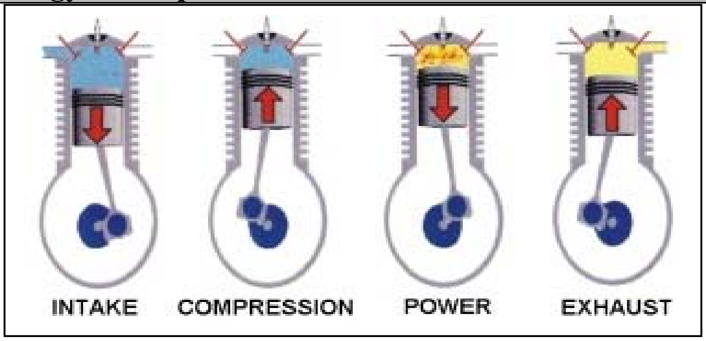
Reciprocating Engines

Technology Description

Reciprocating engines, also known as internal combustion engines, require fuel, air, compression, and a combustion source to function. They make up the largest share of the small power generation market and can be used in a variety of applications due to their small size, low unit costs, and useful thermal output.



System Concepts

- Reciprocating engines fall into one of two categories depending on the ignition source: spark ignition (SI), typically fueled by gasoline or natural gas; or compression ignition (CI), typically fueled by diesel oil.
- Reciprocating engines also are categorized by the number of revolutions it takes to complete a combustion cycle. A two-stroke engine completes its combustion cycle in one revolution, and a four-stroke engine completes the combustion process in two revolutions.

Representative Technologies

- The four-stroke SI engine has an intake, compression, power, and exhaust cycle. In the intake stroke, as the piston moves downward in its cylinder, the intake valve opens and the upper portion of the cylinder fills with fuel and air. When the piston returns upward in the compression cycle, the spark plug fires, igniting the fuel/air mixture. This controlled combustion forces the piston down in the power stroke, turning the crankshaft and producing useful shaft power. Finally, the piston moves up again, exhausting the burnt fuel and air in the exhaust stroke.
- The four-stroke CI engine operates in a similar manner, except diesel fuel and air ignite when the piston compresses the mixture to a critical pressure. At this pressure, no spark or ignition system is needed because the mixture ignites spontaneously, providing the energy to push the piston down in the power stroke.
- The two-stroke engine, whether SI or CI, has a higher power density, because it requires half as many crankshaft revolutions to produce power. However, two-stroke engines are prone to let more fuel pass through, resulting in higher hydrocarbon emissions in the form of unburned fuel.

Technology Applications

- Reciprocating engines can be installed to accommodate baseload, peaking, emergency or standby power applications. Commercially available engines range in size from 10 kW to more than 7 MW, making them suitable for many distributed-power applications. Utility substations and small municipalities can install engines to provide baseload or peak shaving power. However, the most promising markets for reciprocating engines are on-site at commercial, industrial, and institutional facilities. With fast start-up time, reciprocating engines can play integral backup roles in many building energy systems. On-site reciprocating engines become even more attractive in regions with high electric rates (energy/demand charges).
- When properly treated, the engines can run on fuel generated by waste treatment (methane) and other biofuels.
- By using the recuperators that capture and return waste exhaust heat, reciprocating engines can be used in combined heat and power (CHP) systems to achieve energy efficiency levels approaching 80%. In fact, reciprocating engines make up a large portion of the CHP or cogeneration market.

Current Status

- Commercially available engines have efficiencies (LHV) between 28% and 50% and yield NOx emissions of 0.5-2.0 grams per horsepower hour (hp-hr) for lean-burn natural gas engines and 3.5-6.0 g/bhp-hr for conventional dual-fuel engines. CHP engines achieve efficiencies (LHV) of 70-80%.

- Installed cost for reciprocating engines range between \$695 and \$1,350/ kW depending on size and whether the unit is for a straight generation or cogeneration application. Operating and maintenance costs range 0.8 -1.8 ¢/kWh. Production costs are generally lowest for high-speed engines.
- Exhaust temperature for most reciprocating engines is 700-1,200° F in non-CHP mode and 350-500°F in a CHP system after heat recovery.
- Noise levels with sound enclosures are typically between 70-80 dB.
- The reciprocating-engine systems typically include several major parts: fuel storage, handling, and conditioning, prime mover (engine), emission controls, waste recovery (CHP systems) and rejections (radiators), and electrical switchgear.
- Annual shipments of reciprocating engines (sized 10MW or less) have almost doubled to 18 GW between 1997 and 2000. The growth is overwhelming in the diesel market, which represented 16 GW shipments compared with 2 GW of natural gas reciprocating engine shipments in 2000.
- The cost of full maintenance contracts range from 0.7 to 2.0 cents/kWh. Remote monitoring is now available as a part of service contracts.

