8.5: Energy Uses

Electrical and Plug-in Hybrids

Since the early 20th Century, oil and the internal combustion engine have dominated transportation. The fortunes of oil and vehicles have been intertwined, with oil racing to meet the energy demands of the ever growing power and number of personal vehicles, vehicles driving farther in response to growing interstate highway opportunities for long distance personal travel and freight shipping, and greater personal mobility producing living patterns in far-flung suburbs that require oil and cars to function. In recent and future years, the greatest transportation growth will be in developing countries where the need and the market for transportation is growing rapidly. China has an emerging middle class that is larger than the entire population of the United States, a sign that developing countries will soon direct or strongly influence the emergence of new technologies designed to serve their needs. Beyond deploying new technologies, developing countries have a potentially large second advantage: they need not follow the same development path through outdated intermediate technologies taken by the developed world. Leapfrogging directly to the most advanced technologies avoids legacy infrastructures and long turnover times, allowing innovation and deployment on an accelerated scale.

The internal combustion engine and the vehicles it powers have made enormous engineering strides in the past half century, increasing efficiency, durability, comfort and adding such now-standard features as air conditioning, cruise control, hands-free cell phone use, and global positioning systems. Simultaneously, the automobile industry has become global, dramatically increasing competition, consumer choice and marketing reach. The most recent trend in transportation is dramatic swings in the price of oil, the lifeblood of traditional vehicles powered with internal combustion engines.
Hydrogen as an Alternative Fuel

The traditional synergy of oil with automobiles may now be showing signs of strain. The reliance of vehicles on one fuel whose price shows strong fluctuations and whose future course is ultimately unsustainable presents long-term business challenges. Motivated by these business and sustainability concerns, the automobile industry is beginning to diversify to other fuels. Hydrogen made its debut in the early 2000s, and showed that it has the potential to power vehicles using fuel cells to produce on-board electricity for electric motors (Eberle and von Helmholt, 2010, Crabtree, Dresselhaus, & Buchanan, 2004). One advantage of hydrogen is efficiency, up to 50 percent or greater for fuel cells, up to 90 percent or greater for electric motors powering the car, compared with 25 percent efficiency for an internal combustion engine. A second advantage is reduced dependence on foreign oil – hydrogen can be produced from natural gas or from entirely renewable resources such as solar decomposition of water. A third potential advantage of hydrogen is environmental – the emissions from the hydrogen car are harmless: water and a small amount of heat, though the emissions from the hydrogen production chain may significantly offset this advantage.

The vision of hydrogen cars powered by fuel cells remains strong. It must overcome significant challenges, however, before becoming practical, such as storing hydrogen on board vehicles at high densities, finding inexpensive and earth-abundant catalysts to promote the reduction of oxygen to water in fuel cells, and producing enough hydrogen from renewable sources such as solar driven water splitting to fuel the automobile industry (Crabtree & Dresselhaus, 2008). The hydrogen and electric energy chains for automobiles are illustrated in Figure 1. Many scientists and automobile companies are exploring hydrogen as a long-term alternative to oil.

Electricity as an Alternative Fuel

Electric cars represent a second alternative to oil for transportation, with many similarities to hydrogen (see Figure 1). Electric vehicles are run by an electric motor, as in a fuel cell car, up to four times as efficient as a gasoline engine. The electric motor is far simpler than a gasoline engine, having only one moving part, a shaft rotating inside a stationary housing and surrounded by a coil of copper wire. Electricity comes from a battery, whose storage capacity, like that of hydrogen materials, is too small to enable long distance driving. Developing higher energy density batteries for vehicles is a major challenge for the electric car industry. The battery must be charged before driving, which can be done from the grid using excess capacity available at night, or during the day from special solar charging stations that do not add additional load to the grid. Because charging typically takes hours, a potentially attractive alternative is...
switching the battery out in a matter of minutes for a freshly charged one at special swapping stations. A large fleet of electric cars in the United States would require significant additional electricity, as much as 130 GW if the entire passenger and light truck fleet were converted to electricity, or 30 percent of average United States electricity usage in 2008.

