PART

I

TRANSITIONING TO THE NEW ENERGY ECONOMY

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

—Thomas Edison

CHAPTER

1

THE GLOBAL ENERGY MELTDOWN

The world is now facing its most serious challenge ever. The name of that challenge is *peak energy*.

If decisive and immediate action is not taken, peak energy could prove to be a crisis more devastating than world wars, more intractable than plagues, and more disruptive than crop failure. We're talking about a crisis of epic proportions that will change *everything*. And rest assured it will not discriminate. Conservative or liberal, black or white, rich or poor, this will be a crisis of equal-opportunity devastation. That may sound hyperbolic to you now, but by the end of this chapter, you will understand why we say it.

Everything we do depends on some form of energy. Our entire way of life, and all of our economic projections, are built on the assumption that there will always be more energy when we want it. But global energy depletion has already begun, although few have realized it.

You're one of the lucky ones, because after reading this book, you will understand both the challenge of peak energy and some of the solutions early in the game—allowing you the opportunity to be well-positioned to not only profit from the renewable energy revolution that is already under way, but to thrive.

By the time you've completed this chapter, you will have a full understanding of what peak energy is, how it affects the future of the entire global economy, and why it is imperative that this challenge of peak energy is met head-on with renewable energy solutions. This will ultimately lead you to profits via the companies that are providing the solutions both in the near-term and well into the future.

PEAK ENERGY

Before we begin discussing the particulars of peak oil, gas, coal, and uranium, we must first discuss what we mean when we use the term *peak energy*.

The production of any finite resource generally follows a bell curve shape. You start by producing a little, and then increase it over time; then you reach a peak production rate, after which it declines to make the back side of the curve. Between now and 2025, we could see the peak of *every single one* of our finite fuel resources. But why is the peak important? Because after the peak, we witness the rapid decline of these fuels, leaving us vulnerable to what could amount to the biggest disruption the global economy has ever witnessed. This would be a disruption that could spark an international crisis of epic proportions.

Peak Oil

The first resource that will peak is oil, which is also our most important and valuable fuel resource. We have an entire chapter devoted to oil—Chapter 8—so we will merely summarize here. Here are some simple facts about peak oil:

- The world's largest oil reservoirs are mature.
- Approximately three-quarters of the world's current oil production is from fields that were discovered prior to 1970, which are past their peaks and beginning their declines.[1]
- Much of the remaining quarter comes from fields that are 10 to 15 years old.
- New fields are diminishing in number and size every year, and this trend has held for over a decade.[2]

Overall, the oil fields we rely on to meet demand are old, and their production is shrinking, thereby bringing the oil industry closer to the peak and our entire global economy closer to the brink of catastrophe. Because when these fields dry up, so does everything else. And unfortunately, while today's oil fields are struggling at this very moment to keep pace with demand, new field discoveries are diminishing.

Before you can tap a reservoir, you must discover it. Here, too, the picture is clear: The world passed the peak of oil discovery in the early 1960s, and we now find only about one barrel of oil for every three we produce.[3] The fields we're discovering now are smaller, and in more remote and geographically challenging locations, making them far more expensive to produce. And the new oil is of lesser quality: less light sweet crude, and more heavy sour grades. These trends have held firmly for about four decades, despite the latest and greatest technology, and despite increasingly intensive drilling and exploration efforts.

This should be no surprise to anyone. It's the nature of resource exploitation that we use the best, most abundant and lowest-cost resources first, then move on to smaller resources of lower quality, which are harder to produce.

Global conventional oil production peaked in 2005. For "all liquids," including unconventional oil, the peak of global production will likely be around 2010.

With a little less than half the world's total yet to produce, which will increasingly come from ever-smaller reservoirs with less desirable characteristics, peak oil is not about "running out of oil," but rather running out of *cheap* oil.

The outlook for oil exports, on which the United States is dependent for over two-thirds of its petroleum usage, is even worse. Global exports have been on a plateau since 2004. This poses a firm limit to economic growth.

