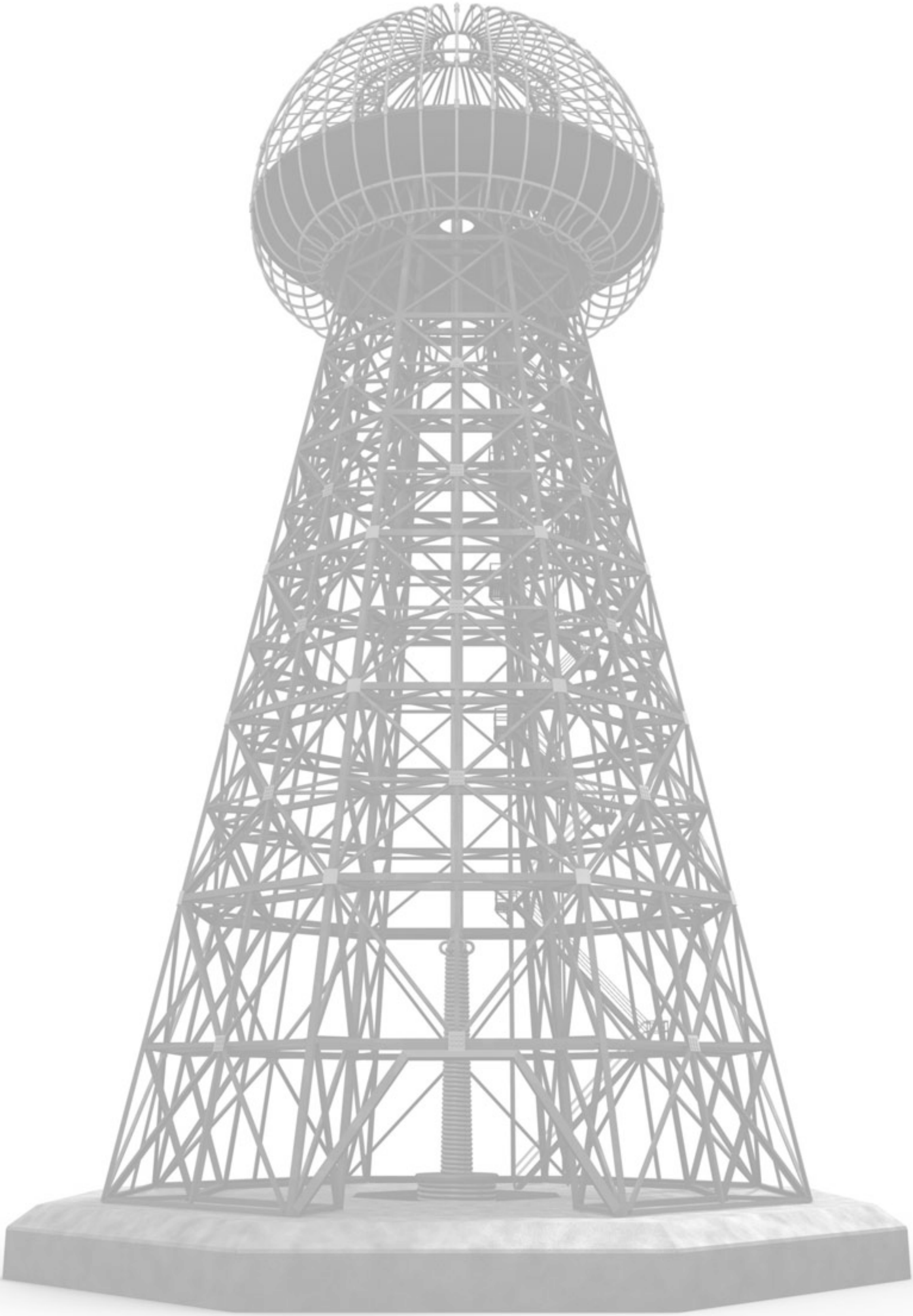

7

Energy and Emissions

This chapter provides basic information for understanding energy and calculating emissions, including common sources of energy, calculating energy and power, impacts of various power sources, batteries and standby power, measuring greenhouse gas (GHG) and other emissions, and additional topics such as energy usage and efficiency opportunities in data centers.

> "The most available, cheap source of energy is that which we waste."
> *—Alexander ("Andy") Karsner, former U.S. Department of Energy Assistant Secretary for Efficiency*

Energy is at the heart of every product or service. Every day more products depend on electricity to operate and more petroleum-based fuels are used to transport products to their customers (and, hopefully someday, to the recycling center). Even purely digital products have an energy component. It has become hard to imagine a useful product or service without energy.

There are three important things to remember about energy.

- Energy is used at every stage of the product or service lifecycle. While the energy consumed during product use is the most visible, it may not be the largest component of energy use in the whole lifecycle.
- All sources of energy have impacts that need to be taken into account, ranging from GHG emissions to security to safety to impacts on natural spaces. While we often refer to certain types of power as "green," there is no such thing as impact-free energy today.
- Every time energy is converted from one form to another there is inefficiency; in other words, energy is lost. In many cases, that lost

energy takes the form of waste heat or other forms of radiation, which have impacts of their own.

Globally, the demand for energy continues to rise.[1] We know what that means to consumers: rising prices for fuels such as gasoline and natural gas, as well as rising prices, shortages, and occasional brownouts or "rolling blackouts" for electricity. In addition, we're increasingly aware of the impacts of our energy usage, particularly in the form of GHG emissions.

