigate power losses.

17.2 Renewable Energy Challenges and Lessons Learned

While many of the issues encountered during an energy project are common and independent of whether it is solar, wind, biomass, or geothermal, each renewable energy area has its own set of challenges. Some of these challenges and lessons learned are described briefly in the following sections.

17.2.1 Solar Challenges

Solar power is the most widely used renewable energy source throughout the DoD. However, solar energy has specific challenges that must be taken into account when considering potential renewable energy sources for a DoD facility. Additional information on the challenges that face electricity generation from solar cells can be found in *Chapter 8*.

17.2.1.1 Intermittency of Electricity Generation

While the sun does shine every day, on cloudy days the amount of electricity that can be harvested from solar rays is significantly less. This fluctuation in the amount of electricity that is generated by a solar energy system must be accounted for when determining the dependence of an installation on this energy source. It is also important to establish realistic expectations for the amount of power that will be generated over the life of the project. It is important to avoid using the ideal conditions because a solar energy system will generate less power than originally forecast due to the changes in weather and efficiency.

17.2.1.2 Large Square Footage Required

Large scale solar electricity systems (1 MW and greater) require a significant amount of land to generate electricity. The availability of the amount of land (usually in the tens of acres) required to build these systems on most DoD installations is typically limited. Thus, former landfill sites can be ideal locations for large solar plants. For example, the 14 MW photovoltaic solar system at Nellis AFB and the 2 MW solar array at Fort Carson both utilize land that was a former landfill. Out of the 140 acres the Nellis solar field required, 33 acres were on a former landfill site.[406] Smaller scale systems can be placed on building rooftops, however, they generate much less electricity (usually not much more than is used by the building the solar panels are built on).

17.2.1.3 Solar Cell Efficiency

Even with a large scale solar electricity plant, the renewable power produced is typically a fraction of the energy used annually on a DoD installation. This relatively small percentage of a DoD installation's total electrical demand is due to the relative inefficiency of the photovoltaic cells. Most PV cells currently used in solar energy systems are approximately 15 percent efficient.[407] As a result of the low efficiency, solar panels occupy a large footprint of land.

17.2.2 Wind Power Challenges

The use of electricity generated from wind turbines has grown significantly since the beginning of the 21st century. Large and small scale wind installations are now in use on federal, state, and private land all across the country. However, wind power has not come without its own set of technical and environmental challenges that must be addressed. Some of these are described briefly in the following sections. Additional information on the challenges that face electricity generation from wind can be found in *Chapter 9*.

17.2.2.1 Radar Interference

Windmills cast a radar shadow that can interfere with not only weather radar, but Federal Aviation Administration (FAA) and military radar. This radar interference severely limits the ability of the installation to track weather patterns, flight paths, and perimeter defenses. As a result, finding a suitable location to construct a wind farm on or near a DoD installation is very difficult. A preliminary screening tool is used by the DoD to help identify the impacts of windmill operation on various types of radar (see *Section 9.8.1*).

As a method to mitigate the effect of windmills on radar, the Navy has looked into constructing wind farms outside of the line of site of its long-range radar systems.[408] In addition, the DoD, along with the departments of Commerce and Transportation have developed a joint program called Next Generation Weather Radar. The goal of this program is to predict the impact that a wind turbine will have on neighboring weather radars once turbine height and location have been determined. More information on the NEXRAD program can be found in *Section 9.8.1*.

17.2.2.2 Flight Path Interference

Much like with radar interference, wind turbines can have a significant impact on flight operations. The height of the wind turbines can potentially interfere with landing on and taking off from the runway and other normal flight operations. One of the best ways to ensure that flight path and radar interference issues are identified and mitigated is to make sure stakeholders from the installation command, FAA, and radar groups are involved early on in the system design process. That way, any issues can be mitigated without any significant financial impact to the project.

17.2.2.3 Long Component Lead Times

As is fairly common with the production of any large piece of equipment, a significant period of time is required to fabricate the components. This lead time needs to be accounted for when compiling the construction schedule. In a recent AFCEE project, the Air Force noted longer lead times for wind turbines than originally forecast.[409] To limit project delays due to longer component lead times, the project managers should be in constant contact with the supplier in regards to production progress. Also, during the RFP process, the selection team should assess the ability of the supplier to meet the delivery schedules they propose.

17.2.2.4 Transmission Issues

Wind farms are commonly constructed in areas that are not close to existing high-voltage transmission lines. As a result, transmission lines and expensive interconnects have to be constructed. The additional cost of constructing these lines can make wind power less cost-effective than other renewable energy sources, primarily because the construction costs cannot be directly passed along to the consumer.

17.2.2.5 Aesthetic and Environmental Concerns

Wind farms face constant scrutiny over the potential danger they pose to the local bird population and indirectly to the surrounding ecosystems. In addition, several communities have opposed the construction of wind mills nearby, claiming that they can damage the aesthetics of the surrounding areas and as a result, decrease property values.

17.2.3 Biomass Challenges

The use of biomass sources to generate electricity has steadily grown since the late 20th century. There are several environmental benefits to processing the byproducts of decaying matter to produce energy. However, biomass-to-energy technologies face considerable challenges as a cost effective DoD renewable energy source. Some of these are described briefly in the following sections. Additional information on the challenges that face electricity generation from biomass sources can be found in *Chapter 10*.

17.2.3.1 Non-Uniform Feedstock Compositions

Municipal solid waste feedstock can vary greatly in physical and chemical compositions. As result, a significant amount of work must be performed to ensure that the system design will maximize energy output given the changing MSW compositions.

17.2.3.2 Limitations of Feedstock in Large Scale Operations

For larger scale biomass energy systems, a significant amount of feedstock is required to maintain continuous operations. Over the long term, acquiring enough feedstock to meet system demand can be challenging. Acquiring alternate supplies should be planned for in case of a supply shortage or other circumstance that would inhibit the needed supply.

17.2.3.3 Lack of Large Commercial Biomass Operations

Unlike other renewable energy sources (e.g., solar and wind), commercial utility companies are not investing as extensively in large-scale biomass energy systems. This is partly because of the volatility in the prices of competing fuels. As a result, there is a smaller, less mature pool of knowledge for the DoD to draw from when they assess the feasibility of biomass energy system designs.

17.2.4 Geothermal Challenges

The viability of power from geothermal sources has improved significantly over the past two decades. The majority of these improvements have come from improvements in geothermal technology and more accurate mapping of available geothermal sources. In 2006, the Government Accountability Office conducted a study on the viability of geothermal energy and how it related to the Department of the Interior.[410] The GAO report generated from this study provided a detailed list of several challenges that must be addressed if geothermal electricity is going to be a viable power source for any federal government office. A few of these challenges are described briefly in the following sections. Additional information on the challenges that face electricity generation from geothermal sources can be found in *Chapter 11*.

17.2.4.1 High Initial Investment Costs

The high investment costs associated with geothermal exploration and system development have made it difficult to acquire the funding for implementing geothermal projects. The development of geothermal systems for a 25-megawatt power plant can cost over $75 million, making even the most modest return on investment difficult to achieve.[410] Ideally such a plant, once constructed can be in operation for 50 or more years in order to achieve a very long-term return-on-investment. However, the DoD cannot participate in such long-term projects.

17.2.4.2 Long Development Times

Construction and scaling up of a geothermal power plant can take three to five years. Given the short timeframe required for the DoD to meet its renewable energy goals, this length of time can make geothermal energy an unattractive energy option as the time required for construction of other renewable energy sources is considerably shorter.[410]

17.2.4.3 Energy Transmission from Remote Areas

Ideally a geothermal plant can be located nearby an installation and thus be easily connected into the existing grid. However, the siting of the plant is dependent on the location of an available geothermal resource. Like wind farms which are often remotely located, most geothermal sources are in remote locations, and thus far from any adequate transmission lines. As a result, new transmission lines have to be constructed, making many of these projects economically unfavorable.[410]

18 APPENDICES

18.1 Appendix A: Acronyms and Symbols

A	
A	Area
A2LA	American Association of Laboratory Accreditation
AAF	Ascension Auxiliary Airfield
AC	Alternating Current
ACFM	Actual Cubic Feet per Minute
AEMR	Annual Energy Management Report
AF/A1	Air Force Deputy Chief of Staff, Manpower and Personnel
AF/A3/5	Air Force Deputy Chief of Staff, Operations, Plans, and Requirements
AF/A3O-AH	Air Force Operations Group – Homeland Defense
AF/A3O-AT	Air Force Operations Group – Training
AF/A4L	Air Force Office of Logistics Readiness
AF/A4/7	Air Force Deputy Chief of Staff, Logistics, Installations, and Mission Support
AF/A7C	Air Force Office of the Civil Engineer
AF/A8	Air Force Deputy Chief of Staff for Strategic Plans and Programs
AF/A9	Air Force Director for Studies and Analyses, Assessments, and Lessons Learned
AFB	Air Force Base
AFC	Alkaline Fuel Cell
AFCEE	Air Force Center for Engineering and the Environment
AFCESA	Air Force Civil Engineer Support Agency
AFCM	Actual Feet Cubed per Minute
AFCO	Alternative Fuel Certification Office
AF/CV	Air Force Vice Chief of Staff
AFFEC	Air Force Facility Energy Center
AFOSR	Air Force Office of Scientific Research
AFPA	Air Force Petroleum Agency
AFRL	Air Force Research Laboratory
AFRPA	Air Force Real Property Agency
AF/ST	Air Force Chief Scientist
AGR	Advanced Gas-Cooled Reactor
AIRR	Adjusted Internal Rate of Return
AMI	Advanced Metering Infrastructure
AMS	Advanced Metering System
AP	Advanced Passive
ARPA-E	Advanced Research Projects Agency – Energy
ARSR-3	Air Route Surveillance Radar 3
As	Arsenic
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
a-Si	Amorphous Silicon
ATC	Air Traffic Control

B	
BBL	Barrel
BDT	Bone-Dry Ton
BIPV	Building Integrated Photovoltaic
BLCC	Building Life Cycle Cost
BLM	Bureau of Land Management (Department of Interior)

BTU	British Thermal Unit
BWR	Boiling Water Reactor

C	
C_2H_6	Ethane
C_3H_8	Propane
C_4H_{10}	Butane
C&D	Construction and Demolition
$CaCO_3$	Calcium Carbonate or Calcite
CAES	Compressed Air Energy Storage
CB	Chlorobenzene
CCS	Carbon Capture and Storage
CDMA	Code Division Multiple Access
CdS	Cadmium Sulfide
CdTe	Cadmium Telluride
CEQ	Council on Environmental Quality
CES	Civil Engineering Squadron
CF	Capacity Factor
CFR	Code of Federal Regulations
CH_4	Methane
CHP	Combined Heat and Power
CIGS	Copper Indium Gallium Diselenide
CNG	Compressed Natural Gas
CO	Carbon Monoxide
COTS	Commercial-Off-The-Shelf
CO_2	Carbon Dioxide
CP	Chlorophenol
C_p	Power Coefficient (Wind)
CPUC	California Public Utilities Commission
CPV	Concentrating Photovoltaics
CTL	Coal-to-Liquid
COTS	Commercial-Off-The-Shelf
Cr	Chromium
CS	Cooling System
CSP	Concentrating Solar Power
$Cu(InGa)Se_2$	Copper Indium Gallium Diselenide
C_y	Costs that occur in year y

D	
d	Discount Rate
DA	Distribution Automation
DARPA	Defense Advanced Research Projects Agency
DC	Direct Current
DER	Distributed Energy Resource
DESC	Defense Energy Support Center
DG	Distributed Generation or Decentralized Generation
DHS	Department of Homeland Security
DLA	Defense Logistics Agency
DM	Direct Methanol
D_{max}	Maximum Demand
DMFC	Direct Methanol Fuel Cell

DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOE	Department of Energy
DOI	Department of Interior
DPB	Discounted Payback
DSIRE	Database of State Incentives for Renewables and Efficiency
DSNG	Direct Supply Natural Gas
DSNGP	Direct Supply Natural Gas Program
DTI	Department of Trade and Industry (UK)
DUSD(I&E)	Deputy Under Secretary of Defense (Installations and Environment)
DUSD(I&E) FED	Deputy Under Secretary of Defense (Installations and Environment) Facilities Energy Directorate

E	
E	Energy
ECIP	Energy Conservation Investment Program
ECOS	Environmental Conservation Online System
EDLC	Electric Double Layer Capacitor
EERE	Office of Energy Efficiency and Renewable Energy
EGS	Enhanced Geothermal System
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act
EJ	Exajoule
EKO	Engineering Knowledge Online
EMCS	Energy Management Control System
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
EO	Executive Order
ER	Equivalence Ratio
ERDC-CERL	Engineering Research and Development Center-Construction Engineering Research Laboratory
ESBWR	Economic and Simplified Boiling Water Reactor
ESCO	Energy Service Company
ESP	Electronic Submersible Pump
ESP	Electrostatic Precipitator
ESPC	Energy Savings Performance Contract
EUD	Energy and Utility Department (NAVFAC)
EUL	Enhanced Use Lease
eV	Electron-Volt

F	
FAA	Federal Aviation Administration
FC	Fuel Cell
FEMP	Federal Energy Management Program
FES	Flywheel Energy Storage
FUPWG	Federal Utility Partnership Working Group
FW	Flywheel
FY	Fiscal Year

G	
g	Gravitational Acceleration
GaAs	Gallium Arsenide
GaInP	Gallium Indium Phosphide
Gal	Gallon
GEA	Geothermal Energy Association
GFR	Gas-Cooled Fast Reactor
GHG	Greenhouse Gas
GHP	Geothermal Heat Pump
GIF	Generation IV International Forum
GPP	Geothermal Power Plant
GSA	General Services Administration
GSF	Gross Square Foot (or Feet)
GT-MHR	Gas Turbine-Modular Helium Reactor
GW_e	Gigawatt-electric
GWh	Gigawatt-hour
GWP	Global Warming Potential

H	
h	Height or Head
H_2	Diatomic Hydrogen
$H_2O(v)$	Water Vapor
H_2S	Hydrogen Sulfide
H_2Se	Hydrogen Selenide
H_2SO_4	Sulfuric Acid
HAWT	Horizontal Axis Wind Turbine
HCl	Hydrogen Chloride or Hydrochloric Acid
HDR	Hot Dry Rock
He	Helium
HF	Hydrofluoric
Hg	Mercury
HgO	Mercuric Oxide
HHV	Higher Heating Value
HP	High Pressure
HPS	High Pressure Steam
hr	Hour
HRC	Heat Recovery Cycle
HTSB	High Temperature Secondary Battery
HVAC	Heating, Ventilation, and Air Conditioning
HWR	Hot Wet Rock

I	
I	Investment
IATF	Interagency Energy Management Task Force
ICE	Internal Combustion Engine
ICS	Integrated Collector Storage
IDIQ	Indefinite-Delivery, Indefinite Quantity
IECC	International Energy Conservation Code
IEEE	Institute of Electrical and Electronics Engineers
IGCC	Integrated Gasification Combined Cycle
IGSHPA	International Ground Source Heat Pump Association

IRIS	International Reactor Innovative and Secure
ISCCS	Integrated Solar Combined Cycle System
ISO	International Organization for Standardization
ISWG	Interagency Sustainability Working Group

J	
JCTD	Joint Capability Technology Demonstration
JP-5	Jet Propellant-5
JP-8	Jet Propellant-8
JP-9	Jet Propellant-9
JP-10	Jet Propellant-10

K	
kg	Kilogram
kHz	Kilohertz
kJ	Kilojoule
KOH	Potassium Hydroxide
kV	Kilovolt
kW	Kilowatt
kWe	Kilowatt-electric
kWh	Kilowatt-hour

L	
L	Liter
λ	Turbine Tip Speed Ratio
L/A	Lead Acid
lb	Pound
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LCOE	Levelized Cost of Energy or Levelized Cost of Electricity
LEED	Leadership in Energy and Environmental Design
LF	Load Factor
LFR	Lead-Cooled Fast Reactor
LHV	Lower Heating Value
Li-ion	Lithium-Ion
LMFBR	Liquid Metal-Cooled Fast-Breeder Reactor
LNG	Liquid Natural Gas
LP	Low Pressure
LPG	Liquefied Petroleum Gas
LRVP	Liquid Ring Vacuum Pump
LWR	Light Water Reactor

M	
M	Million
m	Meter
m^2	Square Meter
m^3	Cubic Meter
M&V	Measurement and Verification
MAJCOM	Major Command
MARR	Minimum Acceptable Rate of Return
MBTU	One Thousand British Thermal Units