In sum, demand for oil is still increasing, while supply is decreasing; the absolute peak of oil production is probably within the next two years; and net importers like the United States are not going to be able to maintain current levels of imports, let alone increase them. This is a very serious situation, because without enough imports to meet demand, we simply cannot function. We will find it increasingly difficult to transport food, medicine, and clothing; to fuel our planes, trains, automobiles, and cargo ships; to provide heat in the winter and cooling in the summer; and to manufacture plastics and other goods that rely on petroleum as a key ingredient.

While the world's top energy data agencies have all commented on the threat of peak oil, along with many of the leaders of the world's top energy producers, the U.S. Government Accountability Office (GAO) may have said it best:

> *[T]he consequences of a peak and permanent decline in oil production could be even more prolonged and severe than those of past oil supply shocks. Because the decline would be neither temporary nor reversible, the effects would continue until alternative transportation technologies to displace oil became available in sufficient quantities at comparable costs.*[4]

Even so, peak oil is just the first hard shock of the energy crisis that will soon be unfolding. Right after peak oil, we will have peak gas.

Peak Gas

In many ways, the story of natural gas is similar to that of oil. It has a bell-shaped production curve (although compared to oil, it hits a longer production plateau, and drops off much faster on the back side), and the peak occurs at about the halfway point.

Like oil, new gas wells are tapping smaller and less productive resources every year, indicating that the best prospects have already been exploited and that we're now relying on "infill drilling" and unconventional sources, such as tight sands gas, coalbed methane, and resources that are deeper and more remote.

Like oil, the largest deposits of gas are few in number and highly concentrated. Just three countries hold 58 percent of global gas reserves: Russia, Iran, and Qatar. All other gas provinces have 4 percent or less.[5]

And like oil, there is the quality issue. It appears that we have already burned through the best and cheapest natural gas—the high-energy-content methane that comes out of the ground easily at a high flow rate. We're now getting down to smaller deposits of "stranded gas" and the last dregs of mature gas fields, and producing gas that has a lower energy content.

Assuming that world economic growth continues, that estimates of conventional reserves are more or less correct, and that there will not be an unexpected spike in unconventional gas, the world will hit a short gas plateau by 2020, and by around 2025 will go into decline.[6]

To illustrate our argument, consider the forecast for natural gas and oil combined, from Dr. Colin Campbell of the Association for the Study of Peak Oil (ASPO), which is shown in Figure 1.1.

However, the local outlook for natural gas is far more important than the global outlook. Natural gas production is mostly a landlocked business, because it's difficult to store and expensive to liquefy for transport. In the United States, we import only 19 percent of the natural gas we use, of which 86 percent is transported by pipeline from Canada and Mexico, both of which are past their peaks. Imports from Canada account for about 17 percent of our total gas consumption,[7] but Canada may have as little as seven years' worth of natural gas reserves left.[8]

Because it's difficult to store, there is little storage or reserve capacity in our nation's web of gas pipelines and storage facilities. In the United States, we have only about a 50-day supply of working storage of natural gas.[9] There isn't much cushion in the system; everything operates on a just-in-time inventory basis, including market pricing.

