Chapter 1

Thermodynamics in Everyday Life

In This Chapter

- Seeing thermodynamics in the world around you
- Changing energy from one form to another
- Getting energy to do work and move heat for you
- Figuring out relationships, reactions, and mixtures (nothing personal)
- Inspiring you to save the world from an energy shortage

Thermodynamics is as old as the universe itself, and the universe is simply the largest known thermodynamic system. When the universe ends in a whimper and the total energy of the universe dissipates to nothingness, so will thermodynamics end.

Broadly speaking, thermodynamics is all about energy: how it gets used and how it changes from one form to another. In many cases, thermodynamics involves using heat to provide work, as in the case of your automobile engine, or doing work to move heat, as in your refrigerator. With thermodynamics, you can find out how efficient things are at using energy for useful purposes, such as moving an airplane, generating electricity, or even riding a bicycle.

The word *thermodynamics* has a Greek heritage. The first part, *thermo,* conveys the idea that heat is somehow involved, and the second part, *dynamics,* makes you think of things that move. Keep these two ideas in mind as you look at your world in terms of the basic laws of thermodynamics. This book is written to help you understand that thermodynamics is about turning heat into power, a concept that really isn't so complicated after all.

Grasping Thermodynamics

Many thermodynamic systems are at work in the natural world. That sun you see in the sky is the ultimate energy source for the earth, warming the air, the ground, and the oceans. Huge masses of air move over the earth's surface. Giant currents of water swirl in the oceans. This movement and swirling happens because of the transformation of heat into work.

Energy takes many different forms — it can't be created or destroyed, but it can change form. This statement is one of the fundamental laws of thermodynamics. Consider how energy changes form in storm clouds:

- Storm clouds have motion within them.
- Motion between moisture droplets in clouds rubbing against each other creates friction.
- Friction causes a buildup of static charge.
- When the charge becomes high enough, the clouds produce lightning.
- This electrical surge of energy can then start a fire on the ground, and before you know it, you have a combustion problem on your hands.

Not only does energy change form, but *matter* (that is, a material or substance) also changes form in many thermodynamic systems. Storm clouds are formed by water evaporating into the air. As the water vapor reaches the colder parts of the atmosphere, it condenses to form clouds. Eventually, the amount of moisture the clouds contain becomes great enough to collect into droplets and form liquid water again, so it rains.

One thing people have observed about energy is that it flows in a preferred direction. This observation is another fundamental law of thermodynamics. Heat flows from a hot object to a cold object. Wind blows from a region of high pressure to a region of low pressure. Some forms of energy are developed by forces of nature. Air bubbles move upwards in water against gravity because buoyancy forces them to rise. Water droplets fall in the atmosphere because the force of gravity pulls them toward the ground.

Another brilliant observation about energy is that if you have absolutely no energy at all, you have no temperature. The concept of absolute zero temperature is a fundamental law of thermodynamics.

I cover the changing forms of energy and matter and the fundamental laws that govern how these changes work in Part I.

Examining Energy's Changing Forms

Many clever people have observed the fundamental laws of thermodynamics in natural systems and applied them to create some wonderful ways of doing work by harnessing energy. Heat is used to generate steam or heat up air that moves a piston in a cylinder or spins a turbine. This movement is used to turn a shaft that can operate a lawn mower; move a car, a truck, a locomotive, or a ship; turn an electric generator; or propel an airplane.

Other clever people have used thermodynamic principles to use work to move heat from one place to another. Refrigerators and heat pumps remove heat from one location to produce a desirable cooling or heating effect. The work required for this cooling shows up on your electric bill every month.

In Part II, I show you how the fundamental laws of thermodynamics can tell you how much heat you need to provide to produce work that can be used to move a car, fly an airplane, or turn an electric generator. You can also use the laws of thermodynamics to find out how efficient something is at using energy.

Energy is the basis of every thermodynamic process. When you use energy to do something, it changes form along the way. When you start your car, the battery causes the starter to turn. The battery is a big, heavy box of chemical energy. The battery's job is to change chemical energy into electrical energy. An electric motor rotates (a form of kinetic energy) the engine, and the spark plugs fire. These sparks ignite fuel via a combustion process wherein the chemical energy from gasoline is turned into a form of thermal energy called internal energy. In the few seconds it takes to start your car, energy changes from chemical to electrical to kinetic to thermal or internal energy.

Kinetic energy

A car battery provides electricity to operate your starter. As the motor turns, the electrical energy is converted into a form of mechanical energy called *kinetic energy.* Kinetic energy involves moving a mass so that it has velocity. The mass doesn't have to be very large to have kinetic energy — even electrons have kinetic energy — but the mass has to be moving. Before you start the car, nothing in the engine is moving so it has no kinetic energy. After the engine is started, it has kinetic energy because of its moving pistons and rotating shafts. If the car is parked while the engine is running, the car as a "system" has no kinetic energy until the engine makes the car move.

Potential energy

If you drive your car up a hill and park it there, you change the kinetic energy of the car into another form of energy called *potential energy.* Potential energy is only available with gravity. You must have a mass located at an elevation above some ground state. Potential energy gets its name from its potential to be converted into kinetic energy. You see this conversion process when you park on a hill and forget to apply the parking brake. Potential energy changes back into kinetic energy as your car rolls down the hill.