MCA	Military Construction Army
MCFC	Molten Carbonate Fuel Cell
MCLB	Marine Corps Logistics Base
MDMS	Metering Data Management System
METS	Meteorological System
MILCON	Military Construction
MJ	Megajoule
MMBTU	One Million British Thermal Units
MnO_2	Manganese Dioxide
Mn_2O_3	Manganese Oxide
MPH	Miles Per Hour
MSR	Million Solar Roofs
MSR	Molten Salt Reactor
MSW	Municipal Solid Waste
MW	Megawatt
MW_e	Megawatt-electric
MWh	Megawatt-hour

N	
N	Newton (Unit of Force)
N	Number of Years in Study Period (Life Cycle Cost)
N_2	Diatomic Nitrogen
NaS	Sodium Sulfur
NAVFAC	Navy Facilities Engineering Command
NAWCWD	Naval Air Warfare Center Weapons Division
NCG	Noncondensable Gas
NDAA	National Defense Authorization Act
Ne	Neon
NECPA	National Energy Conservation Policy Act
NEXRAD	Next Generation Weather Radar
NGV	Natural Gas Vehicle
NH_3	Ammonia
Ni	Nickel
Ni/Al	Nickel/Aluminum
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen Oxides
NPA	Nevada Power Authority
NS	Net Savings
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory

O	
O_2	Diatomic Oxygen
O&M	Operations and Maintenance
OE	Original Equipment
OE/AAA	Obstruction Evaluation/Airport Airspace Analysis
OFOH	Open Feed Organic Heater
OMA	Operations and Maintenance Army

OMB	Office of Management and Budget
ORC	Organic Rankine Cycle
OSD	Office of the Secretary of Defense
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column

P	
P	Power Generated (Wind)
p	Period
ρ	*See rho under "R"*
PACVD	Plasma Assisted Chemical Vapor Deposition
PAFC	Phosphoric Acid Fuel Cell
PAH	Polycyclic-Aromatic Hydrocarbon
P_{avg}	Average Power
Pb	Lead
PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated Dibenzodioxins
PCDF	Polychlorinated Dibenzofuran
PEF	Process Engineered Fuel
PEM	Polymer Electrolyte Membrane
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PFBC	Pressurized Fluidized Bed Combustion
PG&E	Pacific Gas & Electric
PHWR	Pressurized Heavy Water Reactor
P_{max}	Maximum Power
POWER	Portable Waste to Energy Refinery
P_{peak}	Peak Power
PPA	Power Purchase Agreement
ppm	Parts Per Million
PSI	Pounds Per Square Inch
PTC	Production Tax Credit
PuO_2	Plutonium Oxide
PURPA	Public Utilities Regulatory Policies Act
PV	Photovoltaic
PWR	Pressurized Water Reactor

Q	
	Volumetric Flow Rate
Q_n	Energy Output or Energy Saved in Year n

R	
R	Replacement
ρ	Density
ρ_a	Density of air
RDT&E	Research, Development, Testing, and Evaluation
RCI	Residential Communities Initiative
RDF	Refuse-Derived Fuel

REC	Renewable Energy Certificate
REWG	Renewable Energy Working Group
RHE	Recovery Heat Exchanger
ROE	Return on Equity
ROI	Return on Investment
RPM	Revolutions Per Minute
RPS	Renewable Portfolio Standard
RTP	Real Time Pricing

S	
s	Second
S	Salvage (Life Cycle Cost)
S	Sulfur
SA	Substation Automation
SAF	Secretary of the Air Force
SAF/AQ	Assistant Secretary of the Air Force for Acquisition
SAF/FM	Assistant Secretary of the Air Force, Financial Management and Comptroller
SAF/GC	Office of the General Counsel of the Air Force
SAF/IA	Deputy Under Secretary of the Air Force, International Affairs
SAF/IE	Assistant Secretary of the Air Force for Installations, Environment, and Logistics
SAF/IEE	Deputy Assistant Secretary of the Air Force for Energy, Environment, Safety, and Occupational Health
SAF/IEI	Deputy Assistant Secretary of the Air Force for Installations
SAF/PAX	Secretary of the Air Force Office of Public Affairs
SAF/US	Under Secretary of the Air Force
SAF/XC	Air Force Office of Warfighting Integration and Chief Integration Officer
Sb	Antimony
SCADA	Supervisory Control And Data Acquisition
SCE	Southern California Edison
SCFM	Standard Cubic Feet per Minute
SCR	Selective Catalytic Reduction
SCWR	Supercritical Water-Cooled Reactor
SDD	Sustainable Design and Development
Se	Selenium
SEGS	Solar Electric Generating System
SFG	Senior Focus Group
SFR	Sodium-Cooled Fast Reactor
Si	Silicon
SIR	Savings-to-Investment Ratio
SMES	Superconducting Magnetic Energy Storage
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulfur Dioxide
SO#4	Standard offer Number 4
SOFC	Solid Oxide Fuel Cell
SO_x	Sulfur Oxides
SPB	Simple Payback

SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
SPPC	Sierra Pacific Power Company
SPV	Single Present Value
SRC	Standard Reporting Conditions
SRCC	Solar Rating and Certification Corporation
SRF	Solid Recovery Fuel
SRS	Savannah River Site
S/R&M	Sustainment, Restoration, and Modernization
STP	Standard Temperature and Pressure

T	
TAPCHAN	Tapered Channel
TB	Thermal Battery
T_c	Critical Temperature
TGER	Tactical Garbage to Energy Refinery
TOU	Time of Use
TW	Terawatt

U	
U_3O_8	Uranium Oxide
UESC	Utility Energy Service Contract
UF	Utilization Factor
UFC	United Facilities Criteria
UO_2	Uranium Dioxide
UPS	Uninterruptible Power Supply
UPV	Uniform Present Value
USACE	United States Army Corps of Engineers
USC	United States Code
USCG	US Coast Guard
USDA	US Department of Agriculture

V	
v	Velocity
VAWT	Vertical Axis Wind Turbine
VCSAF	Vice Chief of Staff of the US Air Force
VHF	Very High Frequency
VHTR	Very High Temperature Reactor
VOR	VHF Omnidirectional Range

W	
W	Watt
Ω	Turbine Tip Speed
WAPA	Western Area Power Administration
WBDG	Whole Building Design Guide
WCC	Wind Capacity Credit
WG	Working Group
Wh	Watt-hour
W_p	Peak Watt

WPP	Wind Power Potential
WSR-88D	Weather Surveillance Radar-1988 Doppler
WTE	Waste-To-Energy

X	
Xe	Xenon

Z	
Zn	Zinc
ZnBr	Zinc Bromine
ZnO	Zinc Oxide

18.2 Appendix B: Glossary

Active Solar. Incorporates technologies to harness and control solar energy, which include generating electricity, heating and cooling systems.

Advanced Meter. A device that can measure, record, and remotely communicate energy usage data. Sometimes referred to as a smart meter.

Advanced Metering Infrastructure. Hardware and software that enables the measurement, communication, storage, and distribution of energy usage data.

Advanced Metering System. A system that measures energy usage on time-based intervals, communicates the data, manages the data, and distributes the data to users.

Agricultural Residue. Remaining material after biomass has served its primary purpose. *Field residue* is the biomass left in the field after harvest. *Process residue* is the leftover biomass after processing the crop into a usable resource.

Alternative Energy. An unconventional or nontraditional resource that supplants a large scale, traditional energy source.

Anaerobic Digestion. The production of a gaseous CO_2 and CH_4 mixture via bacterial action in the absence of oxygen.

Balancing Authority. Group in charge of balancing power generating systems to meet the required load.

Biomass. Any biological or man-made organic material available on a renewable or recurring basis that can be reduced by a thermal, biological, or chemical process, or combination thereof, for the production of a usable energy product.

Bone-Dry Ton. Two thousand pound mass containing zero moisture.

Carnot Efficiency. Theoretical maximum efficiency of a heat engine.

Cellulose. A rigid, linear, glucose-based polymer that is highly stable and difficult to decompose. Together with hemicellulose and lignin it forms the cell wall in plants.

Coal Liquefaction. A process that converts solid coal into refined gasoline or diesel for use in the transportation industry.

Coal-to-Liquid. (See Coal Liquefaction).

Cofiring. The combustion of two different fuels (e.g., coal and biomass) simultaneously in the same combustion unit.

Cogeneration. Also known as **combined heat and power**, it is the method of producing electricity for power and thermal energy for heating, cooling, or both from one fuel source.

Compression Ratio. A value that represents the ratio of the volume of a combustion chamber from its largest capacity when the piston is at the high point to its smallest when the piston is at its low point.

Concentration Ratio. The ratio of the area of the solar thermal receiver to the aperture of the focused light.

Distributed Energy Resource. Decentralized power source or distributed generation used to provide electricity to specific areas of the microgrid.

Distributed Generation. The production of energy that occurs on-site near the point of use, as opposed to energy that has to be transmitted from the point of generation to a substation. Also referred to as decentralized generation.

Distributed Wind. Wind that is not generated on a utility-scale but rather for onsite local consumption.

Dry Ton. Two thousand pound mass dried to a relatively low or consistent moisture level.

Energy. A system's ability to perform work.

Energy Intensity. A calculated value of the energy use per area, and for facilities it is typically represented as BTUs per gross square foot.

Equivalence Ratio. Amount of oxygen required for gasification relative to the amount of oxygen required for complete combustion of the biomass.

First Law Efficiency. Ratio of useful energy (i.e., net work done by a system) to the energy content of the fuel consumed.

Flue Gas. Gaseous products resulting from combustion that are emitted to the atmosphere or to a post-combustion purification process.

Flue Gas Desulfurization. A process that which sulfur is removed prior to releasing the gaseous combustion product to the atmosphere.

Forced Outage Rate. The probability a unit will not be available for service when required.

Forestry Residue. Remaining material after forest harvesting and forest management operations, including limbs and other woody material.

Fuel. A substance that has stored energy which can be released deliberately to provide useful work or heat.

Gasification. Endothermic decomposition process in which cellulosic biomass can be converted to a gaseous mixture of syngas (i.e., CO, H_2, and CH_4) in the presence of limited oxygen and heat.

Glucose. A monosaccharide. A simple six carbon sugar compound that is produced by photosynthetic processes and is readily consumed by yeast and other organisms.

Grid Integration Costs. Cost required to integrate wind energy to base energy production. This value can directly affect the value of wind farm.

Gross Square Foot. The total area in a building for all floors to the outer surface of exterior walls, including elevator shafts, vertical penetrations, equipment areas, ductwork shafts, and stairwells; and excluding areas having less than a 6'-6" clear ceiling height.

Head. The height change over which the water drops in a hydropower plant.

Hemicellulose. An amorphous polysaccharide compound that is easier to decompose than cellulose into its individual (or monomer) sugar-based units, such as glucose, xylose, mannose, galactose, rhamnose, and arabinose. Together with cellulose and lignin it forms the cell wall in plants.

Higher Heating Value. The measure of the heat released during the complete combustion of the fuel with oxygen at a given temperature and pressure. When using this value it is assumed that the water vapor formed during the combustion process is condensed, collected, and cooled to the initial temperature. Hence, the higher heating value assumes that the latent heat of evaporation is recovered. The higher heating value is the US customary measure of heating value.

Hot Dry Rock. Rock layer that retains geothermal energy but lacks fluid or natural permeability.

Hydrologic Cycle. The continuous movement of water on, above, and below the surface of the earth.

Hydrothermal Resource. Natural body of water that has an elevated temperature due to geothermal heating.

Levelized Cost of Energy. A calculated value of the total life cycle cost divided by the total lifetime energy production that allows a more direct comparison of the costs associated with energy generated by different methods. Also sometimes referred to as the levelized cost of electricity.

Lignin. An abundant, very complex, organic polymer of crosslinked phenylpropane units that is difficult to decompose. Together with cellulose and hemicellulose it forms the cell wall in plants. Serves to cement the cell walls together.

Liquid Ring Vacuum Pump. Compressor-type pumps that are used alone in low-flow applications when high pressure ratios are not required. They are used in series with steam jet ejectors to increase the efficiency of gas removal. Also, when combined with a steam jet ejector, the result is often referred to as a hybrid system.

Lower Heating Value. The measure of the heat released during the complete combustion of the fuel with oxygen at a given temperature and pressure, where the latent heat of evaporation is not recovered.

Met Tower. Metrological tower which measures wind speeds, air density, and other information about the air.

Microgrid. Integrated system of interconnected loads and distributed power generation units that can operate in parallel to an existing grid structure, augment the existing grid, or operate completely separate from the grid.

Monosaccharide. A single sugar, or fundamental carbohydrate unit that cannot be hydrolyzed into a simpler carbohydrate.

Nonrenewable energy. Energy derived from a source which cannot be regenerated or replaced within a timescale that is sufficient to sustain their consumption.

Open Feed Organic Heater. Direct contact heat exchanger in which the steam that is extracted is permitted to mix with the geothermal fluid.

Opportunity Fuel. Any biomass feedstock that a power plant would be paid to take, with no cost for delivery to the plant location, or any biomass feedstock that is obtained at no cost with no additional processing requirements once delivered.

Passive Solar. Harnessing solar energy without any built-in controls, including natural lighting and radiant heating.

Peak Shaving. The method of operating a secondary power generation unit to supplant energy from the utility provider in order to avoid higher prices of electricity associated with peak consumption periods.

Penstock. Penstock is a traditional term that denotes a physical intake and conduit through which water flows. It may also include the gate or water intake and management system.

Polysaccharide. A carbohydrate chain that is made up of many monosaccharide units.

Power. The rate at which energy is transferred to perform work.

Pyrolysis. Thermochemical conversion technology that heats biomass in the absence of oxygen to produce oil, charcoal, and a non-condensable gaseous mixture.

Renewable Energy. Energy derived from a source which can be replenished by natural processes at a rate that exceeds its consumption.

Second Law Efficiency. Ratio first law efficiency to Carnot efficiency or the extent of the theoretical maximum efficiency achieved.

Smart Grid. An electric power transmission and distribution system that can be automatically monitored and controlled using advanced digital components that permit the two-way flow of electricity and information between points of generation, use, and the user.

Smart Meter. See Advanced Meter.

Standby Charge. A fee imposed by the provider of distributed generation energy to the consumer when the system is ready to provide energy, but is not actively providing it.

Thermosiphon. A method of passive heat exchange (i.e., in the absence of a mechanical pump) in which natural convection causes fluid to circulate.

Traditional Energy Source. A resource that has been in use for a long period of time to supply a power on a large scale.

Transesterification. The conversion of oils from biomass and greases into combustible materials, which can be used to generate electricity. The chemical process involves a reaction between an alcohol, catalyst, and oil.

Wind Capacity Credit. The amount of conventional generation that can be replaced by wind generation.

Wind Capacity Factor. The ratio of actual productivity in a year to this theoretical maximum (max rating of generator) is called the capacity factor.

Wind Penetration. The fraction of energy produced by wind compared with the total available generation capacity. This value is high when availability of wind is high and electrical demand is low.

Wind Power Potential. Also known as the wind power density, refers to the measure of the speed of wind through a cylindrical volume of air. A value used to determine how much power can be produced by a turbine at a given location.

Wind Resource Assessment. The process which wind farm developers use to estimate the future energy production of a wind farm.

18.3 Appendix C: Summary of Energy Carrier Properties[67]

	Main Fuel Source	Physical State	Energy Content		
			LHV (BTU/gal)	HHV (BTU/gal)	Gasoline Equivalent[cviii]
Gasoline	Petroleum	Liquid	116,090	124,340	100%
Diesel (No. 2)	Petroleum	Liquid	128,450	137,380	113%
Compressed Natural Gas	Underground reserves	Gas (pressurized)	20,268 (BTU/lb)	22,453 (BTU/lb)	100% at 5.66 lbs or 126.67 ft^3
Liquefied Natural Gas	Underground reserves	Liquid (cryogenic)	74,720	84,820	64%
Liquefied Petroleum Gas	By-product of petroleum and natural gas processing	Liquid (pressurized)	84,950	91,410	73%
Methanol	Natural gas, coal, biomass	Liquid	57,250	65,200	49%
Biodiesel (B100)	Biomass	Liquid	119,550	127,960	103%
Ethanol (E100)	Biomass	Liquid	76,330	84,530	77% (E85)
Electricity	Fossil fuel, nuclear, and renewable sources	Electricity	3,414 (BTU/kWh)	3,414 (BTU/kWh)	100% at 33.40 kWh
Hydrogen	Natural gas, methanol, water	Gas or liquid (pressurized)	51,585 (BTU/lb)	61,013 (BTU/lb)	100% at 1 kg

[cviii] Energy compared to one gallon of gasoline. This is given as percent energy content on a gallon-to-gallon basis unless other units are specified.