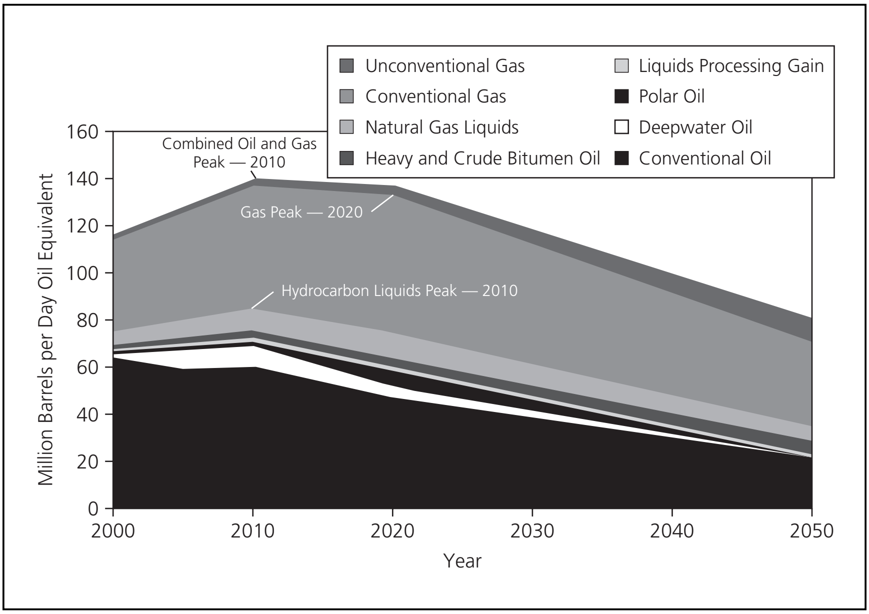

FIGURE 1.1 *Campbell's (2003) Forecast of World Oil and Gas Production*

Sources: Data: C.J. Campbell and Anders Sivertsson, 2003; chart: David J. Hughes slide deck, "Can Energy Supply Meet Forecast World Demand?," November 3, 2004.

Therefore, our main concern with gas is the domestic production peak. North America reached its peak of gas production in 2002, and has been declining ever since—the inevitable result of mature gas basins reaching the end of their productive lives.[10] (See Figure 1.2.)

The onset of the U.S. production peak was in 2001, and production is now declining at the rate of about 1.7 percent per year—far below the projection of the Energy Information Administration, as shown in Figure 1.3.

The declining plateau of production has held despite the application of the world's most advanced technology, and a tripling of producing gas wells since 1971, from approximately 100,000 to more than 300,000. (See Figure 1.4.)

The same is true for Canada, where they've been drilling more than ever, but production is still declining. Consequently, in recent years, gas rigs have been leaving Canada, and going to locations elsewhere in the world where rental fees are higher.

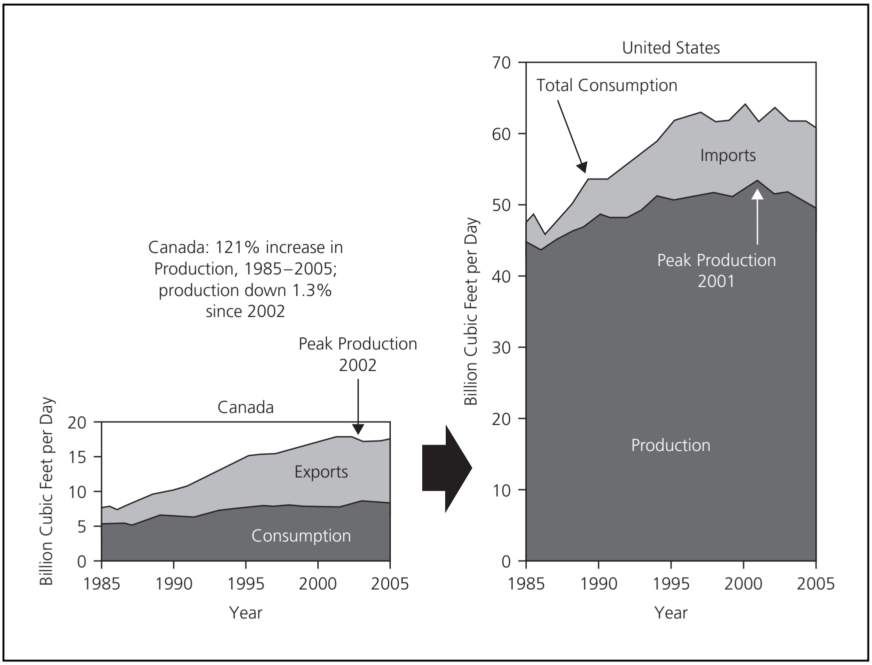

FIGURE 1.2 *North American Gas Production, 1985–2005*
Source: J. David Hughes, "Natural Gas in North America: Should We Be Worried?," October 26, 2006, http://www.aspo-usa.com/fall2006/presentations/pdf/Hughes_D_NatGas_Boston_2006.pdf.