The energy usage of electric cars is about a factor of four less than for gasoline cars, consistent with the higher efficiency of electric motors over internal combustion engines. Although gasoline cars vary significantly in their energy efficiency, a "typical" middle of the road value for a five-passenger car is 80 kWh/100 km. A typical electric car (such as the Think Ox from Norway, the Chevy Volt operating in its electric mode, or the Nissan Leaf) uses ~ 20 kWh/100 km. While the energy cost of electric cars at the point of use is significantly less, one must consider the cost at the point of production, the electricity generating plant. If the vehicle's electricity comes from coal with a conversion efficiency of 33 percent, the primary energy cost is 60 kWh/100 km, approaching but still smaller than that of the gasoline car. If electricity is generated by combined cycle natural gas turbines with 60 percent efficiency, the primary energy cost is 33 kWh/100 km, less than half the primary energy cost for gasoline cars. These comparisons are presented in Table 1.

<table>
<thead>
<tr>
<th>Gasoline Engine 5 Passenger Car</th>
<th>Battery Electric Nissan Leaf, Chevy Volt (battery mode), Think Ox</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy at Point of Use</td>
<td>80 kWh/100 km</td>
</tr>
<tr>
<td></td>
<td>20 kWh/100 km</td>
</tr>
<tr>
<td>Energy use at point of production:</td>
<td></td>
</tr>
<tr>
<td>Coal at 33% efficiency</td>
<td>60 kWh/100 km</td>
</tr>
<tr>
<td>Combined Cycle Natural Gas at 60% efficiency</td>
<td>33 kWh/100 km</td>
</tr>
</tbody>
</table>

**Table 1** Comparisons of Energy Use
Comparison of energy use for gasoline driven and battery driven cars, for the cases of inefficient coal generation (33%) and efficient combined cycle natural gas generation (60%) of electricity. Source: George Crabtree.

<table>
<thead>
<tr>
<th>Gasoline Engine 5 Passenger Car</th>
<th>Battery Electric Nissan Leaf, Chevy Volt (battery mode), Think Ox</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Emissions at point of use</td>
<td>41 lbs</td>
</tr>
<tr>
<td></td>
<td>~ 0</td>
</tr>
<tr>
<td>CO₂ Emissions at point of production:</td>
<td></td>
</tr>
<tr>
<td>Coal @ 2.1 lb CO₂/kWh</td>
<td>42 lbs</td>
</tr>
<tr>
<td>Gas @ 1.3 lb CO₂/kWh</td>
<td>25 lbs</td>
</tr>
<tr>
<td>Nuclear, hydro, wind or solar</td>
<td>&lt; 1 lb</td>
</tr>
</tbody>
</table>

**Table 2** Comparisons of Carbon Emissions
Comparison of carbon emissions from gasoline driven and battery driven cars, for the cases of high emission coal generation (2.1 lb CO₂/kWh), lower emission natural gas (1.3 lb CO₂/kWh) and very low emission nuclear, hydro, wind or solar electricity. Source: George Crabtree.
The carbon footprint of electric cars requires a similar calculation. For coal-fired electricity producing 2.1 lb CO2/kWh, driving 100km produces 42 lbs (19 kgs) of carbon dioxide; for gas-fired electricity producing 1.3 lb CO2/kWh, 100km of driving produces 26 lbs (11.7 kgs) of carbon dioxide. If electricity is produced by nuclear or renewable energy such as wind, solar or hydroelectric, no carbon dioxide is produced. For a "typical" gasoline car, 100km of driving produces 41 lbs (18.5 kgs) of carbon dioxide. Thus the carbon footprint of a "typical" electric car is, at worst equal, to that of a gasoline car and, at best, zero. Table \( \PageIndex{3} \) summarizes the carbon footprint comparisons.

