Appendix A—Distributed Generation Technologies

This appendix provides background and additional detail for distributed generation technologies. Capacity, fuel types, and efficiency information are provided for each. .

Combustion Turbine

Combustion Turbines	
Capacity:	500 kW to 25 MW
Fuels:	Natural Gas
	Liquid Fuels
Efficiency:	20 to 45%
Cogeneration:	As Steam

Combustion turbine (CT) generators are a very mature technology. The size of a CT generator typically ranges from about 500 kW up to 250 MW; however generators above 25 MW qualify as central power generation. CTs are fueled by natural gas, oil, or a combination of fuels (dual fuel).

Single-cycle combustion turbine units typically have efficiencies in the range of 20 to 45 percent at full load. Efficiency can be lower at less than full load. Combined- cycle combustion turbines can reach efficiencies of up to 55 percent by utilizing waste heat to produce steam that generates additional electricity.

Nearly all new central station power plants use combined-cycle combustion turbines. Smaller CTs have characteristics favorable for use in DG applications and because of this, are frequently used by independent power producers and large industrial facilities.

Reciprocating Engine

Reciprocating Engines	
Capacity:	5 kW to 7 MW
Fuels:	Natural Gas
	Diesel
	Landfill Gas
	Digester Gas
Efficiency:	25 to 45%
Cogeneration:	As Steam

Reciprocating engines are the most common and most technically mature of all DG technologies. They are available from small sizes, 5 kW, to large 7 MW generators. Applications range from small backup generators for residential use to large prime movers for base load power at industrial sites. Reciprocating engines use commonly available fuels such as gasoline, natural gas, and diesel fuel. When used in power generation applications, reciprocating engines are typically called gensets.

Gensets are frequently used as a backup power supply in residential, commercial, and industrial applications. In addition, large engine generators may be used as base load, grid support, or peak-shaving devices.

Microturbine

Microturbines are small combustion turbines that produce between 25 kW and 500 kW of power. Microturbines were derived from turbocharger technologies used in large trucks or the turbines in aircraft auxiliary power units (APUs). Most microturbines are single-stage, radial flow devices with high rotating speeds of 90,000 to 120,000 revolutions per minute. However, a few manufacturers have developed alternative systems with multiple stages and/or lower rotation speeds.

Microturbines	
Capacity:	25 kW to 500 kW
Fuels:	Natural Gas
	Hydrogen
	Propane
	Diesel
Efficiency:	20 to 45%
Cogeneration:	As 50-80°C water

Some microturbines have reached commercial status; however, many microturbine installations for DG are still undergoing field tests or are part of large-scale demonstrations.

Small-Scale Hydro Power

Small hydro is often developed using existing dams or through development of new dams whose primary purpose is river and lake water-level control, or irrigation. For making small amounts of electricity without building a dam, water is taken from the stream and moved down slope to the turbine through a long pipe. This kind of system is called a “micro-hydro”, “run-of-river”, or “low impact hydro” system. A small-scale hydro system usually consists of an enclosed water wheel or turbine, which is made to spin by the moving water. The turbine is connected to an electrical generator. Small hydro systems are capable of producing electricty continuously.

Small-Scale Hydro Power	
Capacity:	500 kW – 25 MW
Fuels:	Water
Efficiency:	65 to 70%
Cogeneration:	Not available

Photovoltaic (PV)

Photovoltaic (PV) cells, or solar cells, convert sunlight directly into electricity. PV cells are assembled into flat plate systems that can be mounted on rooftops or other sunny areas. They generate electricity with no moving parts, operate quietly with no emissions, and require little maintenance. However, costs are currently high.

Photovoltaics	
Capacity:	< 1 kW to 100 kW
Fuels:	Sunlight
Efficiency:	5 to 15%
Cogeneration:	Not readily available

Solar system costs have declined dramatically over the past 20 years. In the early 1980s, system costs were over $25/peak watt. Today, costs are about $4/peak watt and are continuing to decline. Costs are expected to be about $2/peak watt by 2010. Life-cycle cost analysis places current solar energy cost at roughly 20 cents per kilowatt hour in the best locations. By the year 2010, these costs are predicted to decline to half this value.