18.4 Appendix D: Energy Content of Various Fuels.[109]

Fuel	Energy Content	Units
	Coal	
Production	20.310	Million BTU per Short Ton
Consumption	20.183	
Coke Plants	26.263	
Industrial	21.652	
Residential and Commercial	22.016	
Electric Power Sector	19.952	
Imports	25.073	
Exports	25.378	
Coal Coke	24.800	
Crude Oil		
Production	5.800	Million BTU per Barrel
Imports	5.980	
	Petroleum Products	
Consumption	5.338	Million BTU per Barrel
Motor Gasoline	5.218	
Jet Fuel	5.670	
Distillate Fuel Oil	5.799	
Residual Fuel Oil	6.287	
Liquefied Petroleum Gas	3.605	
Kerosene	5.670	
Petrochemical Feedstocks	5.554	
Unfinished Oils	6.118	
Imports	5.450	
Exports	5.727	
	Biomass	
Switchgrass	7341	BTU per Pound
Bagasse	6065	
Rice Hulls	6575	
Poultry Litter	6187	
Solid Wood Waste	6000-8000	
Ethanol	3.539	Million BTU per Barrel
Biodiesel	5.376	
	Natural Gas Plant Liquids	
Production	3.712	Million BTU per Barrel
	Natural Gas	
Production, Dry	1029	BTU per Cubic Foot
Consumption	1029	
End-Use Sectors	1030	
Electric Power Sector	1028	
Imports	1024	
Exports	1009	
Electricity Consumption	3412	BTU per Kilowatt-Hour

18.5 Appendix E: Resources

Renewable Energy

Websites

DoD Renewable Assessment Team
http://www.acq.osd.mil/ie/energy/renew_energy/renewable.shtml

Facilities Energy Directorate Energy Manager Program Support
http://www.acq.osd.mil/ie/energy/mgr_support.shtml

Energy Information Administration
http://www.eia.doe.gov/

Database of State Incentives for Renewables & Efficiency
http://www.dsireusa.org/

National Renewable Energy Laboratory
http://www.nrel.gov/

Energy Efficiency & Renewable Energy
http://www.eere.energy.gov/

Open Energy Information, NREL
http://en.openei.org/wiki/Main_Page

Sandia National Laboratory
http://www.sandia.gov/

Lawrence Berkeley National Laboratory
http://www.lbl.gov/

Energy Foundation
http://www.ef.org/home.cfm

Solar Power & Energy

Books

J. A. Duffe and W. A. Beckman, *Solar Engineering of Thermal Processes*, 3rd Edition, John Wiley & Sons, 2006.

R. Foster, M. Ghassemi and A. Cota, *Solar Energy: Renewable Energy and the Environment*, CRC Press, Taylor & Francis Group, 2010.

Handbook of Photovoltaic Science and Engineering, Eds. A. Luque and S. Hegedus, John Wiley & Sons, 2003.

Websites

Market trends and Cost Information
http://www.solarbuzz.com/

Open Energy Info – Gateway:Solar
http://en.openei.org/wiki/Gateway:Solar

Test Standards

Certification and Rating
http://www.solar-rating.org/default.htm

SRCC Document OG-100-06, Operating Guidelines for Certifying Solar Collectors, September, 2006.

ISO Standards
http://www.iso.org/iso/iso_catalogue.htm

IEEE Standards

http://standards.ieee.org/

ASTM International Standards
http://www.astm.org/DIGITAL_LIBRARY/index.shtml

Wind

NREL Wind Research
http://www.nrel.gov/wind/

Biomass

Bioeconomy Institute
http://www.biorenew.iastate.edu/

Bioenergy Feedstock Information Network
http://bioenergy.ornl.gov/

Geothermal

Geothermal Technologies Program
http://www1.eere.energy.gov/geothermal/index.html

Geothermal Education Office
http://geothermal.marin.org/

Energy Financing and Economics

Alternative Financing Summary for Energy Projects
http://www1.eere.energy.gov/femp/pdfs/alternative_financing_fs.pdf

ESPC Success Stories
http://www1.eere.energy.gov/femp/pdfs/espc_ss09_ssa.pdf

ESPC Assistance Summary
http://www1.eere.energy.gov/femp/pdfs/espc_femp_assistance.pdf

ESPC FAQs
http://www1.eere.energy.gov/femp/pdfs/espc_faqs.pdf

UESC Background Document
http://www1.eere.energy.gov/femp/pdfs/uesc_enabling_documents09.pdf

UESC Case Study
http://www1.eere.energy.gov/femp/pdfs/uesc_casestudy_pafb.pdf

PPA Quick Guide
http://www1.eere.energy.gov/femp/pdfs/ppa_guide.pdf

Economic Evaluation Manual
http://www.nrel.gov/docs/legosti/old/5173.pdf

Life-Cycle Costing Manual
http://www.fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf

Energy Storage

2010 Hydrogen and Fuel Cell Global Commercialization & Development Update
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/iphe_commercialization2010.pdf

Energy Metering

Guidance for Electric Metering in Federal Buildings
http://www1.eere.energy.gov/femp/pdfs/adv_metering.pdf

Conferences

GovEnergy
http://www.govenergy.com/

NDIA Environment, Energy Security, and Sustainability
http://e2s2.ndia.org/

World Energy Engineering Congress
http://www.energycongress.com/

GreenGov Symposium
http://www.whitehouse.gov/greengov/symposium

18.6 Appendix F: Biomass Equipment and Service Providers

Company	Equipment	Services	Web Site
Air Pollution Control			
Aget Manufacturing Company	• Cyclone Collectors • Coolant/Mist Collectors • Baghouse Systems		www.agetmfg.com
American Air Filter Co., Inc.	• Pollution Control Equipment		www.aafintl.com
Donaldson Company, Inc.	• Filters and Dust Collection Systems		www.donaldson.com
Fisher-Klosterman, Inc.	• Wet Scrubbers • Air Pollution Control Equipment		www.fkinc.com
FMC Corporation	• Dust Collectors • Scrubbers • NO_x and SO_x Abatement Equipment		www.envsolutions.fmc.com
Hamon Research-Cottrell	• Electrostatic Precipitators • Baghouses • Scrubbers • NO_x Removal • Flue Gas Desulfurization		www.hamon-researchcottrell.com
Met-Pro Systems	• Thermal Oxidizers • Recuperative Oxidizers • Regenerative Thermal Oxidizers • Catalytic Oxidizers • Baghouses • Scrubbers	• Retrofit/Revamp Existing Oxidizer Systems • Equipment Installation • Compliance Testing • Catalyst Activity Testing • Service for Start-Up • Periodic Maintenance	www.met-prosystems.com
Air Quality Services			
Pinnacle Engineering, Inc.		• Air Quality Compliance • Stack Testing • Web-Based Information Management • Contingency Plans • Safety and Risk Management Planning • Water Quality Services • Geotechnical Services	www.pineng.com

Company	Equipment	Services	Web Site
Belting			
Applied Power Products	• Elevator and Conveyor Belting	• Belt Selection Assistance	www.appliedpowerproducts.com
Biomass to Energy			
Eisenmann Environmental Systems	• Biogas	• Emissions Compliance • Energy Conservation • Low Carbon Solutions • Eliminate Dryer Bottlenecks • Reduce Carbon Footprint	www.eisenmann.com/biogasts
Boilers and Combustors			
Aeroglide Corp.			www.aeroglide.com
Alstrom Power	• Industrial and Package Boilers		www.alstrom.com
Andritz Inc.	• Biomass Boilers for Electricity Generation	• Design • Manufacture • Installation	www.andritz.com
Babcock & Wilcox	• Wood-Fired Boilers		www.babcock.com
Bigelow Company	• Wood-Fired Boilers	• Watertube and Firetube Designs	www.thebigelowcompany.com
Biomass Combustion Systems	• Wood-Fired Industrial • Package Boilers		www.biomasscombustion.com
C-B Nebraska Boiler	• Waste Burner Boilers	• Wood • Sawdust • Agricultural Wastes	www.neboiler.com
Coen Company, Inc.	• Wood-Fired Burners	• Suspension and Cyclone	www.coen.com
Combustion Service &Equipment Co.	• Wood-Fired Boilers	• Installation and Service	www.combustionservice.com
Deltak Corporation	• Wood-Fired Boilers • Waste-to-Energy Boilers		www.deltak.com
Detroit Stoker Company	• Reciprograte Stokers for Waste-to-Energy Conversion	• Biomass Combustion Technologies	www.detroitstoker.com
Dorr-Oliver Eimco	• Wood-Fired Fluidized Beds		www.dorrolivereimco.com

Company	Equipment	Services	Web Site
Earth Care Products, Inc.	• Wood-Fired Burners • Suspension and Cyclone Burners		www.ecpisystems.com
Energex Ltc.f	• Wood-Fired Suspension and Cyclone Burners		www.energex.com
Energy Products of Idaho	• Wood Residue Combustion and energy recovery systems • Fluidized beds		www.energyproducts.com
Foster Wheeler Corporation	• Wood Residue Fired Boilers	• Industrial and Utility	www.fwc.com
Heuristic Engineering Inc.	• Complete Wood Energy Combustion Systems		www.heuristicengineering.com
Hurst Boiler & Welding Company	• Wood-Fired Boiler Systems		www.hurstboiler.com
Indeck	• Biomass and Waste Stream Steam Generation Systems	• Design • Manufacture • Installation	www.INDECK.com
Johnston Boiler Company	• Wood-Fired Fluidized Beds		www.johnstonboiler.com
McBurney Boiler Systems	• Complete Biomass Boiler Systems		www.mcburney.com
Met-Pro Systems	• Waste Heat Boilers • Heat Recovery	• Equipment Installation • Compliance Testing • Start-Up Service • Maintenance	www.met-prosystems.com
Ray Burner Company	• Packaged Firetube Wood Residue Boilers and Auxiliary Burners		www.rayburner.com
The Teaford Co. Inc.	• Wood Fired Boiler Systems		www.teafordco.com
Victory Energy Operations, LLC	• Watertube Boilers • Firetube Boilers • Heat Recovery Steam Generators • Solar Powered Boilers • Rental Equipment	• Start-Up and Commissioning	www.victoryenergy.com

Company	Equipment	Services	Web Site
Wellons, Inc.	• Wood Residue Fired Steam Generating Plants • Boilers		www.wellonsusa.com
York-Shipley Boilers Inc.	• Complete Wood-Residue-Fired Combustion Systems • Conversion Units for Existing Boilers		www.wareinc.com/york
Pyrolysis and Gasification Systems			
Biomass Gas and Electric (BG&E)	• Gasification Systems		www.biggreenenergy.com
Energy Products of Idaho	• Single Fluid-Bed Biomass Gasifiers		www.energyproducts.com
Frontline Bioenergy, LLC			www.frontlinebioenergy.com
Heuristic Engineering Inc.	• Biomass Gasification		www.heuristicengineering.com
ICM Inc		• Biomass Conversion-All Feedstock	www.icminc.com
Nexterra Energy Corp.	• Gasification Systems		www.nexterra.ca
Centrifuges			
Roemer Machine & Welding Co. Inc.	• Centrifuge	• Repair Services • Total Reconditioning • Custom Modifications • Upgrade Services • Gearbox Repairs • Conveyor Modifications	
Consultants			
EAD Engineering LLC		• Mechanical, Electrical, Environmental, and Process Engineering • Biomass, Ethanol, and Biodiesel Processes • Construction • Controls	www.eadengineering.com

Company	Equipment	Services	Web Site
Kennedy and Coe, LLC		• Start-Up Consulting • Tax Incentive Consulting • Human Resources Consulting • Strategic Planning • Profit-Driven Tax and Audit Services	www.kcoe.com
Malcolm Pirnie, Inc.		• Environmental Consulting Services • Market Assessment and Procurement • Siting and Permitting • Design and Engineering • Construction, Compliance, and Operations	www.pirnie.com
Sega, Inc.		• Engineering (Mechanical, Electrical, Structural, Civil) and Technical Services • Design, Planning, Procurement, Construction, Training, and Field Services for Power Generation, Power Delivery, Air Quality, and Control Systems	http://www.segainc.com/
WorleyParsons Group, Inc.		• Resources & Engineering • Expertise in Power Generation, Process, and Environmental Engineering	http://www.worleyparsons.com/
Contractors, Engineers, and Millrights			
EAD Engineering LLC		• Engineering, Construction, and Controls • Mechanical, Electrical, Environmental, and Process Engineering • Experience in Biomass, Ethanol, and Biodiesel Processes	www.eadengineering.com
AGRA Industries, Inc.		• Design, Fabrication, and General Contracting (Specializing in Ethanol Facilities) • Storage • Feed Preparation • Traffic Flow • Excavating • Structural Design	www.agraind.com

Company	Equipment	Services	Web Site
Larson Contracting	• Grain Storage • Grain Handling • Pre-Engineered Buildings • Grain Monitoring Systems	• Construction Services	www.larsoncontracting.com
Larson Engineering	• Tanks • Bins • Foundations • Cranes • Conveyors • Supports	• Facilities and Engineering Design • Plant Layout and Design	www.larsonengr.com
McCormick Construction Company	• Steel Bins • Concrete Slip-form • Concrete Foundations and Slabs • Crane Services • Equipment Installation	• Design and Build • Project Management • Custom Fabrication • Millwright Services • Turnkey Construction	www.mccormickconstruction.com
Control Systems			
EAD Control Systems LLC	• Full Service Engineering • Construction • Controls	• Controls Integration Services • On-Site and Remote Service & Support	www.eadcontrols.com
Cooling Towers			
Midwest Towers, Inc.	• Manufacturing Facilities	• Engineering and Design • Pre-Engineered and Custom Designs • Counterflow and Crossflow Designs • Reconstruction and Upgrades	www.midwesttowers.com
Design and Build Contractors			
EAD Constructors, Inc		• Full Service Engineering • Construction • Controls • General Contracting • Design-Build • Construction Management	www.eadconstructors.com
Dryers			

Company	Equipment	Services	Web Site
Aeroglide Corporation	• Single or Triple Pass Rotary Dryers • Mixback Systems • Advanced Controls • Biomass Burner for Alternative Heat Source	• Drying Solutions for DDGS and Cellulose	www.aeroglide.com/ethanol
Aeroglide Corporation	• Dryers		www.aeroglide.com
AGRA Industries, Inc.	• Dryer Structure Fabrication • Fabrication of Dryer Components and Ducting • Custom Catwalks, Towers, Stairways, and Ladders • Custom Platforms and Equipment Structures; • Custom Stainless and Carbon Steel Fabrication	• Design • Fabrication • General Contracting (Specializing in Ethanol Facilities)	www.agraind.com
Brock Grain Systems	• Tower Grain Dryers	• Design and Installation	www.graindryers.com
Davenport Dryer, LLC	• Rotary Steam Tube Dryer	• Design and Manufacture	www.davenportdryer.com
Earth Care Products, Inc.	• Rotary Dryers • Related Fuel-Handling Equipment		www.ecpisystems.com
GEA Barr-Rosin Inc	• Ring Dryers • Superheated Steam Dryers • Rotary Dryers • Energy Integration • Retro-Fits	• Site Surveys and Audits • Biomass Combustion • Ethanol Co-Products	www.barr-rosin.com

Company	Equipment	Services	Web Site
ICM Inc.	• Steam Tube and Gas-Fired Rotary Dryers	• Design • Manufacture • Installation • Start-Up • Replacement Part Supply • Repair • Reconditioning	www.icminc.com
M-E-C Company	• Rotary Drum Dryers • Flash Tube Dryers • Wood Residue Fuel Preparation Systems		www.m-e-c.com
The Dupps Company	• Rotary Drum Dryers • Replacement Rotary Drums • Ring Dryers • Airless Dryer	• Design • Engineering • Manufacturing • Installation	www.dupps.com
Dust Collection			
Imperial Systems, Inc.	• Baghouses • Cyclones	• Installation	www.isystemsweb.com
Kinergy Corporation	• Dust Screens		www,kinergy.com
Waconia Manufacturing	• Dust Devil Telescopic Spout	• Installation	www.dustdevilmn.com
Electric Power Generation			
ABB, Inc	• Turnkey Power Generating Systems • Waste-to-Energy Systems		www.abb.us
Dresser-Rand	• Steam Turbine-Generator Sets (0.5 – 100 MW)		www.dresser-rand.com
Genreal Electric Co.	• Power Generating Systems		www.gepower.com
Siemens Power Generation	• Power Generation Systems		www.powergeneration.siemens.com
The Elliot Company	• Steam Turbines • Power Generation Equipment		www.wlliott-turbo.com
Environmental Compliance			