In an ideal world, we'd have a readily available, zero-impact, safe and cost-effective source of energy that would meet our growing needs. Unfortunately, no such energy source exists today. So, we're left with taking a two-pronged approach: continuing to innovate and put into production new, lower-impact energy sources, while at the same time attempting to dramatically decrease our consumption through increased efficiency and changes of behavior. Of course, we could stop traveling, going to work, surfing the Web, shopping, and so on—and some people would advocate that we need to do that—but most of us would prefer to maintain our current lifestyle, so we need to make some serious headway on these two parallel energy strategies.

To engineers this means we need to wring every last bit of energy out of the products we design. The good news is that efficiency is a true win-win-win situation. If you can make your product using less energy, you can make it for less money. If your product uses less energy to operate, you save money for your customers. And in both cases, the environment wins as well.

Common Sources of Energy

Each type of energy has a different set of impacts. Some require mining or drilling; most require specialized equipment of some kind; and each has a different type and amount of emissions. Let's take a quick look at the most common energy sources today.

- **Coal:** Of the fossil fuels, coal is the most carbon-intensive and environmentally challenging to produce and use. Coal is used for electricity production in countries where the economies of large-scale consumption permit it to be used at low cost and in compliance with regulations on air and other emissions. Burning coal naturally produces very large volumes of CO_2; the mining of coal has undesirable impacts as well.

- Petroleum: Petroleum is relatively easy to transport and use and has an intermediate level of carbon intensity. The proportion of hydrocarbons ranges from as much as 97% by weight in the lighter oils to as little as 50% in the heavier oils and bitumens. Petroleum can be produced from conventional resources with relatively small environmental effects, and is readily available in international markets.
- **Natural gas:** Like petroleum, natural gas is currently abundant in large quantities, but it can be difficult and carbon-intensive to move it to consumers. Also, due to the need to cool natural gas to liquefy it, the cost of liquefied natural gas is typically an order of magnitude greater than that of the gas itself.
- **Propane:**[2] Propane is a byproduct of natural gas processing and petroleum refining. Volatiles such as butane, propane, and large amounts of ethane are removed from the raw gas to prevent condensation in natural gas pipelines. Oil refineries also produce some propane as a byproduct of production of cracking petroleum into gasoline or heating oil. When sold as fuel, it is commonly known as liquefied petroleum gas (LPG or LP-gas), which can be a mixture of propane along with small amounts of propylene, butane, and butylene.
- **Uranium:** Uranium is the primary mineral used as a nuclear fission fuel. Because of the slow growth of nuclear power worldwide, demand for a second fuel source has not yet arisen. By the time it is completely fissioned, one kilogram of uranium-235 can theoretically produce about 20 trillion joules of energy (20×10^{12} joules); as much electricity as 1,500 tons of coal.[3] Uranium is found in many countries but is produced in only a few. Worldwide, conventional uranium resources can meet current demand for at least a century, and even longer if estimated additional resources are taken into account.
- **Biomass:** Biomass includes all living plant matter as well as organic wastes derived from plants, humans, marine life, and animals. Trees, grasses, animal dung, as well as sewage, garbage, wood construction residues, and other components of municipal solid waste are examples of biomass. In the past, biomass was the primary source of fuel for the world. Today, in many developing countries it remains an important energy source for heating and cooking. As concerns about our increasing use of fossil fuels mount, many developed countries are now reexamining the potential for biomass energy to displace some use of fossil fuels. However, its higher costs compared with fossil and

nuclear-based alternatives continue to handicap its growth in developing countries.

- **Geothermal energy:** In general, geothermal energy is thermal energy stored within the Earth's crust. Its big advantage is that it's a heat source that doesn't require the purchase of fossil fuels; however, thermal energy is not always easy to extract. From an economic perspective, geothermal energy is price-competitive with fossil fuels, but from an engineering perspective it can be inefficient since much of the heat energy is lost on extraction.
- **Hydroelectric power (hydropower):** Hydropower captures the stored energy in water that flows from a higher to a lower elevation under the influence of gravity. It produces virtually no harmful emissions and is not a significant contributor to global warming. Hydropower can also be far less expensive than electricity generated from fossil fuels or nuclear energy. Typically, hydroenergy conversion can be very efficient, with installations ranging in scale from a few kilowatts to more than 10,000 megawatts. Hydropower accounted for 6.4% of total U.S. electricity generated in 2005, according to the U.S. Department of Energy.[4]
- **Solar energy:** Solar energy is radiant energy from the sun. Sunlight is converted into electricity via photovoltaic systems or experimental technologies such as thermoelectric converters, solar chimneys, or solar ponds. The EPIA/Greenpeace Advanced Scenario shows that by the year 2030, photovoltaic (PV) systems could be generating approximately 2,600 TWh (terawatt hours) of electricity around the world. This means that, assuming a serious commitment is made to energy efficiency, enough solar power would be produced globally in 25 years to satisfy the electricity needs of almost 14% of the world's population.[5]
- **Wind energy:** Wind energy is an abundant, clean energy source that can reduce GHG emissions when it displaces electricity derived from fossil fuels. At the end of 2007, worldwide capacity of wind-powered generators was 94.1 gigawatts, according to the Global Wind Energy Council News. Most wind power is generated by wind turbines. Large-scale wind farms are connected to electrical grids; individual turbines can provide electricity to isolated locations.

Electricity and **hydrogen** are **secondary sources** of energy, which means they are used to store, move, and deliver energy in easily usable form. Today the cheapest way to get hydrogen is to separate it from natural gas, a nonrenewable energy source. Hydrogen can also be separated from water and from renewables, but hydrogen made from these sources is currently too expensive to compete with other fuels. Figure 7-1 summarizes consumption of primary and secondary sources of energy in the United States.