Internal energy

When you apply the brakes to stop your car, you make energy change form again. You know the car has kinetic energy because it's moving. Stopping the car changes all this kinetic energy into heat. Brake pads squeeze onto steel disks or steel drums, creating friction. Friction generates heat — sometimes a lot of heat. When materials heat up, another form of energy called *internal energy* increases. Have you ever smelled a burning odor while driving down long hills? That odor indicates that someone used their brakes to slow down, and the brakes overheated. Do your brakes a favor: Shift into a lower gear and allow the engine to do the braking for you. When the engine is used as a brake, the kinetic energy of the moving car compresses the air in the cylinders, and the energy changes into internal energy because the air heats up from compression. All that internal energy just goes out the tailpipe.

Watching Energy and Work in Action

Until the invention of the steam engine, man had to slug it out against nature with nature. Horses pulled coaches, mules pulled plows, sails moved ships, windmills ground grain, and water wheels pressed apples into cider that fermented and made man feel happy for all his labors. The steam engine was able to replace these natural work sources and move coaches, plows, and ships, among many other things. For the first time, fire was harnessed to provide something more than just heat — it was used to do work. This use of heat to accomplish work is what Part III is all about. Over time, many different kinds of work machines were developed, theories were made, and experiments were done until a rational system of analyzing heat and work was developed into the field of thermodynamics.

Engines: Letting energy do work

A *heat engine* is a machine that can take some source of heat — burning gasoline, coal, natural gas, or even the sun — and make it do work, usually in the form of turning a shaft. With a rotating shaft, you can make things move — think of elevators or race cars. Every heat engine uses four basic processes that interact with the surroundings to accomplish the engine's job. These processes are heat input, heat rejection, work input, and work output.

Take your automobile engine as an example of a heat engine. Here are the four basic processes that go on under the hood:

1. **Work input**

   Air is compressed in the cylinders. This compression requires work from the engine itself. Initially, this work comes from the starter. As you can imagine, this process takes a lot of work, which is why they don't have those crank handles on the front of cars any more.

2. **Heat input**

   Fuel is burned in the cylinder, where the heat is added to the engine. The heated air in the cylinder naturally wants to increase in pressure and expand. The pressure and expansion move the piston down the cylinder.

3. **Work output**

   As the expanding gas in the cylinder pushes the piston, work is output by the engine. Some of this work compresses the air in adjacent cylinders.

4. **Heat rejection**

   The last process removes heat with the exhaust from the engine.

Refrigeration: Letting work move heat

When Willis Carrier made air conditioners a popular home appliance, he did more than make people comfortable and give electric utilities a reason for growth and expansion. He brought thermodynamics into the home. Thermodynamics has been there all along, and you never realized it. Refrigerators, freezers, air conditioners, and heat pumps are all the same in thermodynamics. Only three basic processes involve energy interacting with the surroundings in what is known as the *refrigeration cycle:*

1. **Heat input**

   Heat is absorbed from the cold space to keep it cold.

2. **Work input**

   Work is added to the system to pump the heat absorbed from the cold space out to the hot space.

3. **Heat rejection**

   Heat is rejected to the hot space.

Actually, a fourth process takes place in most refrigeration cycles, but it doesn't involve a change in energy. Instead of having a work-output process in the cycle like heat engines do, refrigerators simply utilize a pressure-reducing device in the system. Energy doesn't change form in such a device.

Getting into Real Gases, Gas Mixtures, and Combustion Reactions

Using energy to generate electric power, cool your house, fly a jet, or race cars around the Indianapolis Motor Speedway is the glamorous side of thermodynamics. But behind the movie stars are a supporting cast and crew of *thermodynamic relationships* (this is jargon for "mathematical equations") for real gases, gas mixtures, and combustion reactions that make it all happen.

In Part IV, you discover the difference between a real gas and an ideal gas. There you see that real gases behave a bit differently than ideal gases. You also figure out the thermodynamic properties of a mixture of gases, such as water vapor and air for heating, air conditioning, and ventilating purposes. Lastly, you calculate how much energy you can get out of fuel in a combustion reaction to power your jet, your race car, or your lawn mower.

If you want to sell jet engines to an aircraft manufacturer, you have to show that your engine burns fuel efficiently. To build a jet engine, you need to know how much energy a combustion reaction adds to an engine and how much the air in the engine heats up as a result of the combustion. To figure out the latter, you use thermodynamic relationships of real gases to calculate properties such as temperature, pressure, and energy.

Discovering Old Names and New Ways of Saving Energy

As you learn about thermodynamics, you'll run across a number of names. Some of the names may be familiar; others may be new to you. For example, when you get your electric bill, it tells you how many watt-hours of electricity you used last month. If you reheat yesterday's leftover pizza, you set your oven to 350 degrees Fahrenheit. (Or, if you live outside the U.S., you set your oven to some temperature in degrees Celsius.) That big rig that's riding your bumper on the highway burns diesel fuel.

How did these terms — watt, Fahrenheit, Celsius, and Diesel — become part of our language? In Part V, you discover that these words (and six more) are actually the last names of characters bent on figuring out what energy is and how to harness it for the benefit of mankind (and maybe to line their pockets with some folding money).

Pioneers in thermodynamics didn't just work in the good old days; there are modern-day pioneers as well. The world's demand for energy steadily increases while energy resources dwindle. Part V shows you ten ways innovative thinkers have improved energy consumption for automobiles, air conditioners, refrigerators, and electric power plants. Making a better future for all has motivated many people to think of better ways to use energy.

Even Albert Einstein got a patent for making a better air-conditioning system (see Chapter 18). Maybe you'll be inspired to create your own innovation and make a name for yourself in thermodynamics.