Company	Equipment	Services	Web Site
EAD Engineering LLC		• Engineering (Mechanical, Electrical, Environmental, and Process) • Construction • Controls	www.eadengineering.com
ICM Inc		• Site Security Planning • Hazardous Waste Characterization • Leak Detection and Repair • Permitting and Environmental Compliance	www.icminc.com
Pinnacle Engineering, Inc		• Air Quality Compliance • Stack Testing • Information Management • Water Quality Services • Geotechnical Services • Safety and Risk Management Planning • Turnkey Services for Plant Development	www.pineng.com
Hammermill Parts			
Roskamp Champion	• Replacement Parts		www.cpmroskamp.com
Hammermills			
Buhler Inc.	• Vertical Rotor Hammermill	• Design • Manufacture • Installation • Consulting	www.buhlergroup.com
Bliss Industries LLC	• Eliminator "Relief" Hammermill	• Design • Manufacture	www.bliss-industries.com
E.J. Heck & Sons Co.	• Hammermill Screens and Hammers	• Replacement Screens and Parts	www.ejheck.com
Heat Exchangers			
Apache Stainless Equipment Corp.	• Heat Exchangers • Evaporators	• Design • Manufacture	www.apachestainless.com
Lemke Industrial Machine, Inc	• Heat Exchanger Tube Sheets	• Design • Manufacture	www.lemkeindustrial.com

Company	Equipment	Services	Web Site
Manson Mfg., Inc.	• Heat Exchangers and Evaporators • Shell and Tube Heat Exchangers • Rotary Steam Tube Dryers	• Design • Manufacture • Installation	www.masonmfg.com
Peters Machine, Inc.	• Machining of Tube Sheets • Baffles • Flange Rings	• Heat Exchanger Fabrication	www.petersmachine.com
Sulzer Chemtech USA, Inc.		• Design • Manufacture • Servicing	www.sulzerchemtech.com
Victory Energy Operations, LLC	• Feedwater Economizers • Process "Cookwater" Economizers • Blowdown Heat Recovery	• Start-Up and Commissioning	www.victoryenergy.com
Materials Handling			
AGRA Industries, Inc.	• Structural Support Towers • Stairways and Catwalks • Bin Assembly • Hoppers • Tanks • Grinding and Dust Collection Systems	• Design • Fabrication • Erection • General Contracting	www.agraind.com
Advanced Metal Fabricators	• High/Low Pressure Pneumatic Material Conveying Systems		amffiltrex.com
Andritz Sprout-Bauer	• Pelletizing • Size Classification • Size Reduction • Materials Handling		www.andritzsproutbauer.com
Atlas Systems Corporation	• Shredded Wood Residue Storage Silos • Automatic Discharge Systems		www.atlassystems.nets
Brock Grain Systems	• Enclosed Roller-Belt Conveyors	• Design • Manufacture • Installation	www.brockgrain.com
Buhler Inc	• Chain Conveyors	• Design • Manufacture • Installation	www.buhlergroup.com

Company	Equipment	Services	Web Site
Dynatek/ Manierre	• Econoloader and Drag • Screw • Belt • Pneumatic Slide • Pneumatic or Gravity Conveying	• Design • Manufacture • Installation	www.dynatekmanierre.com
Ederer, LLC (PaR Systems)	• Rake Cranes • Conveyors		www.par.com
Eriez Magnetics	• Metal Separators		www.eriez.com
Fulghum Industries, Inc.	• Tree Shears • Wood Chippers • Screens • Sawmills		www.fulghum.com
Harvey Manufacturing Corporation	• Fuel Storage • Handling • Preparation Systems		www.harveymfg.com
Hi Roller	• Enclosed Belt Conveyors	• Design • Manufacture • Installation	www.hiroller.com
Industrial Process Equipment	• Bulk Solids Conveying • Processing • Storage • Weighing Solutions		www.industrialprocessequipment.com
John Deere Corporation	• Crop Residue Densifiers • Feller Bunchers • Skidders • Harvesters		www.deere.com
KC Supply Co., Inc.	• Inspection Doors • Belting • Bin Level Indicators • Hopper Gate Openers • Drag Conveyors	• Supply	www.kcsupply.com

Company	Equipment	Services	Web Site
Kinergy Corporation	• Vibrating Screens • Feeders • Conveyors		www,kinergy.com
K-Tron International	• Solids Handling Equipment • Metering Conveyors		www.ktroninternational.com
Lacey-Harmer Company	• Metal Detectors		www.laceyharmer.com
Laidig Inc.	• Wood Refuse Handling		www.laidig.com
Maren Engineering Corporation	• Baling Press for Wood, Shavings, Sawdust • Hydraulic Balers • Shredders		www.marenengineering.com
Morbark, Inc.	• Fuel Harvesting Machinery • Chip Classification Hardware • Wood Chipping and Grinding Equipment		www.morbark.com
Munson Machinery Company, Inc.	• Hogs • Hammermills • Wood Chipping/Shredding • Size Reduction Equipment		www.munsonmachinery.com
Precision Husky Corporation	• Total-Tree Chippers • Screens • Conveyors		www.precisionhusky.com
RBH Mill & Elevator	• Elevator Buckets and Belting • Screw Conveyors • Gaskets		www.millelevatorsupply.com
Rexnord, Inc	• Vibrating Conveyors • Conveying Accessories		www.rexnord.com
Schlagel, Inc.	• Round Bottom Drag Conveyor • Bucket Elevators	• Supply • Installation	www.schlagel.com

Company	Equipment	Services	Web Site
Schutte-Buffalo Hammer Mill	• Wood Grinders • Air Conveyors • Screw Elevating Equipment • Dumps • Hoists		www.hammermills.com
Screw Conveyor Corporation	• Wood Conveyors		www.screwconveyor.com
Union Iron Works	• Bucket Elevators • Truss and Tower	• Design • Manufacture • Installation	www.unionironworks.com
Warrior Mfg., LLC	• Catwalks • Support Towers	• Design • Manufacture • Installation	www.warriormfgllc.com
Wellons, Inc.	• Wood-Fuel Storage Bins • Conveyors		www.wellonsusa.com
West Salem Machinery	• Wood Grinders • Shredders • Screens		www.westsalem.com
Monitoring Equipment			
ICM Inc.		• Condition Monitoring • Predictive Maintenance Services	www.icminc.com
Maxi-Tronic, Inc		• Hazard Monitoring	www.maxitronic.com
Process-Control Systems, Inc		• Speed Monitors	www.maxigard.com www.zerospeedswitch.com
Pellet Mills			
Buhler Inc.			www.buhlergroup.com
California Pellet Mill	• Pelletizer Equipment		www.cpmroskamp.com
Permitting			

Company	Equipment	Services	Web Site
EAD Engineering LLC		• Engineering (Mechanical, Electrical, Environmental, and Process Engineering) • Construction • Controls	www.eadengineering.com
	Scales and Weigh Systems		
Cardinal Scale Mfg. Co.	• Heavy Duty Truck Scales • Remote Weight Displays	• Manufacture • Supply	www.cardinalscale.com
CompuWeigh	• Computerized Weighing Systems		www.compuweigh.com
	Tanks		
Advance Tank & Construction Co.	• Stainless Steel and Carbon Steel Tanks	• Tank Repair and Maintenance • Service and Construction • Engineering and Design Services	www.advancetank.com
Advanced Metal Fabricators	• Storage Bins		amffiltrex.com
ATEC Steel	• Tanks	• Design • Installation	www.atecsteel.com
Behlen Grain Systems **Behlen Building Systems**	• Storage Tanks • Storage Buildings	• Design • Construction	www.behlengrainsystems.com www.behlenbuildingsystems.com
Brock Grain Systems	• Storage Silos	• Design to Installation Services	www.brockgrain.com
WINBCO Tank Company	• Storage Tanks	• Fabrication • Construction	www.winbco.com
	Thermal Oxidizers		
Eisenmann Corporation	• Valveless Regenerative Thermal Oxidation for VOC Abatement	• Design • Installation	www.eisenmann.com
Indeck Power Equipment Co.	• Energy to Steam Conversion	• Design • Manufacture • Installation	www.indeck.com

Company	Equipment	Services	Web Site
Met-Pro Systems	• Thermal Oxidizers • Recuperative Oxidizers • Regenerative Thermal Oxidizers • Catalytic Oxidizers	• Retrofit/ Revamp of Existing Oxidizer • Equipment Installation • Compliance Testing • Catalyst Activity Testing • Service for Start-Up • Maintenance	www.met-prosystems.com
Pro-Environmental, Inc	• Regenerative Thermal Oxidizers • Regenerative Catalytic Oxidizers • Recuperative Oxidizers • Direct-Fired Oxidizers	• Engineering Feasibility Studies • Equipment Rebuilds and Upgrades • Service Technicians • Parts and Service	www.pro-env.com
Transportation Equipment			
Air-O-Flex Equipment Company	• Truck and Rail Dumps		airoflex.qwestoffice.net
Aldon Company, Inc.	• Railcar Wheel Chocks • Rail Safety Video Library	• Supply	www.aldonco.com
Calbrandt	• Railcar Gate Openers • Indexers • Progressors	• Supply	www.brdt.biz
Hallco Manufacturing Co., Inc.	• Live-Bottom Trailers		www.hallcomfg.com
KC Supply Co., Inc	• Door Demon Hopper Gate Opener	• Supply	www.kcsupply.com
RBH Mill & Elevator	• Automatic Railcar Gate Opener	• Supply	www.millelevatorsupply.com
Screw Conveyor Corporation	• Truck Dumps		www.screwconveyor.com
Shuttlewagon, Inc.	• Mobile Railcar Movers	• Supply	www.shuttlewagon.com
Trackmobile, Inc.	• Titan Railcar Mover	• Supply	www.trackmobile.com

18.7 Appendix G: Strategies and Methods for Implementing Renewable Energy Projects

Devising a plan to initiate renewable energy projects is crucial to getting a project financed. The following steps provide a basic guide to develop a strategy to assess the feasibility and obtain the leadership and support required for implementing renewable projects.

- Step 1: Establish vision and leadership
- Step 2: Determine project feasibility
- Step 3: Develop team and partners
- Step 3: Establish financing
- Step 4: Promote the project
- Step 5: Celebrate, learn, and share information

18.8 Appendix H: Incentives

The Database of State Incentives for Renewables and Efficiency (DSIRE) is a comprehensive source of information on state, local, utility and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995 and funded by the US Department of Energy, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council.[411] The following is a list of the type of information provided by the database.

- 3rd-Party Solar PPA Policies
- Grant Programs for Renewables
- Loan Programs for Renewables
- Interconnection Standards
- Net Metering Policies
- Property Assessed Clean Energy (PACE) Financing Policies
- Property Tax Incentives for Renewables
- Public Benefits Funds for Renewables
- Rebate Programs for Renewables
- Renewable Portfolio Standards
- Sales Tax Incentives for Renewables
- State RPS Policies with Solar/DG Provisions
- Tax Credits for Renewables

The following provides a listing of current financial incentives (as of 2010) from the DSIRE website.

- Corporate Deduction
  - Energy-Efficient Commercial Buildings Tax Deduction
- Corporate Depreciation
  - Modified Accelerated Cost-Recovery System (MACRS) + Bonus Depreciation (2008-2009)
- Corporate Exemption

  - Residential Energy Conservation Subsidy Exclusion (Corporate)
- Corporate Tax Credit
  - Business Energy Investment Tax Credit (ITC)
  - Energy-Efficient New Homes Tax Credit for Home Builders
  - Renewable Electricity Production Tax Credit (PTC)
- Federal Grant Program
  - Tribal Energy Program Grant
  - U.S. Department of Treasury - Renewable Energy Grants
  - USDA - Rural Energy for America Program (REAP) Grants
- Federal Loan Program
  - Clean Renewable Energy Bonds (CREBs)
  - Energy-Efficient Mortgages
  - Qualified Energy Conservation Bonds (QECBs)
  - U.S. Department of Energy - Loan Guarantee Program
  - USDA - Rural Energy for America Program (REAP) Loan Guarantees
  - Industry Recruitment/Support
  - Energy-Efficient Appliance Manufacturing Tax Credit
  - Qualifying Advanced Energy Manufacturing Investment Tax Credit
- Personal Exemption
  - Residential Energy Conservation Subsidy Exclusion (Personal)
- Personal Tax Credit
  - Residential Energy Efficiency Tax Credit
  - Residential Renewable Energy Tax Credit
- Production Incentive
  - Renewable Energy Production Incentive (REPI)

Some of the rules, regulations, and policies included in the database are:

- Appliance/Equipment Efficiency Standards
  - Federal Appliance Standards
- Energy Standards for Public Buildings
  - Energy Goals and Standards for Federal Government
- Green Power Purchasing
  - U.S. Federal Government - Green Power Purchasing Goal
- Interconnection
  - Interconnection Standards for Small Generators

19 BIBLIOGRAPHY

[1] Geiss, K., "Army Energy Security," Society of American Military Engineers, May 2009.

[2] Lally, B.J., "Making a Case for Energy Security in an Energy-Climate Revolution," *GovEnergy*, August 2009.

[3] "Guidance for Electric Metering in Federal Buildings," DOE/EE-0312, US Department of Energy, February 2006.

[4] Strahs, G., and C. Tombari, "Laying the Foundation for a Solar America: The Million Solar Roofs Initiative," Final Report, US Department of Energy, October 2006.

[5] "Energy Independence and Security Act of 2007," One Hundred Tenth Congress, Public Law 110-140, December 2007.

[6] "Energy Independence & Security Act," Federal Energy Management Program, http://www1.eere.energy.gov/femp/regulations/eisa.html, accessed August 2010.

[7] "Installation Energy Management," *Department of Defense Instruction 4170.11*, Under Secretary of Defense for Acquisition, Technology, and Logistics, December 2009.

[8] "Instructions for Implementing Executive Order 13423," The Council on Environmental Quality, March 2007.

[9] Crawley, A. S., "Meet Your Federal Renewable Goals," *GovEnergy*, August 2008.

[10] "Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding," *White House Summit on Federal Sustainable Buildings*, January 2006.

[11] "Military Construction Project Data," Under Secretary of Defense (Comptroller) and Chief Financial Officer, DD Form 1391, July 1999.

[12] "Department of Defense Energy Manager's Handbook," Office of Deputy Under Secretary of Defense (Installations and Environment), August 2005.

[13] "Standard Practice for Unified Facilities Criteria and Unified Facilities Guide Specifications," Department of Defense, MIL-STD-3007F, December 2006.

[14] "Unified Facilities Criteria – Energy Conservation", Department of Defense UFC 3-400-01, July 2002.

[15] "Cool Roofs and Title 24," The California Energy Commission, http://www.energy.ca.gov/title24/coolroofs/, accessed August 2010.

[16] "Facilities Engineering, Army Facilities Management," Army Regulation 420-1, Department of the Army, February 2008.

[17] "Facilities Engineering, Acquisition and Sale of Utilities Services," Army Regulation 420-41, September 1990.

[18] "The U.S. Army Energy and Water Campaign Plan for Installations," Department of the Army, December 2007. (http://army-energy.hqda.pentagon.mil/docs/AEWCampaignPlan.pdf)

[19] "Energy Management," Air Force Policy Directive 90-17, Department of the Air Force, July 2009.

[20] "Energy Management," Air Force Instruction 90-1701, Department of the Air Force, July 2009.

[21] "Air Force Energy Plan 2010," Department of the Air Force. (http://www.safie.hq.af.mil/shared/media/document/AFD-091208-027.pdf)

[22] "Naval Energy: A Strategic Approach," Department of the Navy, October 2009. (http://www.onr.navy.mil/en/naval-energy-forum/~/media/5EFD428CFEB0412391CC321DCAF67138.ashx)

[23] Communications with Timothy Schwartz, Office of the Deputy Assistant Secretary of the Air Force for Energy, Environment, Safety, and Occupational Health, July 2010.

[24] "Energy Conservation Standards for New Federal Commercial and Multi-Family High-Rise Residential Buildings and New Federal Low-Rise Residential Buildings," *Federal Register*, Vol. 72, No. 245, December 2007. (http://www1.eere.energy.gov/femp/pdfs/fr_notice_cfr433_434_435.pdf)

[25] "Air Force Sustainable Design and Development Policy," Department of the Air Force, AFD-080609-022, July 2007.

[26] "Renewable Energy Requirement Guidance for EPAct 2005 and Executive Order 13423," Federal Energy Management Program, January 2008. (http://www1.eere.energy.gov/femp/pdfs/epact05_fedrenewenergyguid.pdf)

[27] "Guidance for Electric Metering in Federal Buildings," Department of Energy, DOE/EE-0312, February 2006. (http://www1.eere.energy.gov/femp/pdfs/adv_metering.pdf)

[28] Sullivan, G.P., R. Pugh, and W.D. Hunt, "Metering Best Practices: A Guide to Achieving Utility Resource Efficiency," Department of Energy, October 2007. (http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf)

[29] "Procuring Energy-Efficient Products," Federal Energy Management Program, http://www1.eere.energy.gov/femp/technologies/procuring_eeproducts.html, accessed August 2010.

[30] "Appropriated Funds – ECIP," Army Energy Program, http://army-energy.hqda.pentagon.mil/funding/ecip.asp, accessed August 2010.