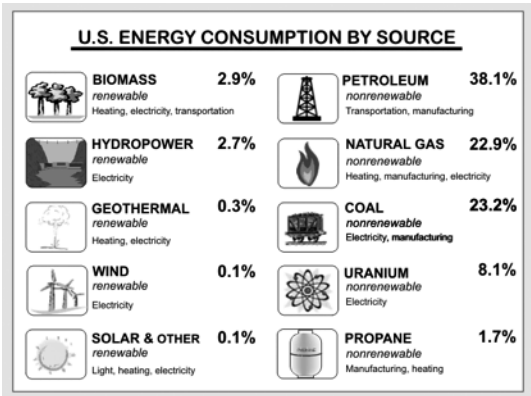

FIGURE 7–1 Sources of Energy Consumed in the United States (Data from the U.S. Department of Energy)

Calculating Energy and Power[6]

Many people (mistakenly) use the terms *energy* and *power* interchangeably. Energy is the ability to do work, and power is the rate at which work is done. To do 100 joules of work, you must expend 100 joules of energy. Power is the rate of using energy, so if you do 100 joules of work in one second (using 100 joules of energy), the power is 100 watts.

Over time, many different units for measuring energy have been developed. Table 7–1 shows some of the most common energy units and their mathematical conversion factors. If you want to convert units of fuel commonly used in the energy trade, such as barrels of oil, into calories or joules or British Thermal Units (BTUs), you simply multiply by the factors shown in the appropriate row (e.g., 1 BTU = 252 calories).

Note that since the chemical composition of some resources is variable with fuel source and extent of purification, the heat contents per unit mass or volume of these fuels also vary. For example, the heat content of 1.0 cubic foot of natural gas can range from 950 to 1,200 BTUs. For many engineering calculations, this provides sufficient accuracy for "orientation" or "scoping" calculations. However, keep in mind that the amount of useful energy obtainable from a given quantity of fuel can depend on how it is processed and utilized, and will always be less than the total energy content of the fuel.

First, a quick recap of the energy units used in the table is in order.

- **BTUs (British Thermal Units):** BTU is a unit of energy commonly used in the power, steam generation, heating, and air conditioning industries. In scientific contexts, the BTU has largely been replaced by the joule: 1 BTU = 1,055.05585 joules.
- **Joules:** Joules is the International System of Units (SI) unit of energy. One joule is the work done, or energy expended, by a force of one newton moving 1 meter along the direction of the force.
- **Quads:** A quad is a unit of energy equal to 10^{5}_{1} (a short-scale quadrillion) BTU, or 1.055×10^{18} joules (1.055 exajoules or EJ). This unit is most commonly used by the U.S. Department of Energy in discussing world and national energy budgets.
- **Calories:** The calorie is a unit of heat. In most fields its use is archaic, and the joule is more widely used. However, it remains in common use as a unit of food energy: 1 calorie = 4.18400 joules.
- **Kilowatt-hours (kWh):** One kilowatt-hour is exactly 3.6 megajoules, and is the amount of energy transferred if work is done at a rate of 1,000 watts for one hour. This unit is typically used by electric utilities to express and charge for energy delivered.
- **Megawatt-years (MWy):** This is a variation on kilowatt-hours. One MWy is 8.76×10^{6} kWh.
- **Barrels of oil (bbls):** A barrel of oil = 158.987295 liters.
- **Metric tonnes (tons) of oil:** The amount of energy released by burning one metric tonne (ton) of crude oil is approximately 42 gigajoules (GJ).
- **Metric tonnes of coal:** Electric power plants need about 1 kg of coal to produce around 2,000 watt-hours of electrical energy.
- **Thousand cubic feet (MCF) gas:** This is a unit of measure typically used in the oil and gas industry for natural gas.
- **Exajoules (EJ):** This is the SI unit of energy equal to 10^{18} joules.

TABLE 7–1 Various Energy Units and Conversion Factors

	BTUs	Calories	kWh	MWy	Joules
BTUs	1	252	2.93×10^{-4}	3.35×10^{-11}	1,055
Quads	10^{15}	2.52×10^{17}	2.93×10^{11}	3.35×10^{4}	1.06×10^{18}
Calories	3.97×10^{-3}	1	1.16×10^{-6}	1.33×10^{-13}	4.19
kWh	3,413	8.60×10^{5}	1	1.14×10^{-7}	3.6×10^{6}
MWy	2.99×10^{10}	7.53×10^{12}	8.76×10^{6}	1	3.15×10^{13}
Bbls oil	5.50×10^{6}	1.38×10^{9}	1,612	1.84×10^{-4}	5.80×10^{9}
Metric tonnes oil	4.04×10^{7}	1.02×10^{10}	1.18×10^{4}	1.35×10^{-3}	4.26×10^{10}
Kg coal	2.78×10^{4}	7×10^{6}	8.14	9.29×10^{-7}	2.93×10^{7}
Metric tonnes coal	2.78×10^{7}	7×10^{9}	8,139	9.29×10^{-4}	2.93×10^{10}
MCF gas	10^{6}	2.52×10^{8}	293	3.35×10^{-5}	1.06×10^{9}
Joules	9.48×10^{-4}	0.239	2.78×10^{-7}	3.17×10^{-14}	1
EJ	9.48×10^{14}	2.39×10^{17}	2.78×10^{11}	3.17×10^{4}	10^{18}

Note: To convert from the first column of units to other units, multiply by the factors shown in the appropriate row (e.g., 1 BTU = 252 calories). Assumed caloric values: oil = 10,180 cal/g; coal = 7,000 cal/g; gas = 1,000 BTU/ft^3 at standard conditions.