(**Source**: Diesel and Gas Turbine Worldwide, 2003).

Key indicators for stationary reciprocating engines:

Installed Worldwide Capacity	Installed US Capacity	Number of CHP sites using Recips in the U.S. in 2000
146 GW	52 GW	1,055

Sources: Distributed Generation: The Power Paradigm for the New Millenium, 2001; "Gas-Fired Distributed Energy Resource Technology Characterizations (2003)."

Technology History

- Natural gas-reciprocating engines have been used for power generation since the 1940s. The earliest engines were derived from diesel blocks and incorporated the same components of the diesel engine. Spark plugs and carburetors replaced fuel injectors, and lower compression-ratio pistons were substituted to run the engine on gaseous fuels. These engines were designed to run without regard to fuel efficiency or emission levels. They were used mainly to produce power at local utilities and to drive pumps and compressors.
- In the mid-1980s, manufacturers were facing pressure to lower NOx emissions and increase fuel economy. Leaner air-fuel mixtures were developed using turbochargers and charge air coolers, and in combination with lower in-cylinder fire temperatures, the engines reduced NOx from 20 to 5 g/bhp-hr. The lower in-cylinder fire temperatures also meant that the BMEP (Brake Mean Effective Pressure) could increase without damaging the valves and manifolds.
- Reciprocating-engine sales have grown more then fivefold from 1988 (2 GW) to 1998 (11.5 GW). Gas-fired engine sales in 1990 were 4% compared to 14% in 1998. The trend is likely to continue for gas-fired reciprocating engines due to strict air-emission regulations and because performance has been steadily improving for the past 15 years.
- More than 35 million reciprocating engine units are produced in North America annually for automobiles, trucks, construction and mining equipment, marine propulsion, lawn care and a diverse range of power-generation applications.

Technology Future

In 1998, The U.S. Department of Energy – in partnership with the Gas Technology Institute, the Southwest Research Institute, and equipment manufacturers – joined the Advanced Reciprocating Engines Systems (ARES) consortium, aimed at further advancing the performance of the engine. Performance targets include:
High Efficiency- Target fuel-to-electricity conversion efficiency (LHV) is 50 % by 2010.

Environment – Engine improvements in efficiency, combustion strategy, and emissions reductions will substantially reduce overall emissions to the environments. The NOx target for the ARES program is 0.1 g/hp-hr, a 90% decrease from today's NOx emissions rate.
Fuel Flexibility – Natural gas-fired engines are to be adapted to handle biogas, renewables, propane and hydrogen, as well as dual fuel capabilities.
Cost of Power – The target for energy costs, including operating and maintenance costs, is 10% less than current state-of-the-art engine systems.
Availability, Reliability, and Maintainability – The goal is to maintain levels equivalent to current state-of-the-art systems.
Other R&D directions include: new turbocharger methods, heat recovery equipment specific to the reciprocating engine, alternate ignition system, emission-control technologies, improved generator technology, frequency inverters, controls/sensors, higher compression ratio, and dedicated natural-gas cylinder heads.

Source: National Renewable Energy Laboratory. *Gas-Fired Distributed Energy Resource Technology Characterizations.* NREL/TP-620-34783. November 2003.

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Technology Performance

Power Ranges (kW) of Selected Manufacturers

Source: Manufacturer Specs

	Low	High
Caterpillar	150	3,350
Waukesha	200	2,800
Cummins	5	1,750
Jenbacher	200	2,600
Wartsila	500	5,000

Market Data

Market Shipments
(GW of units under 10 MW in size)

Source: Debbie Haught, DOE, communication 2/26/02 - from Diesel and Gas Turbine Worldwide.

	1996	1997	1998	1999	2000
Diesel Recips	7.96	7.51	8.23	10.02	16.46
Gas Recips	0.73	1.35	1.19	1.63	2.07