[31] "Energy Conservation Investment Program Guidance," Office of the Assistant Secretary of Defense, March 1993.

[32] "Installation Energy (DLA-Energy)," Defense Logistics Agency, https://www.desc.dla.mil/DCM/DCMPage.asp?pageid=164, accessed August 2010.

[33] "The Energy Branch at CERL," US Army Corps of Engineers, http://www.cecer.army.mil/td/tips/docs/Energy%20Branch%20Systems%20trifold.pdf, accessed August 2010.

[34] "Energy and Utilities Department," Naval Facilities Engineering Command, https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/energy, accessed August 2010.

[35] "Air Force Civil Engineer Support Agency," US Air Force, http://www.afcesa.af.mil/divisions/cen/index.asp, accessed August 2010.

[36] "Engineering Technical Letter (ETL) 09-8: Resource Efficiency Manager (REM) Tracking and Results Verification," Department of the Air Force, March 2009. (http://www.wbdg.org/ccb/AF/AFETL/etl_09_8.pdf)

[37] Smith, J. M., H. C. Van Ness and M. M. Abbott, *Introduction to Chemical Engineering Thermodynamics*, Fifth Edition, McGraw-Hill, 1996.

[38] Podolski, W.F., D.K. Schmalzer, V. Conrad, "Energy Resources, Conversion, and Utilization," *Perry's Chemical Engineering Handbook*, 8th Edition, McGraw-Hill, 2008.

[39] "Natural Gas Transportation Information System," Natural Gas Pipeline Database, Energy Information Administration, December 2008.

[40] Armor, A.F., E.A. Harvego, and K.D. Kok, "Generation Technologies through the Year 2025," *Handbook of Energy Efficiency and Renewable Energy*, CRC Press, 2007, pp. 6.1-6.49.

[41] "Coal Fired Power Plants List," Energy Information Agency, December 2008.

[42] "Existing Generating Units in the United States by State, 2008 Preliminary," Energy Information Agency, http://www.eia.doe.gov/cneaf/electricity/page/capacity/capacity.html, accessed March 2010.

[43] "A Brief History of Coal Use," Fossil Energy Office of Communications, Department of Energy, http://fossil.energy.gov/education/energylessons/coal/coal_history.html, accessed August 2010.

[44] "Knocking the NOx Out of Coal," Department of Energy, http://fossil.energy.gov/education/energylessons/coal/coal_cct3.html, accessed August 2010.

[45] "A 'Bed' for Burning Coal?," Department of Energy, http://fossil.energy.gov/education/energylessons/coal/coal_cct4.html, accessed August 2010.

[46] "Fluidized Bed Technology – Overview," Department of Energy, http://www.fossil.energy.gov/programs/powersystems/combustion/fluidizedbed_overview.html, accessed August 2010.

[47] Duncan, J.V., and J.L. Hebb, "CCPI/ Clean Coal Demonstrations: JEA Large-Scale CFB Combustion Demonstration Project." National Energy Technology Laboratory, http://www.netl.doe.gov/technologies/coalpower/cctc/summaries/jacks/jackeademo.html, accessed May 2010.

[48] "The Clean Coal Technology Program," Department of Energy, http://fossil.energy.gov/education/energylessons/coal/coal_cct2.html, accessed August 2010.

[49] "Carbon Capture and Storage R&D Overview," Department of Energy, http://www.fossil.energy.gov/programs/sequestration/overview.html, accessed August 2010.

[50] "How Coal Gasification Power Plants Work," Fossil Energy Office of Communications, Department of Energy, http://www.fossil.energy.gov/programs/powersystems/gasification/howgasificationworks.html, accessed August 2010.

[51] Bonskowski, R., "EIA Coal Statistics, Projections, and Analyses: What They Say About Changes in the Coal Industry," Energy Information Agency, SME Central Appalachian Section Spring Meeting, April 2004.

[52] Carey, F.A., *Organic Chemistry*, Third Edition, McGraw Hill, 1996.

[53] "Refining and Processing: Refinery Yield," Energy Information Administration, June 2009. (http://tonto.eia.doe.gov/dnav/pet/pet_pnp_pct_dc_nus_pct_a.htm)

[54] "Glossary," Energy Information Administration, http://www.eia.doe.gov/glossary/index.cfm, accessed August 2010.

[55] Ritter, S., *Chemical and Engineering News*, Vol. 83, No. 8, p.37, 2005.

[56] "Definitions, Sources, and Explanatory Notes," Energy Information Administration, http://tonto.eia.doe.gov/dnav/pet/tbldefs/pet_pri_refoth_tbldef2.asp, accessed August 2010.

[57] Hemighaus, G., T. Boval, and J. Bacha, "Aviation Fuels Technical Review," Chevron, 2006.

[58] "Gas Production in Conventional Fields, Lower 48 States," Energy Information Administration, http://www.eia.doe.gov/oil_gas/rpd/conventional_gas.jpg, accessed August 2010.

[59] "Overview of Natural Gas," NaturalGas.org, http://www.naturalgas.org/overview/background.asp, accessed August 2010.

[60] "Composition of Methane," Physics Reference Data, National Institute of Standards and Technology Physics Laboratory, http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=197, accessed August 2010.

[61] "Properties of Air," eFunda Engineering Fundamentals, http://www.efunda.com/Materials/common_matl/show_gas.cfm?MatlName=Air0C, accessed August 2010.

[62] "Clean Alternative Fuels: Compressed Natural Gas," US Environmental Protection Agency, EPA420-F-00-033, March 2002. (http://www.afdc.energy.gov/afdc/pdfs/epa_cng.pdf)

[63] "Natural Gas," Clean Cities Fact Sheet, US Department of Energy Energy Efficiency and Renewable Energy Vehicle Technologies Program, October 2008.

[64] "About U.S. Natural Gas Pipelines: Transporting Natural Gas," Energy Information Administration, 2009.

[65] "What is Propane?," Department of Energy, http://www.afdc.energy.gov/afdc/fuels/propane_what_is.html, accessed August 2010.

[66] "Propane as an Alternative Fuel," Department of Energy, http://www.afdc.energy.gov/afdc/fuels/propane_alternative.html, accessed August 2010.

[67] "Fuel Properties," Department of Energy, http://www.afdc.energy.gov/afdc/fuels/properties.html, accessed August 2010.

[68] Propane Education & Research Council, http://www.propanecouncil.org/, accessed August 2010.

[69] "US Nuclear Reactors," Energy Information Administration," Department of Energy, http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html, accessed August 2010.

[70] Crowley, T.D., T.D. Corrie, D.B. Diamond, S.D. Funk, W.A. Hansen, A.D. Stenhoff, D.C. Swift, "Transforming the Way DoD Looks at Energy: an Approach to Establishing an Energy Strategy," LMI Government Consulting, April 2007.

[71] "Supply of Uranium," World Nuclear Association, http://www.world-nuclear.org/info/inf75.html, accessed August 2010.

[72] "Inherently Safe Nuclear Power for the 21st Century," General Atomics, http://gt-mhr.ga.com/, accessed August 2010.

[73] "Evolution of Nuclear Power," Gen IV International Forum, http://www.gen-4.org/Technology/evolution.htm, accessed August 2010.

[74] Deutch, J.M., and E.J. Moniz, "The Nuclear Option," *Scientific American*, September 2006. (http://www.scientificamerican.com/article.cfm?id=the-nuclear-option)

[75] Dictionary of Scientific and Technical Terms, Fifth Edition, Sybil P. Parker, Ed., McGraw-Hill, 1994.

[76] Blackwell, K.E., "The Department of Defense: Reducing Its Reliance on Fossil-Based Aviation Fuel – Issues for Congress," CRS Report for Congress, RL34062, June 2007.

[77] Smith, E.H., *Mechanical Engineers' Reference Book*, 12th Edition, 1998.

[78] Breen, S.-P., "Community Owned Independent Power Production: Challenges and Opportunities," *Renewable Energy World Magazine North America*, Vol. 1, No. 1, 2009.

[79] Halcrow, S.D., "Green Energy for the Battlefield," Naval Postgraduate School, 2007. (DTIC Doc. ADA475991)

[80] "Types of Hydropower Plants," DOE Energy Efficiency & Renewable Energy Wind & Water Power Program, http://www1.eere.energy.gov/windandhydro/hydro_plant_types.html, accessed May 2010.

[81] Glover, C., and C. Behrens, "Energy: Selected Fuels and Numbers," CRS Report for Congress, 2008.

[82] "Small Hydropower Systems," DOE National Renewable Energy Laboratory, DOE/GO-102001-1173, 2001.

[83] Hall, D.G, K.S. Reeves, J. Brizzee, R.D. Lee, G.R. Carroll, and G.L. Sommers, "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants," Idaho National Laboratory, DOE-ID-11263, January 2006. (http://hydropower.inel.gov/resourceassessment/pdfs/main_report_appendix_a_final.pdf)

[84] "Hydropower: Going With the Flow," National Geographic, http://environment.nationalgeographic.com/environment/global-warming/hydropower-profile/, accessed June 2010.

[85] "Niagara Power Project," New York Power Authority, http://www.nypa.gov/facilities/niagara.htm, accessed May 2010.

[86] "Hydroelectric Dam," Tennessee Valley Authority, http://www.tva.com/power/hydroart.htm, accessed August 2010.

[87] "Generators and Exciters," US Army Corps of Engineers, http://www.nwp.usace.army.mil/HDC/edu_genexcit.asp, accessed August 2010.

[88] "Hydropower," *Secondary Energy Infobook*, The Need Project, 2004, http://www.mms.gov/omm/pacific/kids/Watts/Appendix/92.%20Hydro.pdf, accessed June 2010.

[89] "Hydropower: Types of Hydropower Facilities," Idaho National Laboratory, http://hydropower.inel.gov/hydrofacts/hydropower_facilities.shtml, accessed June 2010.

[90] Munson, B.R., D.F. Young, and T.H. Okiishi, *Fundamentals of Fluid Mechanics*, 5th Edition, John Wiley & Sons, 2006.

[91] Hilsinger, J., "Hydro Turbine Manufacturer's Perspective," *Renewable Energy World Conference*, February 2010.

[92] "Types of Hydropower Turbines," US DOE Wind & Water Power Program, http://www1.eere.energy.gov/windandhydro/hydro_turbine_types.html, accessed June 2010.

[93] "Microhyropower Systems, Turbines, Pumps, and Waterwheels," Department of Energy, http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=11120, accessed June 2010.

[94] "Hydropower Projects," Federal Energy Regulatory Commission, http://www.ferc.gov/media/photo-gallery/photo-gallery-hydro.asp, accessed June 2010.

[95] Agoris, D.P., "New and Renewable Energy Technologies: Prospects for Their Deployment in Small Scale Power Production and Distributed Generation," *Gaseous Dielectrics X*, 2004. (DTIC Doc. ADP019528)

[96] "Hydropower: Plant Costs and Production Expenses," Idaho National Laboratory, http://hydropower.inel.gov/hydrofacts/plant_costs.shtml, accessed June 2010.

[97] "Hydrogen," Periodic Table of Elements, Los Alamos National Laboratory, http://periodic.lanl.gov/elements/1.html, accessed August 2010.

[98] Sandler, S.I., *Chemical and Engineering Thermodynamics*, John Wiley & Sons, 1989, p. 602.

[99] "Hydrogen Data Book," Hydrogen Analysis Resource Center, Department of Energy, http://hydrogen.pnl.gov/cocoon/morf/hydrogen/article/103, accessed August 2010.

[100] "NIST ChemistryWeb Book," National Institute of Standards and Technology, http://webbook.nist.gov/chemistry/, accessed August 2010.

[101] "Safety Standard for Hydrogen and Hydrogen Systems," Office of Safety and Mission Assurance, National Aeronautics and Space Administration, NSS 1740.16, 1997.

[102] "Hydrogen Fuel Cell Engines and Related Technologies. Module 1: Hydrogen Properties," US DOE, 2001. (http://www.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/fcm01r0.pdf)

[103] "Hydrogen Production: Natural Gas Reforming," Hydrogen, Fuel Cells & Infrastructure Technologies Program, US Department of Energy, http://www1.eere.energy.gov/hydrogenandfuelcells/production/natural_gas.html, accessed August 2010.

[104] "Biomass and Conversion Technologies: Gasification," California Integrated Waste Management Board, http://www.ciwmb.ca.gov/, accessed August 2010.

[105] de Almeida, A.T., P.S. Moura, C.W. Gellings, and K.E. Parmenter, "Distributed Generation and Demand-Side Management," *Handbook of Energy Efficiency and Renewable Energy*, CRC Press, 2007, pp. 5.1-5.53.

[106] "Annual Energy Review 2009," Energy Information Administration. DOE/EIA-0384(2009), August 2010.

[107] Mesaros, L., "Energy 101," Federal Energy Management Program, First Thursday Seminars, March 2010.

[108] "DoD Energy Security Task Force," Director, Defense Research and Engineering, http://www.dod.gov/ddre/doc/DoD_Energy_Security_Task_Force.pdf, accessed August 2010.

[109] "2009 Buildings Energy Data Book," US Department of Energy, Energy Efficiency & Renewable Energy, October 2009.

[110] "Department of Defense Base Structure Report: Fiscal Year 2009 Baseline (A Summary of DoD's Real Property Inventory)," Office of the Deputy Under Secretary of Defense (Installations & Environment), September 2009.

[111] "Department of Defense Annual Energy Management Report, Fiscal Year 2009," Office of the Deputy Under Secretary of Defense (Installations & Environment), May 2010.

[112] "Department of Defense Annual Energy Management Report, Fiscal Year 2007," Office of the Deputy Under Secretary of Defense (Installations & Environment), January 2008.

[113] "Department of Defense Annual Energy Management Report, Fiscal Year 2008," Office of the Deputy Under Secretary of Defense (Installations & Environment), January 2009.

[114] Lally, B.J., "Department of Defense Facilities Energy Use, Strategies and Goals," *GovEnergy*, August 2009. (http://www.govenergy.com/2009/pdfs/presentations/Legislation-Session02/Legislation-Session02-Lally_Brian.pdf)

[115] Hancock, B. “Department of Defense Energy Use, Strategies and Goals,” *GovEnergy*, August 2007. (http://www.govenergy.com/2007/pdfs/procurement/Hancock_Procurement_track_S3.pdf)

[116] “The Air Force Renewable Energy Opportunity – Enhanced Use Leasing,” *Renewable Energy World Conference*, February 2010.

[117] “Air Force Infrastructure Energy Plan 2010,” US Air Force, http://www.safie.hq.af.mil/shared/media/document/AFD-091208-024.pdf, accessed August 2010.

[118] Lyle, A., “Air Force, Industry Leaders Brainstorm at Renewable Energy Industry Day,” Secretary of the Air Force Public Affairs, December 2010. (http://www.af.mil/news/story.asp?id=123234529)

[119] “The US Army Energy Strategy for Installations,” Department of the Army, July 2005.

[120] Waugaman, W., “Electrical Energy Security in the Domestic Theater,” *NDIA Environment, Energy Security & Sustainability Conference*, National Defense Industrial Association, June 2010.

[121] “Dynamic Maps, GIS Data, & Analysis Tools,” National Renewable Energy Laboratory, http://www.nrel.gov/gis/data_analysis.html, accessed August 2010.

[122] “Standby Charges and Fuel Cells,” Clean Energy Group, September 2005. (http://www.cleanenergystates.org/library/Reports/Standby_Charges_and_Fuel_Cells_Sept05.pdf)

[123] “Electric Conversions,” Energy Information Administration, http://www.eia.doe.gov/electricity/page/prim2/charts.html, accessed August 2010.

[124] Bellemare, B., “What is a Megawatt?,” UtiliPoint International, http://www.utilipoint.com/issuealert/print.asp?id=1728, accessed August 2010.

[125] “Electric Power Annual,” Energy Information Administration, http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html, accessed August 2010.

[126] “Power Plant Performance Factors,” The Engineering Toolbox, http://www.engineeringtoolbox.com/power-plant-efficiency-d_960.html, accessed August 2010.

[127] Hynes, J., “How to Compare Power Generation Choices,” *Renewable Energy World Magazine North America*, Vol. 1, No. 1, 2009, pp. 38 – 43.

[128] Cordaro, M., “Understanding Base Load Power: What It Is and Why It Matters,” New York Affordable Reliable Electricity Alliance, October 2008.

[129] “Average Capacity Factors by Energy Source, 1997 through 2008,” Energy Information Administration, http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfile5_2.pdf, accessed August 2010.

[130] “Wind Power: Capacity Factor, Intermittency, and What Happens When the Wind Doesn’t Blow?,” Community Wind Power Fact Sheet, No. 2a, University of Massachusetts at Amherst.