Energy Impacts: Finding the Cleanest Source of Power

You may not have considered it, but the power that comes out of your wall socket may have a different set of environmental impacts than the power on the other side of town, or from another state, or from another country.[7]

If your power comes from coal, for example, it causes more GHG emissions than power derived from hydroelectric, nuclear, wind, or solar sources. That's why the CO_2 emissions associated with power generation are higher in Colorado than in California; and it's why France generates near-zero CO_2 for the energy it produces with its large bases of nuclear power plants. And as we've pointed out, these energy sources with lower GHG emissions aren't without their own impacts.

As an engineer, you can't control where your customer uses the product you've designed and built, but you still have an important role to play. You may be able to influence the types of power your suppliers use in manufacturing parts for your product. You can also choose less impactful forms of transportation. You can provide your customers with options to use cleaner energy sources where possible. And, of course, reducing energy usage by design helps avoid the whole discussion.

As an example, one option that corporations with large data centers are now exploring is referred to as "chasing the sun." With this approach, power supplied to data centers is sourced from the cleanest available energy, which is typically being generated from solar panels or wind turbines during daylight hours. Through arrangements with power providers, a data center in Washington, D.C., could be powered from solar cells in California. In theory, this concept could also be applied internationally so that a New York data center could take advantage of a cloudless day in Australia or a company in Japan could take advantage of an especially windy day in Palm Springs or the Sierra foothills—constantly maximizing its use of the greenest energy available.

ENERGY COST OF A SHIRT

Here are some facts courtesy of Patagonia CEO and founder, Yvon Chouinard.[8]

- From raw materials, it costs 110,000 BTUs to make a Patagonia shirt.
- Shipping it airfreight from Ventura, California, to a store in Boston costs 50,000 BTUs.

Generically, the cost to ship per ton is as follows:

- Rail or boat: 400 BTUs per ton per mile
- Truck: 3,300 BTUs per ton per mile
- Air cargo: 21,760 BTUs per ton per mile

Shipping shirts to store shelves via airfreight can increase the total energy expense by almost 50 percent.

Energy and GHG Emissions

The preceding section discussed the connection between energy use and CO_2 emissions, and the need to measure and minimize both throughout the product lifecycle. But there are many other sources of emissions and waste. This section summarizes the key sources of GHG and other emissions, and provides information about measuring and minimizing their impact.

Greenhouse Gas Primer

Although we often discuss GHG emissions as "tons of carbon dioxide" or even less accurately as "tons of carbon," there's more to GHG than CO_2. According to the U.S. Environmental Protection Agency (EPA), the principal GHGs that enter the atmosphere because of human activities are as follows.[9]

- **Carbon dioxide (CO_2):** Carbon dioxide enters the atmosphere when fossil fuels are burned; it is "sequestered" or removed from the atmosphere when it is absorbed by plants.
- **Methane (CH_4):** Methane emissions come from livestock, the decay of organic waste in landfills, and the production and transport of coal, natural gas, and oil.
- **Nitrous oxide (N_2O):** Many different types of agricultural and industrial activities generate nitrous oxide; it is also produced during combustion of fossil fuels and solid waste.
- **Fluorinated gases:** These GHGs are typically emitted in small but potent quantities; they are sometimes referred to as High Global Warming Potential gases. Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are examples of synthetic GHGs that are emitted from industrial processes.

CO_2 Equivalents and Conversions

GHGs contribute to global warming in varying degrees. The term *carbon dioxide equivalent* (CO_2e) provides a standard way to calibrate the global warming potential (GWP) of various gases; specifically, CO_2e is the amount of carbon dioxide that would yield the same warming effect as a particular greenhouse gas or greenhouse gases. It is used in carbon accounting—for example, to account for GHG emissions and reductions over time.

On the scale supported by the Kyoto Protocol, CO_2 is the reference point and has a GWP of 1. Every other GHG has a greater GWP than CO_2. Table 7–2 provides the conversion rates.[10]

TABLE 7–2 CO_2e Conversion Factors

GHG	MULTIPLY BY THE FOLLOWING FIGURE TO OBTAIN THE CO_2E VALUE:
CO_2	1
CH_4	23
N_2O	296
SF_6	22,200
HFCs	12–12,000
PFCs	5,700–11,900

(Source: Third Assessment IPCC Report, 2001)

Calculating GHG Emissions

GHG emissions are usually fairly straightforward to calculate. If you know the specific source of the emissions, there are well-documented formulas for arriving at the resulting amount. For example, burning a gallon of gasoline in a car results in 19.9 pounds of CO_2e emissions (you may be objecting, pointing out that a gallon of gas weighs less than 19.9 pounds, but the extra weight comes from the addition of oxygen in the air during the combustion process). Table 7–3, compiled by the United Kingdom's Department for Environment, Food and Rural Affairs (Defra), provides conversion factors for various fuel types.[11]

In most situations, the standard units of reporting GHG emissions are metric tons of CO_2e. Obviously, tons are cumbersome when dealing with very large or very small amounts of emissions, but they are a good fit for many situations.

In some cases, we don't know the specific source of the emissions. For example, the electricity delivered to your home comes from a wide range of sources. In these situations, you can attempt to get a specific number from your electric company, but that may not always be possible or practical. Fortunately, there are accepted accounting standards for many common situations that you can draw on. For example, if you're interested in the impacts of electricity in the United States and you can't get a number from the source, the U.S. EPA Emissions & Generation Resource Integrated Database (eGRID)[12] is a widely accepted source for calculations.