The Hybrid Solutions

Unlike electric cars, hybrid vehicles rely only on gasoline for their power. Hybrids do, however, have a supplemental electric motor and drive system that operates only when the gasoline engine performance is weak or needs a boost: on starting from a stop, passing, or climbing hills. Conventional gasoline cars have only a single engine that must propel the car under all conditions; it must, therefore, be sized to the largest task. Under normal driving conditions the engine is larger and less efficient than it needs to be. The hybrid solves this dilemma by providing two drive trains, a gasoline engine for normal driving and an electric motor for high power needs when starting, climbing hills and passing. The engine and motor are tailored to their respective tasks, enabling each to be designed for maximum efficiency. As the electric motor is overall much more efficient, its use can raise fuel economy significantly.

The battery in hybrid cars has two functions: it drives the electric motor and also collects electrical energy from regenerative braking, converted from kinetic energy at the wheels by small generators. Regenerative braking is effective in start-stop driving, increasing efficiency up to 20 percent. Unlike gasoline engines, electric motors use no energy while standing still; hybrids therefore shut off the gasoline engine when the car comes to a stop to save the idling energy. Gasoline engines are notoriously inefficient at low speeds (hence the need for low gear ratios), so the electric motor accelerates the hybrid to ~15 mph (24 kph) before the gasoline engine restarts. Shutting the gasoline engine off while stopped increases efficiency as much as 17 percent.

The energy saving features of hybrids typically lower their energy requirements from 80 kWh/100km to 50-60 kWh/100km, a significant savings. It is important to note, however, that despite a supplementary electric motor drive system, all of a hybrid's energy comes from gasoline and none from the electricity grid.

The plug-in hybrid differs from conventional hybrids in tapping both gasoline and the electricity grid for its energy. Most plug-in hybrids are designed to run on electricity first and on gasoline second; the gasoline engine kicks in only when the battery runs out. The plug-in hybrid is thus an electric car with a supplemental gasoline engine, the opposite of the conventional hybrid cars described above. The value of the plug-in hybrid is that it solves the "driving range anxiety" of the consumer: there are no worries about getting home safely from a trip that turns out to be longer than expected. The disadvantage of the plug-in hybrid is the additional supplemental gasoline engine technology, which adds cost and complexity to the automobile.

The Battery Challenge

To achieve reasonable driving range, electric cars and plug-in hybrids need large batteries, one of their greatest design challenges and a potentially significant consumer barrier to widespread sales. Even with the largest practical batteries, driving range on electricity is limited, perhaps to ~100km. Designing higher energy density batteries is currently a major focus of energy research, with advances in Li-ion battery technology expected to bring significant improvements. The second potential barrier to public acceptance of electric vehicles is charging time, up to eight hours from a standard
household outlet. This may suit overnight charging at home, but could be a problem for trips beyond the battery's range – with a gasoline car the driver simply fills up in a few minutes and is on his way. Novel infrastructure solutions such as battery swapping stations for long trips are under consideration.

From a sustainability perspective, the comparison of gasoline, electric, hybrid and plug-in hybrid cars is interesting. Hybrid cars take all their energy from gasoline and represent the least difference from gasoline cars. Their supplementary electric drive systems reduce gasoline usage by 30-40 percent, thus promoting conservation of a finite resource and reducing reliance on foreign oil. Electric cars, however, get all of their energy from grid electricity, a domestic energy source, completely eliminating reliance on foreign oil and use of finite oil resources. Their sustainability value is therefore higher than hybrids. Plug-in hybrids have the same potential as all electric vehicles, provided their gasoline engines are used sparingly. In terms of carbon emissions, the sustainability value of electric vehicles depends entirely on the electricity source: neutral for coal, positive for gas and highly positive for nuclear or renewable hydro, wind or solar. From an energy perspective, electric cars use a factor of four less energy than gasoline cars at the point of use, but this advantage is partially compromised by inefficiencies at the point of electricity generation. Even inefficient coal-fired electricity leaves an advantage for electric cars, and efficient gas-fired combined cycle electricity leaves electric cars more than a factor of two more energy efficient than gasoline cars.