[131] “20% Wind Energy by 2030: Increasing Wind Energy’s Contribution to U.S. Electricity Supply,” Department of Energy, DOE/GO-102008-2567, May 2008. (http://www.windpoweringamerica.gov/pdfs/20_percent_wind_2.pdf)

[132] Meacham, J., “Zero Net Energy Buildings,” *Solar Power International Conference*, October 2009.

[133] “The History of Solar,” Department of Energy, http://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf, accessed August 2010.

[134] “2008 Renewable Energy Technology Data Book,” Department of Energy, July 2009.

[135] Newell, R., “Annual Energy Outlook 2010,” Energy Information Administration, December 2009.

[136] *Handbook of Photovoltaic Science and Engineering*, edited by A. Luque and S. Hegedus, John Wiley and Sons, 2003.

[137] “Crystalline Silicon Shipment and Thin-Film Shipment Market Shares,” Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/figure3_3.html, accessed August 2010.

[138] Kurtz, S., "Reliability Challenges for Solar Energy", *IEEE International Reliability Physics Symposium,* NREL/PR-520-44970, April 2009.

[139] Energy Efficiency & Renewable Energy, Department of Energy, http://www1.eere.energy.gov, accessed August 2010.

[140] Malin, M., "The Greenest of the Green," US Army, April 2009. (www.army.mil/-images/2009/04/16/35347/index.html)

[141] "2009 Nellis Energy Summit," US Air Force, http://www.nellis.af.mil/2009nellisenergysummit.asp, accessed August 2010.

[142] McKenna, P., "Concentrated Solar Set to Shine," *Technology Review*, MIT, April 2010.

[143] National Renewable Energy Laboratory, Department of Energy, http://www.nrel.org, accessed August 2010.

[144] "A Guide to Photovoltaic (PV) System Design and Installation," California Energy Commission, June 2001.

[145] Denholm P., and R. M. Margolis, "Impacts of Array Configuration on Land-Use Requirements for Large-Scale Photovoltaic Deployment in the United States," National Renewable Energy laboratory, NREL/CP-670-42971, May, 2008.

[146] Foster, R., M. Ghasemi, and A. Cota, "Solar Thermal Systems and Applications," *Solar Energy: Renewable Energy and the Environment*, CRC Press, 2010.

[147] "Average Thermal Performance Rating of Solar Thermal Collectors by Type Shipped," Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_14.html, accessed August 2010.

[148] Energy Efficiency and Renewable Energy, Department of Energy, http://www1.eere.energy.gov/, accessed August 2010.

[149] Foster, R., M. Ghassemi and A. Cota, "Solar Energy: Renewable Energy and the Environment," CRC Press, 2010.

[150] "Transpired Solar Collectors: Success Stories," Office of Power Technologies, Energy Efficiency and Renewable Energy, Department of Energy, 1998.

[151] Brown, D.S., "An Evaluation of Solar Air Heating at United States Air Force Installations," Air force Institute of Technology, AFIT/GCA/ENV/09-M03, March 2009.

[152] "Overview of Solar Thermal Technologies," Department of Energy, www1.eere.energy.gov/ba/pba/pdfs/solar_overview.pdf, accessed August 2010.

[153] Burkholder, F., and C. Kutscher, "Heat Loss Testing of Sobel's UVAC3 Parabolic Trough Receiver," National Renewable Energy Laboratory, NREL/TP-550-42394, January 2008.

[154] Burkholder F., and C. Kutscher, "Heat Loss Testing of Schott's 2008 PTR70 Parabolic Trough Receiver," National Renewable Energy Laboratory, NREL/TP-550-45633, May 2009.

[155] "U.S. Parabolic Trough Power Plant Data," National Renewable Energy Laboratory, http://www.nrel.gov/csp/troughnet/power_plant_data.html, accessed August 2010.

[156] "Survey of Thermal Storage for Parabolic Trough Power Plants," National Renewable energy Laboratory, NREL/SR-550-27925, September 2000.

[157] Geyer, M.A., "Thermal Storage for Solar Power Plants," C.-J. Winter, R.L. Sizmann, L.L. Vant-Hull (Eds.), *Solar Power Plants*, 1991.

[158] "Status Report on Solar Thermal Power Plants," Pilkington Solar International, 1996. (ISBN 3-9804901-0-6)

[159] Burroughs, C., "Record-Setting Solar Power," *Sandia Technology Magazine*, Sandia National Laboratories, http://www.sandia.gov/news/publications/technology/2008/1008/solar.html#top, accessed August 2010.

[160] "Solar-to-Grid Power System Achieves 31.25% Efficiency," *Advanced Materials & Processes*, ASM International, Vol. 166, No. 6, June 2008.

[161] Bureau of Land Management, US Department of the Interior, http://www.blm.gov/pgdata/etc/medialib/blm/ca/images/pa/energy/solar.Par.79604.Image.500.333.1.gif, accessed August 2010.

[162] "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts," National Renewable Energy Laboratory, NREL/SR-550-34440, October 2003.

[163] Coonen, S., "Building Integrated Photovoltaics," *ORNL Solar Summit*, October 2007.

[164] "DoD Renewable Energy Assessment," Final Report, Office of the Secretary of Defense, March 2005.

[165] "Solar Photovoltaic Cell/Module Manufacturing Activities," Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/solarphotv/solarpv.html, accessed August 2010.

[166] Wiser, R., G. Barbose, and C. Peterman, "Tracking the Sun: The Installed Cost of Photovoltaics in the U.S. from 1998-2007," Lawrence Berkeley National Laboratory, LBNL-1516E, February 2009.

[167] "Solar Thermal," Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/solarthermal/solarthermal.html, accessed August 2010.

[168] "Dynamic Maps, GIS Data, & Analysis Tools: Solar Maps," National Renewable Energy Laboratory, http://www.nrel.gov/gis/solar.html, accessed August 2010.

[169] Fort Carson Renewable Energy Presentation (courtesy of Vince Guthrie, Utilities Program, Ft. Carson).

[170] Lopez, C.T., "Army Aims to Reduce Greenhouse Gases, 'Carbon Bootprint'," US Army, April 2009. (http://www.army.mil/-news/2009/04/06/19315-army-aims-to-reduce-greenhouse-gases-carbon-bootprint/)

[171] "U.S. Army – Ft. Carson, Colorado," Federal Energy Management Program, Department of Energy, http://www1.eere.energy.gov/femp/technologies/renewable_ftcarson.html, accessed August 2010.

[172] "Success Stories: Siting Renewable Energy on Contaminated Land," US Environmental Protection Agency.

[173] Henley, C.D., S.C. Hunt, and D.A. Phillips, "Nellis Air Force Base, Nevada Photovoltaic Project," Naval Postgraduate School, December 2007.

[174] "Ascension Island Greenway," US Air Force, June 2009.

[175] "Achieving U.S. Energy Security," The Industrial College of the Armed Forces, 2008. (DTIC Doc. ADA487623)

[176] Thresher, R., M. Robinson, and P. Veers, "The Future of Wind Energy Technology in the United States," *World Renewable Energy Congress*, October 2008.

[177] "US Department of Energy Wind and Hydropower Technologies: Top 10 Accomplishments," Department of Energy, May 2008. (OSTI ID 929589)

[178] Newhouse, N., A. Bennett, "AWEA National Survey," AWEA, March 2010.

[179] Phadke, R., C. Manning, A. Diebolt, and M. Kazinka, "Wind Energy and Scenic Considerations in Wyoming: Workshop Report," University of Wyoming, August 2009.

[180] Sagrillo, M., "Wind Turbines and Birds: Putting the Situation in Perspective in Wisconsin," *Wisconsin Focus on Energy*, 2007. (REN-2033-0207)

[181] "U.S. Fish and Wildlife Service Wind Turbine Guidelines Advisory Committee: Recommendations to the Secretary of Interior," Wind Turbine Guidelines Advisory Committee, March 2010.

[182] "How Loud Is a Wind Turbine?," GE Reports, http://www.gereports.com/how-loud-is-a-wind-turbine/, accessed February 2011.

[183] “"Why Are Wind Turbines Getting Bigger?," Terra-Magnetica, http://www.terramagnetica.com/2009/08/01/why-are-wind-turbines-getting-bigger/, accessed August 2010.

[184] Halcrow, S.D., "Green Energy for the Battlefield," Naval Postgraduate School, December 2007. (DTIC Doc. ADA199574)

[185] "What Is a Wind Turbine and How Does It Work?," US Coast Guard, http://www.uscg.mil/d1/SFOSouthwestHarbor/innovation/wind/wind_101.asp, accessed August 2010.

[186] Robinson, M., and W. Musial, "Offshore Wind Technology Overview," Department of Energy, NREL/PR-500-40462, October 2006. (http://www.nrel.gov/docs/gen/fy07/40462.pdf)

[187] Hurst, T.B., "Plans for Floating Offshore Wind Farm Making Waves in Mass.," Crisp Green, October 2009.

[188] Bratland, S.H.-, "The World's First Full Scale Floating Wind Turbine: Experience and Possibilities," *2010 WindPower Conference & Exhibition*, May 2010.

[189] Milligan, M., and K. Porter, "Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation, *2008 WindPower Conference & Exhibition*, June 2008.

[190] Lopez, M., and J-C. Vannier, "Stand-Alone Wind Energy Conversion System With Maximum Power Transfer Control," *Ingeniare Revista Chilena de Ingenieria*, Vol. 17, No. 3, pp. 329-336, 2009.

[191] White, E., "Resolving Wind Plant Underperformance: A Follow-Up from Renewable Energy World 2009," *Renewable Energy World Conference*, February 2010.

[192] "Wind Turbine Technology," *Renewable Energy World Conference*, February 2010.

[193] Nelson, V., *Wind Energy: Renewable Energy and the Environment*, CRC Press, 2009.

[194] "Wind," Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/wind/wind.html, accessed August 2010.

[195] "United States – Annual Average Wind Speed at 80 m," Department of Energy, http://www.windpoweringamerica.gov/pdfs/wind_maps/us_windmap_80meters.pdf, accessed August 2010.

[196] Blackman, G.N., "Military, Radar, and Aviation Issues: Growing Concerns and Ways to Navigate Potential Problems," *2010 WindPower Conference & Exhibition*, May, 2010.

[197] "Wind Turbines and Radar: An Informational Resource," American Wind Energy Association, February 2006.

[198] "The Effect of Wind Farms on Military Readiness. Report to the Congressional Defense Committees, Office of the Director of Defense Research and Engineering, 2006.

[199] "Wind Turbine Impact Mitigation for QVN ARSR-3 Radar," Massachusetts Institute of Technology Lincoln Laboratory, June 2010.

[200] Van Houten, W., "Department of Defense Energy Policy," Office of the Secretary of Defense, http://www.nellis.af.mil/shared/media/document/AFD-090501-099.pdf, accessed August 2010.

[201] Lestyan, H. "Charting a Course to Energy Independence," *2009 WindPower Conference & Exhibition*, August 2009.

[202] "Utah's Clean Energy Future: Resource Potential and Associated Economic Benefits," Utah Clean Energy, April, 2008.

[203] "Wind Systems Integration Basics," National Renewable Energy Laboratory, http://www.nrel.gov/wind/systemsintegration/system_integration_basics.html, accessed August 2010.

[204] "PJM on Wind," *E^3*, Vol. 9, No. 5, December, 2007.

[205] "Nebraska Statewide Wind Integration Study: Executive Summary of the Final Report," National Renewable Energy Laboratory, NREL/SR-550-47285, March 2010.

[206] Drouilhet, S.M., "Power Flow Management in a High Penetration Wind-Diesel Hybrid Power System with Short-Term Energy Storage," *WindPower Conference & Exhibition*, June 1999. (OSTI ID_12196)

[207] Logan, J., and S.M. Kaplan, "Wind Power in the United States: Technology, Economic, and Policy Issues," CRS Report for Congress RL34546, June 2008.

[208] "Production Tax Credit for Renewable Energy," Union of Concerned Scientists, http://www.ucsusa.org/clean_energy/solutions/big_picture_solutions/production-tax-credit-for.html, accessed August 2010.

[209] Wiser, R., and M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007 – Report Summary," Department of Energy, May 2008. (http://eetd.lbl.gov/ea/ems/reports/lbnl-275e-ppt.pdf)

[210] Bell, B., "Wind Turbine Technology," *Renewable Energy World Conference & Expo*, February 2010.

[211] "The Economics of Wind Energy," AWEA, February 2005.

[212] "Winds of Energy, US Air Force, April 2010.

[213] "Ascension Island Green Way," US Air Force.

[214] Baker, T., "Steady Winds Blow in Fuel Savings," US Air Force, October 2008.

[215] Philemonoff, R., "Wind Diesel in Alaska," Alaska Power Association 2006 Annual Meeting, August 2006.

[216] McGowan, T.F., *Biomass and Alternate Fuel Systems: An Engineering and Economic Guide*, Wiley Press, 2009.

[217] Scurlock, J., "Bioenergy Feedstock Characteristics," Oak Ridge National Laboratory, http://bioenergy.ornl.gov/papers/misc/biochar_factsheet.html, accessed August 2010.

[218] Altman, I., and T. Johnson, "Organization of the Current U.S. Biopower Industry: A Template for Future Bioenergy Industries," *Biomass and Bioenergy*, Vol. 33, pp. 779-784, 2009.

[219] Rosillo-Calle, F., P. deGroot, S.L. Hemstock, and J. Woods, *The Biomass Assessment Handbook: Bioenergy for a Sustainable Environment*, *Earthscan*, 2007.

[220] "Dynamic Maps, GIS Data, & Analysis Tools: Biomass Maps," National Renewable Energy Laboratory, http://www.nrel.gov/gis/biomass.html, accessed August 2010.

[221] "Plant Feedstock Genomics for Bioenergy," US Department of Energy Office of Science, Genomic Science Program, April 2010.

[222] Perlack, R.D., L.L Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach, "Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," United States Departments of Energy and Agriculture, April 2005. (http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf)

[223] Haag, A.L., "Pond-Powered Biofuels: Turning Algae into America's New Energy," *Popular Mechanics*, 29 March 2007. (http://www.popularmechanics.com/science/energy/biofuel/4213775)

[224] Allnutt, T., "Phycal Algal Biofuel Production," *Renewable Energy World Conference*, February 2010.

[225] Groenewold, G.H., "EERC: EERC Technology…Putting Research into Practice," *Renewable Energy World Conference*, February 2010.

[226] Bain, R.L., W.A. Amos, M. Downing, and R.L. Perlack, "Biopower Technical Assessment: State of the Industry and Technology," National Renewable Energy Laboratory, NREL/ TP-510-33123, March 2003.

[227] Marshall, A., and B. Loftis, "The Growing Viability of Biomass," *Renewable Energy World Magazine North America*, Vol. 2, No. 2, March/April 2010.

[228] Easterly, J., "Elements of Biopower Success," *Renewable Energy World Conference*, February 2010.

[229] "State Assessment for Biomass Resources," US Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuels & Advanced Vehicles Data Center, http://www.afdc.energy.gov/afdc/sabre/index.php, accessed June 2010.

[230] Gallagher, P., M. Dikeman, J. Fritz, E. Wailes, W. Gauther, and H. Shapour, "Biomass from Crop Residues: Cost and Supply Estimates," *Economist*, Office of Energy Policy and New Uses, Agricultural Economic Report 819.

[231] Milbrandt, A., "A Geographic Perspective on the Current Biomass Resource Availability in the United States," National Renewable Energy Laboratory, NREL/ TP-560-39181, November 2005.

[232] U.S. Department of Energy, Energy Efficiency & Renewable Energy Biomass Program, "Biomass Feedstock Composition and Property Database," http://www.afdc.energy.gov/biomass/progs/search1.cgi, accessed August 2010.

[233] Sandvig, E., G. Walling, R.C. Brown, R. Pletka, D. Radlein, and W. Johnson, "Integrated Pyrolysis Combined Cycle biomass Power System Concept Definition Report," Department of Energy, DE-FS26-01NT41353, March 2003.

[234] Badge, P.C., "Processing Cost Analysis for Biomass Feedstocks," Oak Ridge National Laboratory, ORNL/TM-2002/199, October 2002.

[235] Theis, K.B., "Research Advances Cellulosic Ethanol, NREL Leads the Way," National Renewable Energy Laboratory, US Department of Energy, NREL/BR-510-40742, March 2007. (http://www.afdc.energy.gov/afdc/pdfs/40742.pdf)

[236] "Biomass Conversion: Emerging Technologies, Feedstocks, and Products." United States Environmental Protection Agency, EPA/ 600/R-07/144, December 2007.

[237] "Feedstock Composition Glossary," Energy Efficiency & Renewable Energy Biomass Program, US Department of Energy, November 2005. (http://www1.eere.energy.gov/biomass/feedstock_glossary.html)

[238] Caputo, A.C., M. Palumbo, P.M. Pelagagge, and F. Scacchia, "Economics of Biomass Energy Utilization in Combustion and Gasification Plants: Effects on Logistic Variables," *Biomass and Bioenergy*, Vol. 28, pp. 35-51, 2005.