In North America, the best and cheapest natural gas at high flow rates is gone. For the United States, this is again a very serious situation. Current supply-and-demand forecasts indicate that a shortfall in natural gas supply is looming, possibly by as much as 11 trillion cubic feet (tcf) per year by 2025, or *about half of U.S. current usage* of 22 tcf/year.

When we passed the North American gas peak, as seen in Figure 1.5, the price of gas imports skyrocketed. Yet demand has continued to increase, in part due to increased demand for grid power, but also in part due to switching over to gas from petroleum, which has increased in price even more rapidly than gas. Now we're needing more imports every year, but getting about the same amounts, and paying more for them. This trend shows no signs of abating.

Therefore, North America will increasingly have to rely on *liquefied natural gas* (LNG) imported by sea.

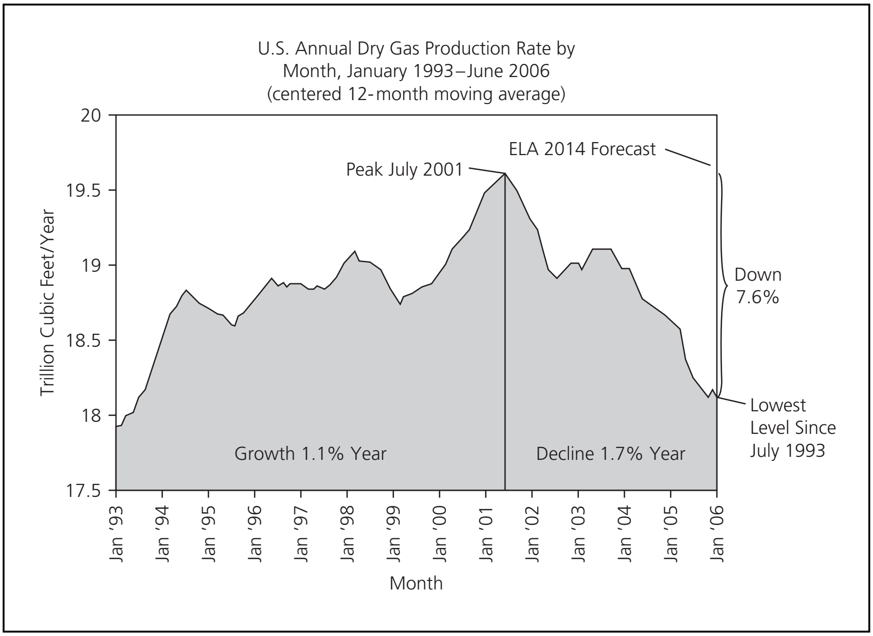

FIGURE 1.3 *U.S. Gas Production Rate, 1993–2006*

Source: J. David Hughes, "Natural Gas in North America: Should We Be Worried?," October 26, 2006, http://www.aspo-usa.com/fall2006/presentations/pdf/Hughes_D_NatGas_Boston_2006.pdf.