Summary

Electricity offers an attractive alternative to oil as a transportation fuel: it is domestically produced, uses energy more efficiently, and, depending on the mode of electricity generation, can emit much less carbon. Electric vehicles can be powered by fuel cells producing electricity from hydrogen, or from batteries charged from the electricity grid. The hydrogen option presents greater technological challenges of fuel cell cost and durability and high capacity on-board hydrogen storage. The battery option is ready for implementation in the nearer term but requires higher energy density batteries for extended driving range, and a fast charging or battery swapping alternative to long battery charging times.

Combined Heat and Power

Electricity in the United States is generated, for the most part, from central station power plants at a conversion efficiency of roughly 30 to 35 percent. Meaning, for every 100 units of fuel energy into a simple cycle central station electric power plant, we get only 30 to 35 units of electricity. The remainder of the energy in the fuel is lost to the atmosphere in the form of heat.

The thermal requirements of our buildings and facilities are generally provided on-site through the use of a boiler or furnace. The efficiencies of this equipment have improved over the years and now it is common to have boilers and furnaces in commercial and industrial facilities with efficiencies of 80 percent and higher. Meaning, for every 100 units of fuel energy into the boiler/furnace, we get about 80 units of useful thermal energy.

Commercial and industrial facilities that utilize the conventional energy system found in the United States (electricity supplied from the electric grid and thermal energy produced on-site through the use of a boiler/furnace) will often times experience overall fuel efficiencies of between 40 to 55 percent (actual efficiency depends on the facilities heat to power ratio).

Combined Heat and Power (CHP) is a form of distributed generation. It is an integrated system located at or near the
building/facility that generates utility grade electricity which satisfies at least a portion of the electrical load of the facility, and captures and recycles the waste heat from the electric generating equipment to provide useful thermal energy to the facility.

Conventional CHP (also referred to as topping cycle CHP) utilizes a single dedicated fuel source to sequentially produce useful electric and thermal power. Figure \(\PageIndex{2}\) provides a diagram of a typical topping cycle CHP system. A variety of fossil fuels, renewable fuels, and waste products are utilized as input fuel to power a prime mover that generates mechanical shaft power (exception is fuel cells). Prime movers might include reciprocating engines, gas turbines, steam turbines or fuel cells. The mechanical shaft power is converted into utility grade electricity through a highly efficient generator. Since the CHP system is located at or near the building/facility, the heat lost through the prime mover can be recycled through a heat exchanger and provide heating, cooling (absorption chillers), and/or dehumidification (desiccants) to meet the thermal load of the building. These systems can reach fuel use efficiencies of as high as 75 to 85 percent (versus the conventional energy system at approximately 40 to 55 percent).

Key Factor: Coincidence of Electric and Thermal Loads

Figure \(\PageIndex{3}\) Conventional (Topping Cycle) CHP Diagram illustrates a typical topping cycle of CHP systems.
Source: John Cuttica

In our example of 100 units of fuel into the CHP system, only 30 to 35 units of electricity are generated, but another 40 to 50 units of the fuels energy can be recovered and utilized to produce thermal power. What this tells us is that for conventional CHP systems to reach the high efficiency level, there must be a use for the recovered thermal energy. Thus a key factor for conventional CHP systems is the coincidence of electric and thermal loads in the building. This is shown in Figure \(\PageIndex{3}\). The “Y” axis represents the cost of generating electricity with a CHP system utilizing a 32 percent efficient reciprocating engine. The “X” axis represents the cost of natural gas utilized to operate the CHP system and also the value of the natural gas being displaced if the recycled heat from the engine can be utilized. The lines in the chart show various levels of recoverable heat available from the engine. If no heat is recovered (no use for the thermal energy), the cost of generating electricity with the CHP system is $0.08/kWhr. When the full amount of heat from the engine is recovered (full use of the thermal energy), the cost of generating electricity with the CHP system then drops to $0.03/kWhr.
Since the high efficiency of a CHP system is dependent on the effective use of the recoverable heat, CHP systems are often times sized to meet the thermal load of the application and the amount of electricity produced is the by-product. The electricity is used to offset the electricity otherwise purchased from the local electric utility. When the CHP system does not produce enough electricity to satisfy the load, the utility supplies the difference from the grid. When the CHP system (sized from the thermal requirements) produces more electricity than the load requires, the excess electricity can be sold to the local utility (normally at the avoided cost of power to the utility).