[239] Short, N.M., "Life in the Universe: I. Background in Biology," *Remote Sensing Tutorial,* http://rst.gsfc.nasa.gov/Sect20/A12.html, accessed January 2011.

[240] "Starch- and Sugar-Based Ethanol Production," Alternative Fuels & Advanced Vehicles Data Center, Department of Energy, http://www.afdc.energy.gov/afdc/ethanol/production_starch_sugar.html, accessed January 2011.

[241] "Genomics: GTL Roadmap: Systems Biology for Energy and Environment," Office of Science, US Department of Energy, DOE/SC-0090, August 2005. (http://genomicscience.energy.gov/roadmap/)

[242] "From Biomass to Cellulosic Ethanol: Genomics for Alternative Fuels," Office of Science, Department of Energy, May 2007, http://genomicscience.energy.gov/biofuels/Biofuels_Placemat2.pdf, accessed January 2011.

[243] "How Cellulosic Ethanol is Made," Genome Management Information System, Oak Ridge National Laboratory, Department of Energy, http://genomics.energy.gov/gallery/biomass/detail.np/detail-881.html, accessed January 2011.

[244] Marshall, A., and B. Loftis, "The Growing Viability of Biomass," *Renewable Energy World Magazine North America*, Vol. 2, No. 2, March/April 2010.

[245] Bain, R.L., W.A. Amos, M. Downing, and R.L. Perlack, "Biopower Technical Assessment: State of the Industry and Technology," National Renewable Energy Laboratory, NREL TP-510-33123, March 2003.

[246] Altman, I., and T. Johnson. "Organization of the Current U.S. Biopower Industry: A Template for Future Bioenergy Industries," *Biomass and Bioenergy*, Vol. 33, 2009, pp. 779-784.

[247] "Pre-feasibility Study: Biomass Power Plant, Ft. Bragg, Mendocino County, California," North Coast Resource Conservation & Development Council, August 2007.

[248] McGowan, T.F., *Biomass and Alternate Fuel Systems: An Engineering and Economic Guide*, Wiley Press, 2009.

[249] Velzy, C.O., and L.M. Grillo, "Waste-to-Energy Combustion," *Handbook of Energy Efficiency and Renewable Energy*, CRC Press, 2007.

[250] Wright, L., B. Boundy, P.C. Badger, B. Perlack, and S. Davis, *Biomass Energy Data Book*, 2nd Edition, US DOE Energy Efficiency and Renewable Energy, Oak Ridge National Laboratory, December 2009.

[251] Wang, L., C.L. Weller, D.D Jones, and M.A. Hanna, "Contemporary Issues in Thermal Gasification of Biomass and Its Application to Electricity and Fuel," *Biomass and Bioenergy*, Elsevier Science Ltd., Vol. 32, 2008, pp. 573-581.

[252] vanden Broek, R., A. Faau, and A. van Wijk, "Biomass Combustion for Power Generation," *Biomass and Bioenergy*, Vol. 11, No. 4, pp. 271-281, 1996.

[253] McGowin, C. R., and G.A. Wiltsee, "Strategic Analysis of Biomass and Waste Fuels for Electric Power Generation," *Biomass and Bioenergy*, Elsevier Science Ltd., Vol. 10, Nos. 2-3, pp. 167-175, 1996.

[254] Easterly, J., "Elements of Biopower Success," *Renewable Energy World Conference*, February 2010.

[255] "Thermal Properties of Wood and Wood Wastes," US Forestry Department, http://www.fao.org/docrep/P2396e/p2396e03.htm, accessed August 2010.

[256] "Generation Technology," A.T. Biopower, www.atbiopower.co.th/news_highlights/gen_tech_e.htm, accessed August 2010.

[257] "FBC Boilers," India Bureau of Energy Efficiency, http://www.em-ea.org/Guide%20Books/book-2/2.6%20FBC.pdf, accessed August 2010.

[258] Duncan, J.V., and J.L. Hebb, "CCPI/Clean Coal Demonstrations: JEA Large-Scale CFB Combustion Demonstration Project," National Energy Technology Laboratory, http://www.netl.doe.gov/technologies/coalpower/cctc/summaries/jacks/jackeademo.html, accessed May 2010.

[259] Brammer, J.G., and A.V. Bridgewater, "The Influence of Feedstock Drying on the Performance and Economics of a Biomass Gasifier-Engine CHP System," *Biomass and Bioenergy*, Vol. 22, 2002, pp. 271-281.

[260] Brennan, M., D. Specca, B. Schilling, D. Tulloch, S. Paul, K. Sullivan, Z. Helsel, P. Hayes, J. Melillo, B. Simkins, C. Phillipuk, A.J. Both, D. Fennell, S. Bonos, M. Westendorf, and R. Brekke, "Assessment of Biomass Energy Potential in New Jersey," *New Jersey Agricultural Experiment Station Publication*, No. 2007-1, Rutgers, the State University of New Jersey, July 2007.

[261] Badger, P.C., P. Fransham, "Use of Mobile Fast Pyrolysis Plants to Densify Biomass and Reduce Biomass Handling Costs - A Preliminary Assessment," *Biomass and Bioenergy*, Vol. 30, 2006, pp. 321-325.

[262] Rogers, J.G., and J.G. Brammer, "Analysis of Transport Costs for Energy Crops for Use in Biomass Pyrolysis Plant Networks," *Biomass and Bioenergy*, Vol. 33, 2009, pp. 1367-1375.

[263] "Waste to Energy: Waste," *The Cleantech Report*, Lux Research Inc, 2007.

[264] Parker, R., "Waste to Energy Workshop Background Document," Waste to Energy Workshop, May 2008.

[265] Wiltsee, G, "Lessons Learned from Existing Biomass Power Plants," National Renewable Energy Laboratory, NREL/SR-570-26946, February 2000.

[266] Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/biomass/biomass.jpg, accessed August 2010.

[267] "Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors," US EPA, http://www.epa.gov/ttn/chief/ap42/index.html#toc, accessed August 2010.

[268] "Module 6: Air Pollutants and Control Techniques," *Basic Concepts in Environmental Sciences*, US Environmental Protection Agency, http://www.epa.gov/apti/bces/module6/, accessed January 2011.

[269] Young, C., "MCLB Albany, Partners Break Ground on Landfill Gas-to-Energy Project," Marine Corps Logistics Base Albany, May 2010, http://www.marines.mil/unit/mclbalbany/Pages/2010/052010/MCLBAlbany,partnersbreakgroundonlandfillgas-to-energyproject.aspx, accessed 1 June 2010.

[270] Price, J., and D. Abbott, "Hill Air Force Base Landfill Gas to Energy: Biogas Case Study," *GovEnergy*, August 2007.

[271] "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008," US EPA, http://www.epa.gov/osw/nonhaz/municipal/pubs/msw2008rpt.pdf, accessed August 2010.

[272] Khoo, H.H., "Life Cycle Impact Assessment of Various Waste Conversion Technologies," *Waste Management*, Vol. 29, 2009, pp. 1892-1900.

[273] DiPippo, R., *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact,* Second Edition, Butterworth-Heinemann, 2008.

[274] Gallup, D. "Production Engineering in Geothermal Technology: A Review." *Geothermics,* Vol. 38, pp. 326-334.

[275] Einstat, L., Lehfeldt, R. "Geothermal From the Ground Up: Realizing the Potential of Geothermal Power." *North American Clean Energy*, Vol. 4, No. 1, pp. 57-58.

[276] Duffield, W., and J.H. Sass, "Geothermal Energy – Clean Power from the Earth's Heat," US Geological Survey, Circular 1249, 2003. (http://pubs.usgs.gov/circ/2004/c1249/c1249.pdf)

[277] "Probing Question: What Heats the Earth's Core?" Physorg.com, March 2006.

[278] Elert, G., "Temperature on the Surface of the Sun," The Physics Factbook, 1997.

[279] Blodgett, L., and K. Slack, "Geothermal 101: Basics of Geothermal Energy Production and Use," Geothermal Energy Association, February 2009.

[280] "BP Statistical Review of World Energy," BP, June 2010. (http://www.bp.com/statisticalreview)

[281] "US Geothermal Resource Map," Department of Energy, http://www1.eere.energy.gov/geothermal/geomap.html, accessed August 2010.

[282] Davis, A. and Michaelides, E. "Geothermal Power Production from Abandoned Oil Wells." *Energy,* No. 34, pp. 866-872. (Geo 12)

[283] DOE Geothermal Technologies Program (GTP): Multi-Year Research, Development and Demonstration Plan. US Department of Energy, Draft.

[284] Zais, E.J., "Types of Geothermal Reservoirs," *Geothermal Potential of the Cascade Mountain Range: Exploration and Development*, Special Report No. 10, Geothermal Resources Council, May 1981.

[285] Blackwell, D., "Geothermal Technologies Program," *Technology Planning Workshop for Low-Temperature, Coproduced, and Geopressured Geothermal Energy*, July 2010. (http://www1.eere.energy.gov/geothermal/pdfs/20100713_lowtemp_blackwell.pdf)

[286] Balta, M.T., Dincer, I., Hepbasli, A. "Thermodynamic Assessment of Geothermal Energy Use in Hydrogen Production." *International Journal of Hydrogen Energy*. Vol. 34, pp. 2925-2939.

[287] Imroz Sohel, M., Sellier, M., Brackney, L., and Krumdieck, S. "Efficiency Improvement for Geothermal Power Generation to meet Summer Peak Demand," *Energy Policy*, No. 37, pp. 3370-3376.

[288] Ozcan, N.Y., and Gokcen, G. "Thermodynamic Assessment of Gas Removal Systems for Single-Flash Geothermal Power Plants." *Applied Thermal Engineering,* Vol. 29, pp. 3246-3253.

[289] "Energy Conversion," Office of Geothermal Technologies, Department of Energy, DOE/GO-10098-537, March 1998. (http://www1.eere.energy.gov/geothermal/pdfs/conversion.pdf)

[290] Yari, M., "Exergetic Analysis of Various Types of Geothermal Power Plants," *Renewable Energy*, Vol. 35, 2010, pp. 112-121. (doi:10.1016/j.renene.2009.07.023)

[291] Franco, A., Villani, M. "Optimal Design of Binary Cycle Power Plants for Water-Dominated, Medium-Temperature Geothermal Fields." *Geothermics No. 38,* pp. 379-391.

[292] Vanderburg, D. D., "Comparative Energy and Cost Analysis Between Conventional HVAC Systems and Geothermal Heat Pump Systems," Air Force institute of Technology, March 2002.

[293] Fischer, J., Price, R., and Finnell, J. "Examining Geothermal Energy." *Resource*, Vol. 13, No. 3, pp. 13-14.

[294] Kulcar, B., Goricanec, D., and Krope, J. "Economy of Exploiting Heat from Low-Temperature Geothermal Sources Using a Heat Pump." *Energy and Buildings*, Vol. 40, pp. 323-329.

[295] Huttrer, G. "Geothermal Heat Pumps: An Increasingly Successful Technology." *Renewable Energy,* Vol. 10, No. 2/3, pp. 481-488.

[296] "An Evaluation of Enhanced Geothermal Systems Technology," Geothermal Technologies Program, Department of Energy, 2008, http://www1.eere.energy.gov/geothermal/pdfs/evaluation_egs_tech_2008.pdf, accessed February 2011.

[297] "Enhanced Geothermal Systems," Department of Energy, http://www1.eere.energy.gov/geothermal/enhanced_geothermal_systems.html, accessed August 2010.

[298] Wood, W. "Enhanced Geothermal Systems: An Opportunity for Hydrogeology," *Ground Water,* Vol. 47, No. 6, p. 751.

[299] "Geothermal Energy," Idaho National Laboratory, http://geothermal.inel.gov/, accessed August 2010.

[300] "Underground Heat: An Omnipresent Source of Electricity," MIT Energy Research Council, http://web.mit.edu/erc/spotlights/underground_heat.html, accessed August 2010.

[301] Pruess, K. "On Production Behavior of Enhanced Geothermal Systems with CO_2 as Working Fluid." *Energy Conversion and Management*, No. 49, pp. 1446-1454.

[302] Green, B.D., and R.G. Nix, "Geothermal – The Energy Under Our Feet," National Renewable Energy Laboratory, Department of Energy, NREL/TP-840-40665, November 2006. (http://www1.eere.energy.gov/geothermal/pdfs/40665.pdf)

[303] "April 2010 US Geothermal Power Production and Development Update," Geothermal Energy Association, April 2010.

[304] "Geothermal Grows 26% in 2009: GEA Identifies New Projects Underway in 15 States," Geothermal Energy Association, April 2010. (http://www.geo-energy.org/pdf/press_releases/April_2010_Update_Release_FINAL.pdf)

[305] "Geothermal Basic Introduction," Geothermal Energy Association, www.geo-energy.org/geo_introduction.aspx, accessed August 2010.

[306] Jennejohn, D., "U.S. Geothermal Power Production and Development Update," Geothermal Energy Association, April 2010. (http://www.geo-energy.org/pdf/reports/April_2010_US_Geothermal_Industry_Update_Final.pdf)

[307] Jean, G. "Renewable Energy – Navy Taps Oceans for Power," *National Defense*, April 2010, pp. 33-35.

[308] Geothermal Power Generation at Coso Hot Springs, NAVAIR, http://www.navair.navy.mil/techTrans/index.cfm?map=local.ccms.view.aB&doc=paper.16, accessed August 2010.

[309] *Renewable Energy Focus* ,September/October 2009.

[310] "Blue Mountain: The Power Is On At Faulkner 1!," Nevada Geothermal Power, http://www.nevadageothermal.com/i/pdf/BlueMountain%20FactSheetDecember2010.pdf, accessed February 2011.

[311] "Geothermal Energy: Information on the Navy's Geothermal Program," Government Accountability Office, GAO-04-513, 2004.

[312] Taron, J., and Elsworth, D. "Thermal–Hydrologic–Mechanical–Chemical Processes in the Evolution of Engineered Geothermal Reservoirs." *International Journal of Rock Mechanics & Mining Sciences,* No. 46, pp. 855-864 (Geo 15).

[313] "Federal Budget Continues to Feed Geothermal Growth," Geothermal Energy Association, http://geo-energy.org/pressReleases/2010/2011_Federal_Budget.pdf, accessed August 2010.

[314] Okorie, P.O, and A. Owen, "Turbulence: Characteristics and its Implications in Tidal Current Energy Device Testing," MTS/ IEEE Oceans 2008 Conference and Exhibition, September 2008, ADA502211.

[315] Banerjee, S., L. Duckers, R. Blanchard, and B.K. Choudhury, "Assessment of Tidal Power," World Energy Engineering Congress, November 2009.

[316] "E.ON and Lunar Energy to Build 8-Megawatt Tidal Power Project," Department of Energy, March 2007, http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=10659, accessed August 2010.

[317] "Tidal Power! Another Best Energy Alternate," Renewable Energy Blog, http://www.solarpowerwindenergy.org/in_renewable_energy/tide-mills/, accessed August 2010.

[318] Lagan, C., "Earth Day 2010 – Reducing Our Environmental Footprint," Coast Guard Compass, April, 2010. (http://coastguard.dodlive.mil/index.php/2010/04/earth-day-2010-reducing-our-environmental-footprint/)

[319] Energy Efficiency & Renewable Energy, Energy Savers, "Ocean Tidal Power," December 2008, http://www.energysavers.gov/renewable_energy/ocean/index.cfm/mytopic=50008, accessed 8 June 2010.

[320] Childress, E., "Ocean Wave Energy Harvesting Devices, Phase 3 Final Report," Defense Advanced Research Projects Agency: Advanced Technology Office, ADA476891.

[321] Energy Efficiency & Renewable Energy, Energy Savers, "Ocean Wave Power," December 2008, http://www.energysavers.gov/renewable_energy/ocean/index.cfm/mytopic=50009, accessed June 2010.

[322] RISE, Research Institute for Sustainable Energy, "Wave," Murdoch University, 2008, http://www.rise.org.au/info/Tech/wave/index.html, accessed June 2010.

[323] "Pelamis, World's First Commercial Wave Energy Project, Agucadoura, Portugal," Net Resources International, http://www.power-technology.com/projects/pelamis/pelamis5.html, accessed June 2010.

[324] "Water Power Devices," Earth Science Australia, http://earthsci.org/mineral/energy/wavpwr/wavepwr.html, accessed August 2010.

[325] Department of Energy, http://www1.eere.energy.gov/windandhydro/hydrokinetic/images/technologies/c2f3e19e-5e9e-44ba-bef5-b453ac8f7b2d.JPG , accessed August 2010.