The eGRID numbers are also good if you are estimating the impact of power use at a customer or manufacturing partner and don't know the source of their electricity. Here are a few interesting facts and examples from eGRID.[13] In the United States:

- 12,100 pounds of CO_2e emissions from gasoline is about average for one vehicle over a year (assuming an average of 231 miles/week per vehicle).
- 11,000 pounds of CO_2e emissions from natural gas use is average for a household of two people over a year.
- 16,290 pounds of CO_2e emissions from electricity usage is about average for a household of two people over a year.

If all of this sounds a little like corporate accounting, it is. A GHG inventory is a formal accounting of the amount of GHGs emitted to or removed from the atmosphere over a specific period of time (e.g., one year) from a defined set of activities. A GHG inventory also provides information on the

TABLE 7–3 Fuel Conversion Factors

Converting fuel types to CO_2			Net CV Basis
Fuel Type	Units	x	kg CO_2 per unit
Electricity	See Annex 3		
Natural Gas	kWh	x	0.206
	therms	x	6.023
Gas Oil	tonnes	x	3190
	kWh	x	0.265
	litres	x	2.674
Diesel	tonnes	x	3164
	kWh	x	0.263
	litres	x	2.630
Petrol	tonnes	x	3135
	kWh	x	0.253
	litres	x	2.315
Fuel Oil	tonnes	x	3223
	kWh	x	0.281
Burning Oil	tonnes	x	3150
	kWh	x	0.258
	litres	x	2.518
Coal	tonnes	x	2457
	kWh	x	0.346
LPG	kWh	x	0.225
	therms	x	6.608
	litres	x	1.498
Coking Coal	tonnes	x	2810
	kWh	x	0.349
Aviation Spirit	tonnes	x	3128
	kWh	x	0.250
	litres	x	2.233
Aviation Turbine Fuel	tonnes	x	3150
	kWh	x	0.258
	litres	x	2.518
Other Petroleum Gas	tonnes	x	2894
	kWh	x	0.217
Naphtha	tonnes	x	3131
	kWh	x	0.249
Lubricants	tonnes	x	3171
	kWh	x	0.263
Petroleum Coke	tonnes	x	3410
	kWh	x	0.361
Refinery Miscellaneous	kWh	x	0.259
	therms	x	7.585
Total			

Note: Carbon emissions are usually quoted in kg CO_2/kWh. If you wish to convert the carbon dioxide factors into carbon equivalents (i.e., kgC/kWh), multiply the figure by 12 and divide by 44.

activities that cause emissions and removals, as well as background on the methods used to make the calculations.

A thorough discussion of GHG accounting and the WRI/WBCSD Greenhouse Gas Protocol (the most widely used international accounting tool), along with tools for calculating direct and indirect GHG emissions, is available at www.ghgprotocol.org.

The GHG Protocol's **Corporate Standard** (see www.ghgprotocol.org/standards/corporate-standard) provides standards and guidance for companies and other organizations preparing a GHG emissions inventory. It covers the accounting and reporting of the GHGs covered by the Kyoto Protocol, and was designed to help companies prepare a GHG inventory that represents a true and fair account of their emissions; to simplify and reduce the costs of compiling a GHG inventory; to provide information that can be used to build an effective strategy to manage and reduce GHG emissions; and to increase consistency and transparency in GHG accounting and reporting.

The Greenhouse Gas Protocol Initiative also provides a range of calculation tools for GHG emissions and answers specific questions about GHG accounting. The tools and guidance are available at www.ghgprotocol.org/calculation-tools.

Putting a Value on Carbon (Dioxide!)

In recent years **carbon trading** markets have emerged to place economic incentives on reducing GHG emissions. For example, in a **cap and trade** program, a central authority (usually a government) sets a limit or *cap* on the amount of a pollutant that can be emitted; companies or other groups are then issued emission permits and are required to hold an equivalent number of allowances or credits that represent the right to emit a specific amount. The total amount of allowances and credits cannot exceed the cap, limiting total emissions to that level. Companies that need to increase their emissions must buy credits from those that pollute less.

With lots of buyers and sellers, a market has emerged for the right to emit a certain amount of GHG. In effect, the buyer is paying a charge for polluting, and the seller is being rewarded for having reduced emissions by more than was needed.* Thus, in theory, those that can easily reduce emissions most

* The **Acid Rain Program** undertaken by the U.S. EPA provides a good example. In an effort to reduce overall atmospheric levels of sulfur dioxide and nitrogen oxides, which cause acid rain, the program implemented emissions trading primarily targeting coal-burning power plants, allowing them to buy and sell emission permits (called "allowances") according to individual needs and costs. For details see www.epa.gov/acidrain/index.html.

cheaply will do so, achieving the pollution reduction at the lowest possible cost to society.[14]

There are many ways to implement a cap and trade system, and we suspect that we're all going to be hearing more about them over the coming years. Other proposals involve a **carbon tax,** whereby emitters would have to pay the government a set amount. In places such as the United States where there is no mandatory GHG market or tax, some companies voluntarily participate in carbon trading to support internal goals such as carbon neutrality (see some additional thoughts on carbon neutrality in Chapter 11).

An important result of any of these systems is that companies that are involved (by law or voluntarily) can now put a real financial value on the right to emit GHGs. Rather than discussing the soft-dollar benefits and potential savings of a product, companies can perform a true ROI analysis that includes hard-dollar carbon savings.

As an engineer, it is important to know whether your company, partners, or customers have established a "price for carbon" for their internal use. If they have, you will find that the ROI analysis related to energy efficiency will now reflect an increased savings due to the decrease in GHG emissions that will accompany decreases in energy use. As a result, some projects that could not clear the financial hurdle based only on energy savings may now be able to clear it and get the green light.