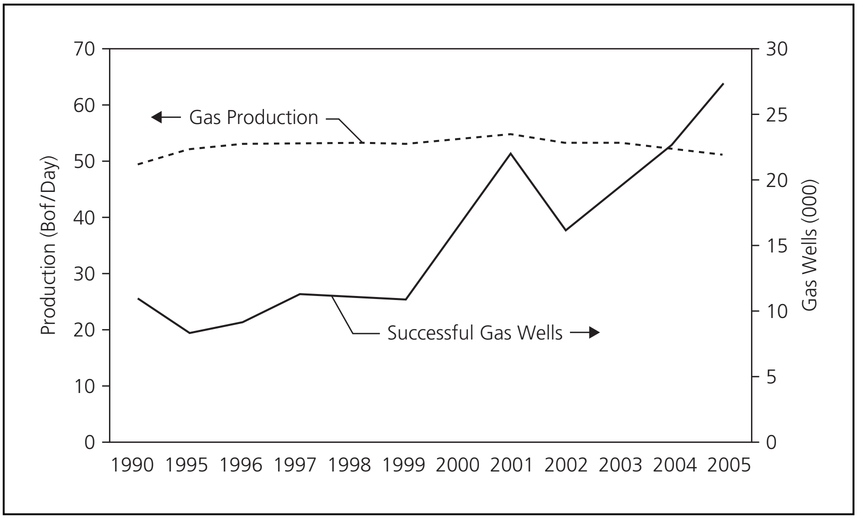

FIGURE 1.4 *U.S. L48 Gas Production versus Successful Drilling*

Source: "Balancing Natural Gas Supply and Demand," notes from Department of Energy Meeting, December 2005, http://www.fossil.energy.gov/programs/oilgas/publications/naturalgas_general/ng_supply_overview.pdf.

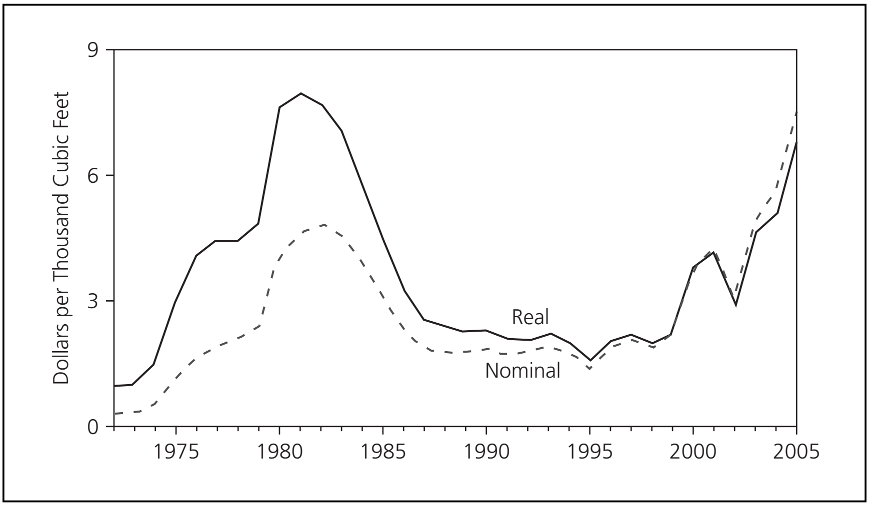

FIGURE 1.5 *Cost of Gas Imports, 1970–2005*
Source: EIA *Annual Energy Review,* 2005.

Liquefied Natural Gas LNG is made by carefully cooling natural gas to minus 260 degrees Fahrenheit, at which point it condenses into a liquid. It then must be kept under controlled temperature and pressure to stay liquefied, with some of it "boiling off" along the way, and transported in superinsulated, very expensive, pressurized tanker vessels. Then when it reaches its destination, it must be slowly *regasified*—warmed back up—before it can be sent through a pipeline to the end-user.

All of this requires significant inputs of energy and large facilities for both liquefaction and regasification. The whole LNG process, from cooling to transporting to regasification, entails a 15 to 30 percent loss of the energy in the gas. It also makes the gas more expensive than domestic gas.

What is the potential LNG supply for the United States? At present, it's uncertain. Consider the outlook for the three countries with the largest gas reserves: Russia, Iran, and Qatar.

In Russia, the investment climate for international energy companies has turned less than hospitable after a vicious round of resource renationalization under President Putin in recent years, and the outlook for LNG exports is dubious. Russia's planned gas exportation capacity appears to be focused on pipeline transport, and a dispute with Royal Dutch Shell over the rising costs of Russia's very first LNG plant at the Sakhalin II field has delayed progress on the project.

As for Iran, it seems unlikely that the geopolitical standoff over its nuclear development program will be resolved any time soon, such that it might become a hospitable investment climate for gas exportation projects. So we can probably rule out Iran as a major source of LNG for North America, at least for now.

That leaves Qatar, which is friendly to the United States and making significant investments in its LNG export capacity. Unfortunately—again due to rising costs—plans to build several much-anticipated LNG export facilities in Qatar were canceled in February 2007, such as a proposed $15 billion LNG facility in partnership with ExxonMobil. "Right now, everyone around us is postponing and delaying projects," Qatari Oil Minister al-Attiyah commented.[11]

At the same time, a rising sentiment of NIMBYism (Not In My Backyard) has nixed planned LNG import facilities in the United States, from Louisiana to Long Beach.