[326] Minerals Management Service, Renewable Energy and Alternate User Program, "Wave Energy Potential on the U.S. Outer Continental Shelf," US Department of the Interior, May 2006, http://www.ocsenergy.anl.gov/documents/docs/OCS_EIS_WhitePaper_Wave.pdf, accessed June 2010.

[327] National Renewable Energy Laboratory, "Benefits of OTEC," http://www.nrel.gov/otec/benefits.html, accessed June 2010.

[328] Jenkins, J.F., "Corrosion and Biofouling of OTEC System Surfaces-Design Factors (Final)," Civil Engineering Laboratory (Navy), November 1978, ADA066115

[329] Energy Efficiency & Renewable Energy, Energy Savers, "Ocean Thermal Energy Conversion," December 2008, http://www.energysavers.gov/renewable_energy/ocean/index.cfm/mytopic=50010, accessed June 2010.

[330] Miller, R., "Wind Integration Utilizing Pumped Storage," *Renewable Energy World Conference and Expo*, February 2010.

[331] "Electrical Battery' of Leyden Jars, 1760-1769," The Benjamin Franklin Tercentenary, http://www.benfranklin300.org/frankliniana/result.php?id=72&sec=1 , accessed August 2010.

[332] "Alkaline Manganese Dioxide Batteries," RadioShack's On-line Battery Guidebook, RadioShack, 2004.

[333] "Alkaline-Manganese Dioxide," Duracell Technical Bulletin, http://www.duracell.com/oem/Pdf/others/ATB-full.pdf, accessed August 2010.

[334] Sinclair, I. R. and J. Dunton, *Practical Electronics Handbook*, 6th Edition, Elsevier, 2007.

[335] Naidu, M. S., and S. Kamakshaiah, "Introduction to Electrical Engineering," Tate McGraw-Hill Publishing Company, 1995.

[336] "Consumer and Commercial Products - Mercury," US EPA, http://epa.gov/mercury/consumer.htm#bat, accessed August 2010.

[337] "Primary Systems: Zinc-Air," Duracell Technical Bulletin, http://www.duracell.com/oem/Primary/Zinc/Zinc_Air_Tech_Bulletin.pdf, accessed August 2010.

[338] Craig, B., Ingold, B. and O. Conniff, "TechSolutions 11 – An Introduction to Power and Energy." *AMMTIAC Quarterly*, Vol. 4, No. 1.

[339] "Round Trip Energy Efficiency of NASA Glenn Regenerative Fuel Cell System, NASA, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20060008706_2006006323.pdf, accessed August 2010.

[340] "Comparison of Fuel Cell Technologies," US DOE Hydrogen Program, December 2008, http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs/fc_comparison_chart.pdf.

[341] "How They Work: PEM Fuel Cells," Fueleconomy.gov, http://www.fueleconomy.gov/feg/fcv_pem.shtml, accessed August 2010.

[342] "Super Capacitors," National Renewable Energy Laboratory, http://www.nrel.gov/learning/eds_supercapacitors.html, accessed August 2010

[343] Craig, B., and R. Lane, YBCO Blazes the Trail for High-Temperature Superconductors, AMPTIAC Quarterly, http://ammtiac.alionscience.com/pdf/AMPQ7_1ART03.pdf, accessed August 2010.

[344] "California Distributed Energy Resource Guide," The California Energy Commission, http://www.energy.ca.gov/distgen/equipment/energy_storage/energy_storage.html, accessed August 2010.

[345] "Learning About Renewable Energy – Flywheels," National Renewable Energy Laboratory, http://www.nrel.gov/learning/eds_flywheels.html, accessed August 2010.

[346] "Flywheel Energy Storage," Wikipedia, http://en.wikipedia.org/wiki/Flywheel_energy_storage, accessed August 2010.

[347] Smith, T. "How Flywheels Work," http://www.ehow.com/how-does_5565044_flywheels-work.html, accessed August 2010.

[348] "Learning About Renewable Energy – Pumped Hydropower," National Renewable Energy Laboratory, http://www.nrel.gov/learning/eds_pumped_hydropower.html, accessed August 2010.

[349] "Compressed Air Energy Storage," http://www.nrel.gov/learning/eds_Compressed_air.html, accessed August 2010.

[350] "Compressed air energy storage," Wikipedia, http://en.wikipedia.org/wiki/compressed_air_energy_storage, accessed August 2010.

[351] V.A. Khokhlov, N. Batalov. High Temperature Electrochemical Power Sources. Euchem 2004. Molten Salts Conference Proceedings, June 2004. ADP019752

[352] "U.S. Census Bureau Announces 2010 Census Population Counts – Apportionment Counts Delivered to President," US Census Bureau, December 2010, http://2010.census.gov/news/releases/operations/cb10-cn93.html, accessed February 2011.

[353] "Electricity Explained: Use of Electricity," US Energy Information Administration, http://www.eia.doe.gov/energyexplained/index.cfm?page=electricity_use, accessed February 2011.

[354] Kenchington, H., "Grid Modernization and the Smart Grid," *GovEnergy*, August 2010. (http://www.govenergy.com/2010/Files/Presentations/Energy%20Security/Kenchington_Session8.pdf)

[355] "National Electric Transmission Congestion Study," Department of Energy, December 2009. (http://congestion09.anl.gov/)

[356] "Smart Grid Basics," Smartgrid.gov, http://www.smartgrid.gov/basics, accessed February 2011.

[357] "Smart Grid Technologies," Smartgrid.gov, http://www.smartgrid.gov/technologies, accessed February 2011.

[358] "Guidance for Electric Metering in Federal Buildings," Department of Energy, DOE/EE-0312, February 2006. (http://www1.eere.energy.gov/femp/pdfs/adv_metering.pdf)

[359] "NAS Kingsville First Region Southeast Command to Install Energy Smart Meters," US Navy, http://www.navy.mil/search/display.asp?story_id=56979, accessed February 2011.

[360] Valine, D., "Advanced Meters Developed by Corps of Engineers Help Army Installations Reduce Energy Use, Save Money," US Army, August 2009, http://www.army.mil/-news/2009/08/31/26770-advanced-meters-developed-by-corps-of-engineers-help-army-installations-reduce-energy-use-save-money/, accessed February 2011.

[361] "Operations & Maintenance Best Practices: A Guide to Achieving Operational Efficiency," Department of Energy, Federal Energy Management Program, August 2010. (http://www1.eere.energy.gov/femp/pdfs/omguide_complete.pdf)

[362] "Metering Approaches," Department of Energy, Federal Energy Management Program, http://www1.eere.energy.gov/femp/program/om_meteringapproaches.html, accessed February 2011.

[363] Sullivan, G.P., R. Pugh, and W.D. Hunt, "Metering Best Practices: A Guide to Achieving Utility Resource Efficiency," Department of Energy, Federal Energy Management Program, October 2007. (http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf)

[364] "Advanced Control Methods," *Appendix B4: A Systems View of the Modern Grid*, Department of Energy, March 2007. (http://www.netl.doe.gov/smartgrid/referenceshelf/whitepapers/Advanced%20Control%20Methods_Final_v2_0.pdf)

[365] Elmor, J., "Energy-Saving Efforts Earn Bases National Awards," Air Force Civil Engineer Support Agency, October 2010. (http://www.afcesa.af.mil/news/story.asp?id=123225228)

[366] Anderson, B., "Advanced Metering Infrastructure (AMI) Program," *GovEnergy*, August 2009. (http://www.govenergy.com/2009/pdfs/presentations/Metering-Session06/Metering-Session06-Anderson_Bill.pdf)

[367] Blount, J., C. Murdock, and S. Lee, "The Army Metering Data Management System (MDMS): Using MDMS To Meet the Army's Energy Goals," *Environment, Energy Security, & Sustainability Symposium & Exhibition*, June 2010.

[368] Lee, L.S., "Army Metering Program – Closing the Gap," US Army Corps of Engineers, https://www.hnd.usace.army.mil/pao/NewsReleases/2011/11-007%20-%20Resend%20of%2010-031%20Army%20metering.pdf, accessed March 2011.

[369] MacDonald, R., "Potential Microgrid Applications for California," Joint Workshop on California's Distribution Infrastructure Challenges, May 2007. (http://www.energy.ca.gov/2007_energypolicy/documents/2007-05-10_workshop/presentations/PM%203%20Rachel%20MacDonald%20of%20PIER%20Distribution%20Program.pdf)

[370] McGranaghan, M., T. Ortmeyer, D. Crudele, T. Key, J. Smith, and P. Barker, "Renewable Systems Interconnection Study: Advanced Grid Planning and Operations," Sandia National Laboratories, SAND2008-0944, February 2008. (http://www1.eere.energy.gov/solar/pdfs/advanced_grid_planning_operations.pdf)

[371] "Electric Power eTool: Illustrated Glossary: Substations," US Department of Labor, http://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/substation.html#Distribution, accessed March 2011.

[372] "Using Distributed Energy Resources: A How-To Guide for Federal Facility Managers," US Department of Energy, Federal Energy Management Program, http://www1.eere.energy.gov/femp/pdfs/31570.pdf, accessed March 2011.

[373] "Applying Energy Surety to Military Bases," Sandia Technology, Sandia National Laboratories, http://www.sandia.gov/news/publications/technology/2006/0803/energy-surety_2.html, accessed March 2011.

[374] Hightower, M., "Energy Surety Microgrids for Critical Mission Assurance to Support DOE and DoD Energy Initiatives," Sandia National Laboratories, Smart Grid Peer Review, November 2010.

(http://events.energetics.com/SmartGridPeerReview2010/pdfs/presentations/day2/am/16_Energy_Surety_Microgrids_and_SPIDERS_NEW.pdf)

[375] Ka'iliwai, G., B. Bolden, R. Roley, B. McConnell, M. Dana, and B. Waugaman, "SPIDERS Energy Security JCTD Proposal," *Rebuild Hawaii Consortium*, March 2010. (http://hawaii.gov/dbedt/info/energy/efficiency/RebuildHawaiiConsortium/Events/PastEvents/2010-03-10/SPIDERS%20for%20D.C.%20-%20Feb%202010.pdf)

[376] Torres, J., "Energy Surety Microgrids," *Army Renewable Energy Rodeo*, June 2010. (https://renewable-energy-rodeo.com/agenda/Presentations/SmartGrids_topic1.pdf)

[377] Shah, C., "Power Purchase Agreements," GovEnergy, August 2010. (http://www.govenergy.com/Files/Presentations/Project%20Financing/GovEnergy%202010%20PPA%20Chandra%20Shah.pdf)

[378] "3rd-Party Solar PV Power Purchase Agreements (PPAs)," *Database of State Incentives for Renewables & Efficiency*, N.C. Solar Center and the Interstate Renewable Energy Council, October 2010. (www.dsireusa.org/documents/summarymaps/3rd_party_ppa_ map.pptx)

[379] "Utility Energy Services Contracts: Enabling Documents," Federal Energy Management Program, Department of Energy, DOE/G0-102009-2588, May 2009. (http://www1.eere.energy.gov/femp/pdfs/uesc_enabling_documents09.pdf)

[380] Schell, S., "Financing Renewable Energy Projects," *GreenGov Symposium*, October 2010.

[381] "Federal Real Property: Authorities and Actions Regarding Enhanced Use Leases and Sale of Unneeded Real Property," Government Accountability Office, GAO-09-283R, February 2009.

[382] Guadarrama, D., "Air Force Real Property Agency," *Renewable Energy World Conference*, February 2010.

[383] King, A.D., "Energy Project Contracting," *GovEnergy*, August 2010. (http://www.govenergy.com/2010/Files/Presentations/Contracting/Contracting%20S8%20-%20King.pdf)

[384] "Guide to Purchasing Green Power: Renewable Electricity, Renewable Energy Certificates, and On-Site Renewable Generation," Department of Energy, DOE/EE-0307, March 2010. (http://www1.eere.energy.gov/femp/pdfs/purchase_green_power.pdf)

[385] "Basics of the Carbon Cycle and the Greenhouse Effect," US Department of Commerce, National Oceanic and Atmospheric Administration, http://www.esrl.noaa.gov/gmd/outreach/carbon_toolkit/basics.html (accessed December 2010)

[386] "Field Testing and Demonstration of Solar Systems," Department of Energy, Federal Energy Management Program, http://www1.eere.energy.gov/solar/field_testing_demonstration.html (accessed December 2010).

[387] "Federal Energy Regulators Propose Priorities for Smart Grid Standards," *EERE Network News*, March 2009. (http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=12364)

[388] "Renewable Energy Certificates," Environmental Protection Agency, July 2008. (http://www.epa.gov/greenpower/documents/gpp_basics-recs.pdf)

[389] Wagman, D., "Top 5 in 2010," *Power Engineering*, p. 4, December 2010.

[390] "Greening the Government through Efficient Energy Management," Executive Order 13123, June 1999**.**

[391] Fuller, S.K., and S.R. Peterson, "Life-Cycle Costing Manual for the Federal Energy Management Program," NIST Handbook 135, 1995 Edition, February 1996. (http://www.fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf)

[392] "Life Cycle Costs," US Code of Federal Regulations, 10 CFR 436 Subpart A, Subsection 436.19.

[393] "Establishing Energy or Water Cost Data," US Code of Federal Regulations, 10 CFR 436 Subpart A, Subsection 436.17.

[394] "Building Life-Cycle Cost (BLCC) Programs," Department of Energy, Federal Energy Management Program, http://www1.eere.energy.gov/femp/information/printable_versions/download_blcc.html, accessed April 2010.

[395] Fuller, S.K., "Guidance on Life-Cycle Cost Analysis Required by Executive Order 13123," Department of Energy, Federal Energy Management Program, April 2005. (http://www.eere.energy.gov/femp/pdfs/lcc_guide_05.pdf)

[396] "Biomass Cofiring in Coal-Fired Boilers," *Federal Technology Alert*, DOE/EE-0288, May 2004. (http://www.nrel.gov/docs/fy04osti/33811.pdf)

[397] "The Drivers of the Levelized Cost of Energy for Utility-Scale Photovoltaics," Sunpower Corporation, August 2008. (http://us.sunpowercorp.com/downloads/SunPower_levelized_cost_of_electricity.pdf)

[398] Ruegg, R., and W. Short, "Economics Methods," *Handbook of Energy Efficiency and Renewable Energy*, CRC Press, 2007, pp. 3.1-3.24.

[399] Short, W., D.J. Packey, and T. Holt, "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies," Department of Energy, National Renewable Energy Laboratory, NREL/TP-462-5173, March 2005. (http://www.nrel.gov/docs/legosti/old/5173.pdf)

[400] "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011," Department of Energy, http://www.eia.doe.gov/oiaf/aeo/pdf/2016levelized_costs_aeo2011.pdf, accessed March 2011.

[401] "Annual Energy Outlook 2011," Energy Information Administration, DOE/EIA-0383(2010), December 2010.

[402] "DOD Needs to Take Actions to Address Challenges in Meeting Federal Renewable Energy Goals," Government Accountability Office, GAO-10-104, December 2009. (http://www.gao.gov/new.items/d10104.pdf)

[403] Butterfield, K., "A Developer's View of Solar (PV) Projects on Federal Sites A Look at 2010 and Beyond," *GovEnergy*, August 2010.

[404] Walker, A., and R. Robichaud, "Federal Wind Energy Update", *GovEnergy*, August 2009.

[405] "DoD Renewable Energy Assessment Final Report" Office of the Secretary of Defense, Report to Congress, March 2005. (http://www.acq.osd.mil/ie/energy/library/final_renew_asesmtreport.pdf)

[406] "RE-Powering America's Land: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites, Nellis Air Force Base, Nevada Success Story," Environmental Protection Agency, February 2009, http://www.epa.gov/renewableenergyland/docs/success_nellis_nv.pdf, accessed February 2011.

[407] Quick, D., "SunPower Claims New Solar Cell Efficiency Record of 24.2 Percent," Gizmag, June 2010. (http://www.gizmag.com/sunpower-corp-solar-cell-efficiency-record/15536/)

[408] Baker, S., and B. Long, "Wind Energy and the US NAVY," *GovEnergy*, August 2007. (http://www.govenergy.com/2007/pdfs/renewable/Baker_and_Long_Renewable_track_S1.pdf)

[409] Forbes, R., "AFCEE Wind Turbine Project," *GovEnergy*, August 2009. (http://www.govenergy.com/2009/pdfs/presentations/Renewables-Session06/Renewables-Session06-Forbes_Rose.pdf)

[410] "Renewable Energy: Increased Geothermal Development Will Depend on Overcoming Many Challenges," Government Accountability Office, GAO-06-629, May 2006. (http://www.gao.gov/new.items/d06629.pdf)

[411] "Database of State Incentives for Renewables & Efficiency," Department of Energy, http://www.dsireusa.org/, accessed August 2010.

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