Heat, Noise, Light, and Radio Emissions

Products that use energy give off emissions beyond GHGs. Each of the following categories is actually worth a book in itself, but here are just a few basic guidelines.

- **Heat:** Heat is a wasteful side effect of just about every energy-using product. How long will your car run without engine coolant? How long are you comfortable working with your laptop on your lap before your legs get uncomfortable? Waste heat can be dangerous to both humans and the products themselves. And not only does heat represent wasted energy, but some products—such as computers and cars—have to expend even more energy to help cool themselves. So, from an environmental perspective, a financial perspective, and a human perspective, engineers need to find new ways to minimize waste heat. Choosing components carefully and being willing to pay a price premium for cool-running and low-noise characteristics can help a lot.

No single book or reference source covers every aspect of this topic for the vast spectrum of device types being made today, but you can get many broadly applicable pointers from *Building the Perfect PC,* Second Edition, by Robert Bruce Thompson and Barbara Fritchman Thompson.[15]

- **Noise:** Unless your product plays music, is a growling roadster, or needs to alert people, product noise is generally not a good thing. Since sound waves are just another form of energy, unwanted noise represents wasted energy and can be a sign of mechanical or electrical inefficiency. It's often a sign of components that might be under additional stress and may be liable to fail. But the impact goes beyond inefficiency: Unintended noise can represent a human health hazard or create unexpected environmental effects—or even disrupt migratory patterns. Unintentional noise from a product is a sign of mechanical or electrical inefficiencies. That's why there are laws relating to product noise. In the United States, state and local laws will apply, but depending on where your product is going to go you may need to familiarize yourself with international noise laws as well.
- **Electromagnetic interference:** Electromagnetic radiation from products, including light and radio emissions, can result in electromagnetic interference (EMI, also known as radio frequency interference when it is isolated to the radio frequency bands), and can, in some cases, be directly dangerous to humans (hence the lead vest when you get your dental X-rays). Standards are in place to specify which EMI levels are acceptable for various products under various conditions. The most common EMI testing on electronic equipment for the United States is FCC Part 15 testing. FCC Part 15 covers unintentional testing and evaluation as well as low-power unlicensed transmitters. You can find more information on this at www.cclab.com/fcc-part-15.htm. In Japan, the EMI testing standard is outlined by the VCCI. More information about VCCI testing is available at www.cclab.com/vcci.htm.

Process-Related GHG Emissions

While we've focused on energy as the main source of GHG emissions, GHGs are also emitted from manufacturing processes. High-GWP gases are emitted from a variety of industrial processes, including aluminum production, semiconductor manufacturing, electric power transmission, and magnesium production and processing. In addition, some high-GWP gases are being used to replace ozone-depleting substitutes such as chlorofluorocarbons (CFCs).

This is yet another advantage of recycling, as the process difference can also result in emissions differences. For example, high-GWP gases are emitted during primary aluminum production, not aluminum recycling.

Energy Efficiency in Product Design

For products that use energy in operation, one of the most impactful things to do as an engineer is to improve the energy efficiency. Here are a few specific topics to consider.

Core Efficiency

In most cases, the bulk of the power a product uses during operation is being converted into core functionality. The car is converting gasoline into mechanical power that can spin the wheels. The smartphone is converting stored electricity into processing, transmitting, and receiving radio waves, illuminating a screen, and so forth. An oven is converting gas or electricity into heat.

By improving core efficiency, you can reduce the cost of your product for the customer—but equally important, you can create other positive side effects. For example, using less energy means less conversion loss (discussed shortly). Lower energy requirements can enable you to use smaller batteries or other components, resulting in lower weight and decreased manufacturing cost and impact. And less energy usually means less waste heat, which can result in lower power requirements for fans or air conditioning.

Every product design effort should spend time setting goals regarding core efficiency, and invest in engineering and innovation to optimize this important area. The direct benefits can be huge, and can often result in product improvements in other areas as well.

Energy Transmission and Conversion

Every time energy is converted or moved, we lose some of it. When we convert electricity from AC to DC or from 12V to 5V, we lose energy in the process. When we convert gas to motion, we lose energy. When we convert electricity to chemical energy stored in a battery, we lose energy. When we transmit energy from one region to another, from one room to another, or even from one side of a silicon chip to another, we lose energy.

A few years ago it was not uncommon for a computer to waste 30% to 40% of the power that it consumed during the process of converting from alternating current (AC) that comes from the wall to direct current (DC) that computer electronics use. With recent improvements most manufacturers have now reduced those losses to 20% or less, but these are still significant losses.

There are three ways to attack this problem. First, you can reduce the energy that the product uses. If you need to convert less energy, you will lose less in the process. Second, you can focus on the core transmission or conversion process. This may be as easy as selecting a different component, or it may require some fundamental design changes. Pay special attention to ensure that conversion components are not oversized. Many types of conversion have a sweet spot where the percentage loss is minimized, and operating way outside of that can result in higher waste. Finally, you can look at the overall system and try to eliminate unnecessary conversions.

Power States

Increasingly, product designers are using the concept of **power states** to reduce the total power used by a product. Power states are different modes that products can switch between, either automatically or under user control. One of the most common examples is your home computer, which has separate power states for the monitor and processing unit. For cars, Chevy now has a motor for some of its trucks that recognizes when the vehicle is being used in a highway situation, and automatically converts from a V-8 to a more efficient V-4 engine by turning off four of the pistons. Your cell phone will blank its screen if you haven't touched it for a while.