There are three general modes of operation for CHP on-site generators relative to the electric utility grid:

- Stand Alone (totally isolated from the grid)
- Isolated from the grid with utility back-up (when needed)
- Parallel operation with the grid

The preferred mode of operation is parallel with the grid. Both the on-site CHP system and the utility grid power the facility simultaneously. With a proper sizing and configuration of the CHP system, the parallel mode of operation provides the most flexibility. Should the grid go down, the CHP system can keep operating (e.g. during the 2003 Northeast Blackout and the 2005 Hurricane Katrina), and should the CHP system go down, the utility grid can supply power to the load. Overall reliability of power to the load is increased.

The basic components of a conventional (topping cycle) CHP system are:

- Prime Mover that generates mechanical shaft energy
  - Reciprocating engine
  - Turbines (gas, micro, steam)
  - Fuel Cell (fuel cells utilize an electrochemical process rather than a mechanical shaft process)
- Generator converts the mechanical shaft energy into electrical energy
  - Synchronous generator (provides most flexibility and independence from the grid)
  - Induction generator (grid goes down - the CHP system stops operating)
  - Inverter (used mainly on fuel cells - converts DC power to utility grade AC power)
- Waste Heat Recovery is one or more heat exchangers that capture and recycle the heat from the prime mover
• Thermal Utilization equipment converts the recycled heat into useful heating, cooling (absorption chillers) and/or dehumidification (deisiccant dehumidifiers)
• Operating Control Systems insure the CHP components function properly together

Reducing CO₂ Emissions

In 2007, McKinsey & Company published a study on reducing United States greenhouse gas emissions. The report analyzed the cost and potential impact of over 250 technology options regarding contribution to reducing CO₂ emissions. Two conclusions stated in the report were:

• Abatement opportunities are highly fragmented and spread across the economy.
• Almost 40 percent of abatement could be achieved at negative marginal costs.

Figure \(\PageIndex{4}\) emphasizes both of these points. It is interesting to point out that CHP (both industrial and commercial applications), when sized and installed appropriately, delivers CO₂ reductions at a negative marginal cost. All the technologies that show a negative marginal cost on the chart generate positive economic returns over the technology’s life cycle. The figure also shows that in terms of cost effectiveness of the wide range of abatement technologies, energy efficiency measures are by far more effective than renewable, nuclear and clean coal generating technologies. CHP technologies stand out as having negative marginal costs and overall positive cost effectiveness comparable to most of the energy efficiency measures.

Long operating hours (normally more than 3,000 hours annually)
Need for good power quality and reliability

The following are just a few of the type applications where CHP makes sense:

- Hospitals
- Colleges and Universities
- High Schools
- Fitness Centers
- Office Buildings
- Hotels
- Data Centers
- Prisons
- Pulp and Paper Mills
- Chemical Manufacturing Plants
- Metal Fabrication Facilities
- Glass Manufacturers
- Ethanol Plants
- Food Processing Plants
- Waste Water Treatment Facilities
- Livestock Farms