This is not a scenario to inspire hope for a dramatic increase in LNG imports. But according to respected Canadian geologist J. David Hughes, who provided the figures referenced earlier on gas, to cover the projected 2025 gas shortfall of 10 to 11 tcf/year in the United States alone, we would need to *double* (or, after competition sets in, *triple*) the *world's* current LNG capacity. Hughes estimates that this would require:

- Two hundred new LNG tankers, each with capacity of three billion cubic feet (bcf).
- Thirty new North America–based receiving terminals, each with capacity of one bcf per day.
- Some 56 new foreign-based 200 bcf/year liquefaction trains.
- Capital investment on the order of $US100–200 billion.
- Time to build total capacity = 10 to 20+ years.[12]

Even if we had no difficulty at all in building new gas liquefaction and receiving plants, this stretches the imagination and is virtually impossible.

The End of the Line Where does this leave us? In short, when it comes to natural gas, we're on our own in the United States. Although new drilling in the Lower 48, the Gulf, and, eventually, in Alaska will produce some additional gas, it won't be nearly enough to change the basic peak production profile. At best, it will thicken and extend the tail. That leaves one remaining option: switching fuels.

Natural gas is commonly used for heating and cooking, because it is safe, clean burning, efficient, and easy to control. Switching those uses to something else, like coal, wood, or fuel oil, means really stepping backward in time and technology, and comes with high carbon emissions.

But 29 percent of the natural gas used in the United States is for generating grid power, and accounts for 20 percent of the grid power produced.[13] That portion we can shift: to renewables!

Recognizing the serious threat that the natural gas supply poses to grid power generation, and the importance of renewables to fill the gap, former IEA chief Claude Mandil remarked in May 2007:

> *A heavy investment cycle in power generation is looming in most IEA countries and governments need to play an assertive role in reducing uncertainty and making sure appropriate investment takes place. . . . A window of opportunity now exists to push for a cleaner and more efficient generation portfolio that will have significant impact on the energy sector and the environment for the next 40–50 years.*[14]

This window is yawning wider every year, as we approach the end of the line for natural gas–fired power plants.

The next obvious choice would be to increase our reliance on coal, the dominant fuel used for grid power. However, there may be a slight problem with that.

Peak Coal

Coal is by far the dirtiest form of fossil fuel we use, but it's also the most readily usable fuel that we still have in relative abundance. Coal provides about one-quarter of the total energy the world uses. Worldwide electricity production is 40 percent powered by coal. Two-thirds of the steel industry relies on it for fuel, and that coal must be high-energy "black coal."

Like oil and gas, the best deposits of coal are highly concentrated. The major deposits of coal—about 90 percent—are located in just six countries: the United States, which has the most, plus Russia, India, China, Australia, and South Africa.

The United States has 496.1 billion tons of demonstrated coal reserves, 27 percent of the world total,[15] and thus is often called "the Saudi Arabia of coal." Our coal endowment has been widely estimated to be a 250-year supply. But that estimate was based on a USGS study from the 1970s, which assumed that 25 percent of the known coal could be recovered with current technology and at current prices. Now the USGS believes that only 5 percent is recoverable with today's technology and at current prices.[16]

This startling conclusion came from a 2007 study by the National Academy of Sciences. The researchers looked at recent updated surveys from the

United States Geological Survey (USGS) and determined that some of the old assumptions were wrong. "There is probably sufficient coal to meet the nation's needs for more than 100 years at current rates of consumption," the study says. "However, it is not possible to confirm the often-quoted assertion that there is a sufficient supply of coal for the next 250 years."[17]

Note that the 100-year estimate is based on our *current* consumption rate: about 1.1 billion tons a year. By 2030, due to users switching over to coal from other rapidly depleting fuels, the rate of coal consumption could be as much as 70 percent higher than it is today, in which case that "100-year" supply could be depleted much more quickly.[18]

Similarly, a separate study of world coal reserves in March 2007, which was conducted by a German consultancy called the Energy Watch Group (EWG), found that the United States does not have anywhere near its claimed 250-year supply of coal.[19] Indeed, EWG claims that in terms of energy content, the United States passed its peak of coal production in 1998!