"The key is to ensure that a product's energy consumption is proportional to the work it's doing," says Sun engineer Subodh Bapat. "Today, unfortunately, that's not the case with most products. And the reason boils down to bad design. In many cases, a small chip and a bit of code could solve the problem entirely."

Since power states usually have some impact on the functionality of the product, it is important that you give users some control over when automatic state transitions occur. And it's important to do some work to try to get a good "out of the box" setting—the design work you do on power states will be worthless if users get fed up and just turn them off.

Standby Power

One common power state, standby power, is not as eco-friendly as it first appears. This is because consumers are led to believe that the product is in a low-power state, or in many cases even totally off, when in fact the product is still drawing a not insignificant amount of electricity. And since these are common products in many countries, the total amount is adding up.

Televisions, for example, use standby power to save settings and to make the TV turn on quicker. But that standby power amounts to 10% to 15% of the total energy use on average. Even when the TV is "off" it's on, drawing 15–20 watts. Microwave ovens, game consoles, DVD players, and digital cable boxes all draw 20–25 watts of power when they're not being used. Desktop computers and laptops have historically drawn about 25 watts even while in sleep mode.[16]

Fortunately, engineers are now beginning to improve product design to reduce even standby power consumption. For example, some of the newer PCs will typically draw only about 2–3 watts of power while they sleep, which is a big improvement.[17]

Solutions for consumers are also emerging. You can now purchase special power strips (called Smart Strips or Watt Stoppers) that monitor power consumption, sense when devices are using standby power, and turn them off. Usage monitors measure precisely how much power is being used (or wasted) by a given device at a given time. And many lighting systems now detect the lack of people in a room and will turn off the lights.

Batteries

Batteries play an important role in a wide range of products. Some are obvious, such as watches and mobile personal electronics (iPods, cell phones, etc.). Others are hidden, overshadowed by another primary energy source. Cars use batteries to start and maintain some functions when the engine is off; PCs and electric clocks use batteries to remember the time when electricity isn't available; video games and pinball machines use batteries to remember high scores.

One of the important decisions in product design concerns whether to use rechargeable or disposable batteries. Disposable batteries are convenient, but lose effectiveness over time and have disposal issues. Rechargeable batteries can be used for a much longer period of time, but still have disposal issues, can be inconvenient (users need to carry a charger and remember to charge them), and can lose effectiveness over time. In addition, chargers are often inefficient, wasting energy when they have completed charging up the battery.

This last point has become an issue, especially for large-volume products such as cell phones, where billions are in use today. Most people will plug them in for long periods of time to recharge, unaware that the recharger continues to draw some power even after the battery is charged.

In the end, different products take different approaches. Apple, for example, went with a built-in battery in its iPod designs, thereby simplifying both the use of the product for customers and the take-back of batteries because Apple does the battery replacement as a service. We suspect that Apple realized that most consumers will get a new iPod before they'll need a new battery. Cell phones also typically use built-in batteries today, but ones that are easy for consumers to replace. This means it is easier for consumers to replace a bad battery, but stores now have to stock huge arrays of replacement batteries and it's harder to ensure that the dead batteries are recycled correctly. Some products are better off with disposable batteries; for example, a GPS device for hikers that's used only a few times each year. It's easier to throw a few spare AA batteries into your backpack than it is to go out and buy one or more expensive, product-specific replacement batteries that need to be charged.

In short, deciding whether to use batteries and deciding on the type of battery to use can be important decisions for product designers, and shouldn't be taken lightly. If your product is going to use batteries, try to use the smallest possible battery. If there is an option for avoiding battery use, explore it.

Tracking Lost Energy

As you model efficiency and look at the places that energy is lost in your product, it's important to ask yourself where the lost energy is going. Is it turning into heat that could injure a user, require fans or air conditioning, or increase the failure rate of the product? Is it turning into electromagnetic radiation that could cause issues with meeting key product requirements? Is it being lost in mechanical systems and resulting in excess wear on parts?

The unintended consequences of lost energy can significantly impact not only the total footprint of your product, but also its viability in the market. Make sure you fully understand and account for the energy use of your product.

An Example: Energy Efficiency in Data Centers

Data centers full of servers and data storage systems are at the heart of our modern economy. In developed countries, every economic transaction is recorded at least once, and often in multiple places. Just think about how much electronics is involved when you perform a simple search on Google: your desktop, the network in your house, the network to Google (which goes through multiple large net-centric data centers), and the servers and storage in the data centers at Google (which, the search results tell us, is not insubstantial). Then when you click on a result all of those paths are used again, but this time to go to another data center that houses the site you want to visit. Every email, medical procedure, phone call, paycheck, online purchase, plane ticket, and electronic toll payment involves one or more data centers.

Power consumption of data centers doubled between 2000 and 2005, and is expected to double again by 2010. For the entire world, doubling server consumption from 2005 to 2010 would require additional capacity equal to more than ten additional 1,000-megawatt power plants.[18] And today, according to analyst firm IDC, roughly 50 cents is spent on energy for every dollar of computer hardware—this is expected to increase by 54% to 71 cents over the next four years.[19]

So, although data centers represent a small fraction of global GHG emissions (estimated to be less than 2%), their rapid growth and the economic impacts of their energy use are attracting attention. Even Congress has gotten into the act with Public Law 109–431 (enacted in 2007), “to study and promote the use of energy-efficient computer servers in the United States.”

Where Energy Goes in Data Centers

It’s not just the servers and storage systems that consume energy. Often, the equipment that is required to cool the servers and the server room uses as much power as the systems themselves. Add to that the energy used to light the data center, the power distribution loss, and other factors, and you’ll see that the majority of power coming into the data center is used for something other than IT equipment.