**CHP Benefits**

CHP is not the only solution to our energy problems. In fact, CHP is not the most cost effective solution in all applications or in all areas of the country. There are many variables that determine the viability of CHP installations. However, when the technical and financial requirements of the application are met, a well designed, installed and operated CHP system provides benefits for the facility owner (end user), the electric utility, and society in general. The high efficiency attained by the CHP system provides the end user with lower overall energy costs, improved electric reliability, improved electric power quality, and improved energy security. In areas where the electric utility distribution grid is in need of expansion and/or upgrades, CHP systems can provide the electric utility with a means of deferring costly modifications to the grid. Although the electricity generated on-site by the end user displaces the electricity purchased from the local electric utility and is seen as lost revenue by many utilities, energy efficiency and lower utility costs are in the best interest of the utility customer and should be considered as a reasonable customer option by forward-looking customer oriented utilities. Finally, society in general benefits from the high efficiencies realized by CHP systems. The high efficiencies translate to less air pollutants (lower greenhouse gas and NOx emissions) than produced from central station electric power plants.

**Waste Heat to Power**

There is a second type of CHP system, referred to as Waste Heat to Power (Bottoming Cycle CHP). Unlike conventional
CHP where a dedicated fuel is combusted in a prime mover, Waste Heat to Power CHP systems captures the heat otherwise wasted in an industrial or commercial process. The waste heat, rather than the process fuel, becomes the fuel source for the waste heat to power system. It is used to generate steam or hot water, which in turn is utilized to drive a steam turbine or (for lower temperatures) an organic rankine cycle heat engine. In this case, the waste heat from the industrial/commercial process is converted to electric power. Figure \( \PageIndex{5} \).

- No Additional Fuel Consumed
- No Additional On-Site Emissions
- May or May Not Generate Additional Thermal Energy

Figure \( \PageIndex{5} \) Waste Heat to Power (Bottoming Cycle) CHP Diagram illustrates a waste heat to power (bottoming cycle) CHP system. Source: John Cuttica

Summary

Combined Heat and Power (CHP) represents a proven and effective near-term alternative energy option that can enhance energy efficiency, ensure environmental quality, and promote economic growth. The concept of generating electricity on-site allows one to capture and recycle the waste heat from the prime mover providing fuel use efficiencies as high as 75 to 85 percent. Like other forms of alternative energy, CHP should be considered and included in any portfolio of energy options.

References


Questions

1. Transportation relies almost exclusively for its fuel on oil, whose price fluctuates significantly in response to global geopolitics and whose long-term availability is limited. What are the motivations for each of the stakeholders, including citizens, companies and governments, to find alternatives to oil as a transportation fuel?
2. Electricity can replace oil as a transportation fuel in two ways: by on board production in a hydrogen fuel cell, and
by on board storage in a battery. What research and development, infrastructure and production challenges must be overcome for each of these electrification options to be widely deployed?

3. Electric- and gasoline-driven cars each use energy and emit carbon dioxide. Which is more sustainable?

4. How do gasoline-driven, battery-driven and hybrid cars (like the Prius) compare for (i) energy efficiency, (ii) carbon emissions, and (iii) reducing dependence on foreign oil?

5. What drives the system efficiency in a conventional CHP system?

6. To ensure high system efficiency, how would you size a conventional CHP system?

7. What is the preferred method of operating a CHP system that provides the most flexibility with the utility grid?

8. Why are CHP systems considered one of the most cost-effective CO2 abatement practices?

9. Name at least three application characteristics that make CHP an attractive choice.

Glossary

Hybrid Vehicle

A car that contains two drive systems, one based on the internal combustion engine and one on the electric motor. Conventional hybrids, such as the Toyota Prius, use the electric motor only when high power is needed: starting from a stop, passing, and going uphill. The electricity to run the motor is generated on board by an alternator powered by the internal combustion engine and by regenerative breaking. Plug-in hybrids such as the Chevy Volt, in contrast, use the electric motor as the main drive for the car, relying on the gasoline engine only when the battery is low or empty.

Internal Combustion Engine

The engine that converts the chemical energy of gasoline into the mechanical energy of motion, by exploding small amounts of fuel in the confined space of fixed cylinder containing a moving piston. A precise amount of fuel must be metered in, and a spark created at a precise moment in the piston's journey to produce the maximum explosive force to drive the piston. The internal combustion engine is an engineering marvel (the word engineering celebrates it) perfected over more than a century. In contrast, the electric motor is much simpler, more efficient and less expensive for the same power output.