The distinction is based on the fact that various types of coal contain different amounts of energy. Anthracite (also known as black coal) from Appalachia and Illinois has 30 megajoules of energy per kilogram (30 Mj/kg), but it has long been a tiny fraction of our overall coal production, and has been in decline for over half a century.

Our supposedly vast reserves are mainly of lower-quality bituminous coal, delivering 18 to 29 Mj/kg, and subbituminous coal and lignite ("brown coal"), delivering a mere 5 to 25 Mj/kg. (See Figure 1.6.)

For comparison purposes, EWG translated the energy content of the coal produced into *tons of oil equivalent*. In terms of *volumes of stuff mined*, they found that U.S. coal production can continue to grow for about another 10 to 15 years. But in terms of *energy*, which is the only metric that really matters, U.S. coal production peaked in 1998 at 598 million tons of oil equivalent, and had fallen to 576 million by 2005.

Just as we have burned through the world's best sources of oil and natural gas, we have burned the best sources of coal. The remaining coal we produce will be of progressively lower quality, and will be progressively more expensive to transport due to the escalating cost of diesel.

In a replay of the well-worn debate about oil reserves, it appears that the global reserve numbers for coal have been vastly overstated. The information we've had for the world, like the U.S. data, is decades old and unreliable, and modern reassessments by nice, transparent countries like Germany and the United Kingdom have resulted in 90 percent reductions!

The reserve numbers from Asia are particularly suspect, some dating back to the 1960s. China hasn't reduced its reported reserve numbers in

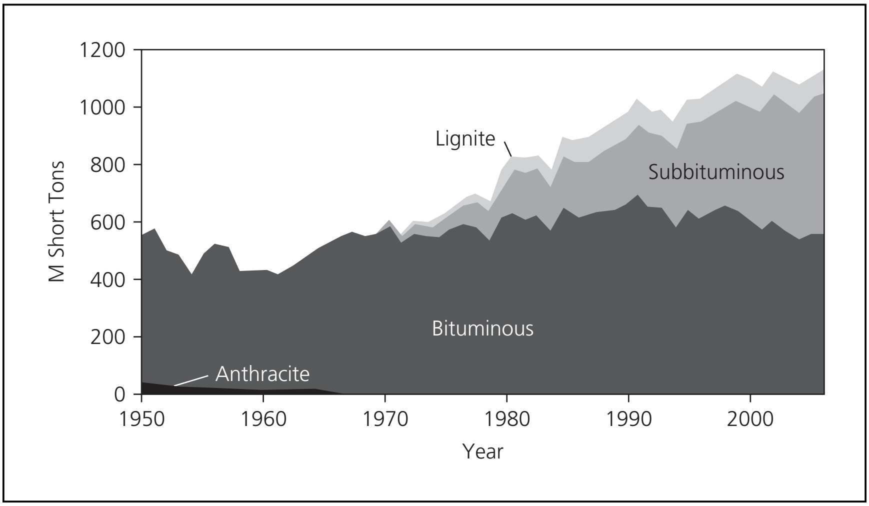

FIGURE 1.6 *Coal Production in the United States*
Source: Energy Watch Group.

15 years, even though we know it has produced some 20 percent of its reserves since then.

In fact, for the past 20 years, *all* major coal-producing nations that have updated their reserve numbers have adjusted them downward. And in the past 25 years, the global total reserve estimate has been cut by 60 percent.

The EWG report concludes, "The present and past experience does not support the common argument that reserves are increasing over time as new areas are explored and prices rise."

Let's look at the data.

- Total global reserves stand at about 909 billion tons.
- The world's largest producer of coal is China, which will likely peak between 2012 and 2022, followed by a steep decline.
- The next-largest producer is the United States, which will likely peak between 2020 and 2030.