Figure 7–2 illustrates this point.[20] Where the energy goes in any individual data center depends upon the age and efficiency of the equipment, adherence

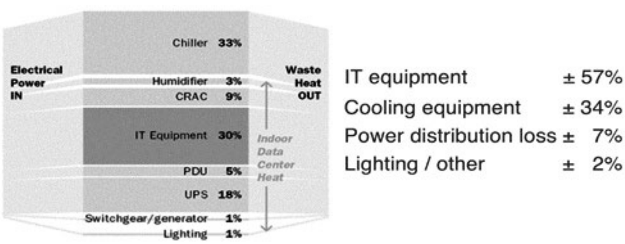

FIGURE 7–2 Use of Power in a Typical Data Center

to best practices, levels of redundancy, and so on, but this graphic shows why IT equipment often consumes less than half the power used in a typical data center. It also drives home the point that the overall energy system is far bigger than the energy-consuming devices themselves.

Let's start at the bottom of the picture and work our way up. First we have to light the room, since humans sometimes have to work there. Next, a large electric feed from the utility enters the building and is switched. Since many data centers are business (or mission) critical, and since power from the utility is not fully reliable, we put in an uninterruptible power supply (UPS) as a backup in case of power supply glitches. Finally, the power passes through power distribution units (PDUs), where it is distributed out to racks of equipment.

The equipment (networking, servers, storage) takes the energy in, converts it to different voltages (losing some energy in the process), and powers the components. Since very little physical activity is involved (spinning disks and fans, mostly), the bulk of the power ends up converted to heat (with a little noise and mechanical vibration thrown in). Also note that the PDUs and UPS are not totally efficient, so they generate some heat as well.

Getting rid of megawatts worth of heat day-in and day-out is not easy. First there are computer room air conditioners (CRACs), which capture the heat and get it out of the room. That heat is then finally taken care of by industrial chillers (these often use fresh water and have become a separate target for eco improvement). Finally, you may have noticed that 3% or so of the power is used for humidifiers. Why, you might ask? The air conditioning process removes moisture from the air, and eventually the air can get too dry. As a result, we need to add a step to put some of the moisture back into the air.

Amazingly, when you add this up, the IT equipment itself is using only about one-third of the energy, but *other than the lights, all of the remaining energy is there just to support the delivery and removal of that energy.* In other words, every watt of IT equipment in this scenario requires two more watts just to process it.

Making Data Centers More Efficient

With rising energy prices, the energy usage by these large data centers has not gone unnoticed. Companies throughout the industry are working individually, and in groups such as the Green Grid, to try to drive out inefficiencies throughout the system. Here are some examples.

- **More efficient products:** As we've seen, if you can use one less watt in IT equipment, you will often save one or more additional watts that would have been lost in delivery and used for cooling. Advances such as chip multithreading (CMT), slower disk drives, and automated power-down technology are beginning to be widely used with good results.

- **Rating systems for equipment purchasers:** While eco-rating schemes such as Energy Star, 80 Plus, EPEAT, and Climate Savers Computing have long been available for desktops, standard ratings for servers tend to be more complicated, so they have lagged behind. In the meantime, Sun and other companies have devised increasingly accurate power calculators that help you compute the expected power consumption of specific server configurations. These are useful for two reasons. First, they allow some head-to-head comparisons (recognizing that you're trying vendors' own numbers). Second, they can help customers to size infrastructure equipment such as PDUs and CRACs, since oversizing those systems can lead to very large inefficiencies.
- **Consolidation:** Most existing servers use most of their peak power whether they are 20% loaded or 80% loaded. As a result, you can realize big savings by combining jobs onto the same system, which ideally you can keep at a higher utilization level. Virtualization technology, which enables different jobs to run safely on the same system, is one of the most dynamic areas in computing today.
- **Conversion/transmission efficiency:** A recent study by Lawrence Berkeley Labs and Sun examines new ways to obtain more efficient high-voltage power distribution, and compares high-voltage AC and DC and the potential energy savings of each. "The first order estimates are that high-voltage DC could save 5% to 7% over high-voltage AC, but the big savings is going to high voltage in general," says Hal Stern, vice president of Systems Engineering at Sun. Customers and vendors are also looking to minimize the number of power conversions that occur from the utility feed to the equipment.
- **Power states:** You generally don't want your servers to put themselves totally to sleep, but many new kinds of power states are being experimented with in upcoming server and storage designs.
- **Creative cooling:** Cooling is suddenly an area of major innovation, with customers and vendors exploring new options such as integrating cooling technology directly into server racks, using variable-speed fans rather than single-speed fans, and making better use of cool external air (a.k.a. "fresh air cooling").

- **Code efficiency:** Less code, executed more efficiently, means fewer CPU cycles expended in processing workloads. For large compute farms, a 10% improvement in efficiency can mean 10% fewer machines and 10% less energy.
- **Technology refresh:** Computing technology continues to follow an exponential improvement curve. Combine that with new features such as power states and upgrading older equipment and you can often save enough energy to fund the project.

Example Results

We can point to our own experience to illustrate how significant the results of energy-saving efforts can be: Sun recently built new energy-efficient data centers in the United Kingdom, India, and the United States, compressing a total of 152 data centers (202,000 square feet) into 14 new centers (76,000 square feet), resulting in a 60% reduction in overall power consumption—which cut utility bills by $860,000 in the first nine months. The new data centers also reduced new construction requirements at existing facilities, a cost avoidance of $9 million. The new facilities will reduce carbon emissions by 3,227 metric tons annually, according to Dean Nelson, Sun's director of Global Lab and Datacenter Design Services.[21]