Point of Production

The first (or at least an early) step in the energy chain, where the energy that ultimately will perform a function at the point of use is put into its working form. For gasoline-driven cars, this is the refinery where gasoline is produced from crude oil, for battery-driven cars this is the power generation plant were electricity is produced. Gasoline is then delivered to the pump and finally to the car, where it is converted (the point of use) to mechanical motion by the engine. Similarly, electricity is delivered to the battery of an electric car by the grid, and converted by the electric motor of the car (the point of use) to mechanical motion.

Point of Use
The last step in the energy chain, where energy accomplishes its intended function. For vehicles, this is the conversion of chemical energy in gasoline cars or electric energy in battery cars to motion of the wheels that moves the car along the road.

**Absorption Chiller**

Utilizes heat instead of mechanical energy to provide cooling. A thermal compressor (fueled by the waste heat from the CHP system) is used in place of an electrically powered mechanical compressor in the refrigeration process.

**Avoided Cost of Power**

The marginal cost for a utility to produce one more unit of power.

**Combined Heat and Power (CHP)**

An integrated system, located at or near the building or facility, that generates utility grade electricity which satisfies at least a portion of the electrical load of the facility and captures/recycles the waste heat from the electric generating equipment to provide useful thermal energy to the facility.

**Conventional CHP (Topping Cycle CHP)**

Utilizes a single dedicated fuel source to sequentially produce useful electric and thermal power.

**Desiccant Dehumidification**

Process that removes moisture (latent load) from a building air stream by passing the air over a desiccant wheel (normally a silica gel). The recovered heat from a CHP system is utilized to regenerate the desiccant by driving the moisture off the desiccant wheel to the outside.

**Fuel Cell**

An exothermic electrochemical reaction that combines hydrogen and oxygen ions through an electrolyte material to generate electricity (DC) and heat.

**Gas Turbine**

An internal-combustion engine consisting essentially of an air compressor, combustion chamber, and turbine wheel that is turned by the expanding products of combustion.

**Induction Generator**

Converts the mechanical shaft power from the CHP prime mover to utility grade Alternating Current Power. An induction generator can only operate when connected to an external reactive power source (normally provided by the utility grid).

**Inverter**

Converts Direct Current electric power into utility grade Alternating Current electric power. Normally used with fuel cell
systems.

**Organic Rankine Cycle (ORC)**

Uses an organic, high molecular mass fluid with a liquid-vapor phase change or boiling point occurring at a lower temperature than the water-steam phase change. The fluid allows rankine cycle heat recovery from lower temperature sources where the heat is converted into useful work, which can then be converted into electricity.

**Prime Mover**

The term utilized to denote the CHP system equipment that converts input fuel into mechanical shaft power (reciprocating engine, gas turbine, steam turbine, micro-turbine).

**Reciprocating Engine**

A heat engine that uses one or more reciprocating pistons to convert pressure into mechanical rotating shaft power.

**Steam Turbine**

Utilizes the Rankine Cycle to extract heat from steam and transform the heat into mechanical shaft power by expanding the steam from high pressure to low pressure through the turbine blades.

**Synchronous Generator**

Converts the mechanical shaft power from the CHP prime mover to utility grade Alternating Current Power. A synchronous generator is self-exciting (contains its own source of reactive power) and can operate independent of, or isolated from, the utility grid.

**Waste Heat to Power (Bottoming Cycle CHP)**

Captures the waste heat generated by an industrial or commercial process, utilizing the waste heat as the free fuel source for generating electricity.

**Energy Density**

The energy contained in a volume or mass divided by the volume or mass it occupies. High energy density materials pack a large energy into a small space or mass; low energy density materials require more space or mass to store the same amount of energy. The electrical energy of batteries is at the low end of the energy density scale, the chemical energy of gasoline is at the high end, approximately a factor of 30-50 larger than batteries.