Wind Generators

Wind turbines use the wind to produce electrical power. A generator is equipped with fan blades and placed at the top of a tall tower. As the turbine rotates in the wind, the generator produces electrical power. The tower is tall in order to harness wind moving at a greater velocity, free of turbulence caused by interference from ground obstacles such as trees, hills and buildings. A single wind turbine can range in size from a few kW for residential applications to several MW. Typically, individual wind turbines are grouped into wind farms containing several turbines. Many wind farms are MW scale, ranging from a few MW to tens of MW.

Wind Generators	
Capacity:	few kW to several MW
Fuels:	Wind
Efficiency:	20 to 40%
Cogeneration:	Not available

Combined Heat and Power (CHP)

Combined heat and power (CHP) systems use the excess heat generated during the normal production of electric power. Distributed power generation systems, which are frequently located near thermal loads, are particularly well suited for CHP applications. Many DG technologies, such as reciprocating engines and combustion turbines, produce heat. The heat can be used for a variety of applications, including process heating at an industrial site, air and water heating, or the generation of additional electricity (cogeneration) with a steam generator.

Emerging Technologies

The following emerging technologies offer many environmental advantages; however, the technologies have not advanced to be economical in wide use applications.

- Fuel Cells
  - Molten carbonate fuel cells (MCFC)
  - Phosphoric acid fuel cells (PAFC)
  - Proton exchange membrane fuel cells (PEMFC)
  - Solid oxide fuel cells (SOFC)
- Stirling Engines

Fuel Cells

While the concept of the fuel cell has been around for more than 100 years, the first practical fuel cells were developed for the U.S. space program in the 1960s. NASA continues its reliance on fuel cells to power space shuttle vehicles. Because of technology improvements in recent years and significant investment by auto companies, utilities,

Fuel Cells	
Capacity:	1 kW to 10 MW
Fuels:	Natural Gas
	Hydrogen
	Landfill Gas
	Propane
	Fuel Oil
	Diesel
Efficiency:	25 to 60%
Cogeneration:	As hot water, LP or HP steam

NASA, and the military, fuel cells are expected to have applications for distributed power generation within the next few years.

Fuel cells promise to deliver electrical conversion efficiencies in the range of 40 to 60%. Even higher total energy conversion efficiencies (approaching 80 to 90%) are possible when used in cogeneration applications, where both electricity and the heat of reaction are utilized. Fuel cells operate quietly and reliably while producing minimal emissions. Electricity is produced without the use of combustion.

Fuel cells are being developed in the size range of a few kilowatts up to a few megawatts. However, larger units (up to 20 MW), and smaller micro-fuel cells (for portable electronic devices) are also being investigated. The driving force behind fuel cell development is not just the electric power industry but also the automotive/transportation industry. This cross-industry interest has helped to accelerate progress towards commercially available products.

There are four primary fuel cell technologies, including phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), and proton exchange membrane fuel cells (PEMFC). The technologies are at varying stages of development or commercialization. Fuel cell stacks utilize hydrogen and oxygen as the primary reactants. However, depending on the type of fuel processor and reformer used, fuel cells can use a number of fuel sources including gasoline, diesel, LNG, methane, methanol, natural gas, “waste gas” and solid carbon.

Stirling Engines

Stirling engines are classed as external combustion engines. They are sealed systems with an inert working fluid, usually helium or hydrogen. They are generally found in small sizes (1 - 25 kW) and are currently being produced in small quantities for specialized applications.

Stirling Engines

Capacity:	1 kW to 25 kW
Fuels:	Natural Gas
	Fuel Flexible
Efficiency:	12 to 20%
Cogeneration:	Available

Stirling engines were patented in 1816 and were commonly used prior to World War I. Stirling engines lost favor as competing technologies emerged. Recent interest in DG and use by the space and marine industries has revived interest in Stirling engines and as a result, research and development efforts have increased.

One concept for utilizing the Stirling engine is in combination with concentrating solar collectors. In this configuration, solar arrays concentrate the heat used to power the Stirling engine. Until recently, this application was undergoing research and was viewed as too costly. However, several large-scale installations are currently underway in southern California.