Figure 1.7 is EWG's chart of possible worldwide coal production. Based on this scenario, the EWG estimates that the absolute peak of global coal production will occur around 2020, about 10 years after peak oil, and at about the same time as peak gas!

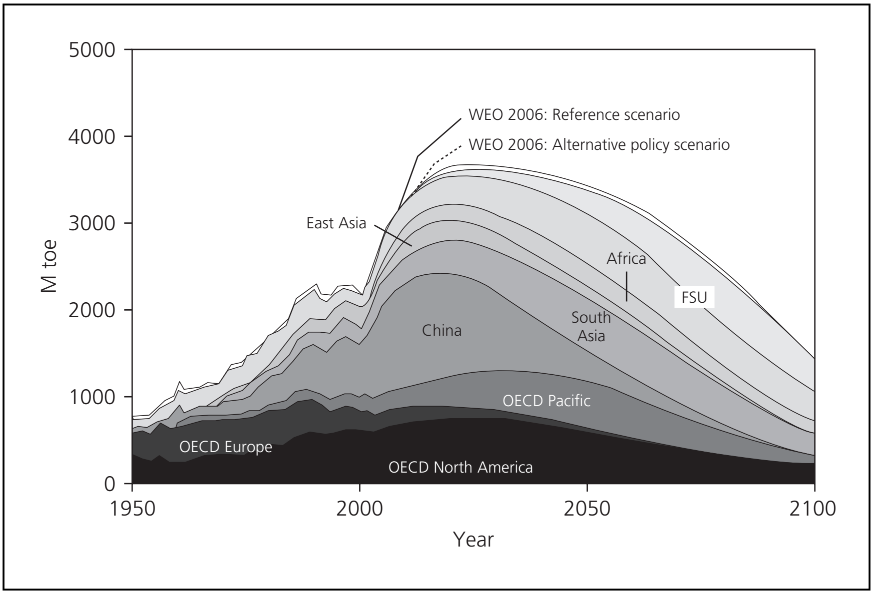

FIGURE 1.7 *Worldwide Possible Coal Production*
Source: Energy Watch Group.

Although coal depletion is another prong of the threat of global energy depletion, in terms of the long-term survival of life on Earth, it's a good thing. Coal is a greenhouse gas nightmare, and is the second-dirtiest form of hydrocarbons (after oil sands and shales). As we will see in Chapter 11, the problem of global warming demands that we reduce our consumption of coal. Even scaling up coal-to-liquids (CTL) production would require a large increase in emissions.

Many governmental and business leaders have expressed hope for dramatically expanding coal usage while avoiding an explosion of greenhouse gas emissions through the use of carbon capture and sequestration (CCS). CCS technology has been available for years, but it has failed to really catch on because it has always been considered to be too expensive. Before we assume that it will become a common feature of coal-burning plants in the future, we must ask ourselves what will be different in the future such that the cost of CCS will be deemed acceptable. At this point, we must view "clean coal" strictly as a sound bite. In real-life, commercial power doesn't yet exist.

There is also a cost attached to CCS that is almost never mentioned: that of energy. An interesting and detailed study by oil industry analyst Rembrandt

Koppelaar of ASPO-Netherlands looked at the energy cost of CCS, and compared that to the aforementioned EWG study, which had projected a gentle slope past the peak. Koppelaar determined that adding CCS technology shifted the peak of coal forward five years, to between 2015 and 2025, and significantly sharpened the slope of the decline. (See Figure 1.8.)

We can therefore imagine a scenario in which we push for increased coal usage due to peak oil and peak natural gas, but we do it responsibly by requiring CCS technology on every coal plant—only to advance the date of peak coal.

With or without CCS, peak coal suggests that powering the grid may become a challenge within a decade, leaving many observers to conclude that a nuclear energy renaissance may be the next best solution. According to the Energy Information Administration (EIA)'s *International Energy Outlook 2007*, world electricity generation will need to nearly double from 2004 to 2030.[20] Can nuclear energy meet that massively surging demand?

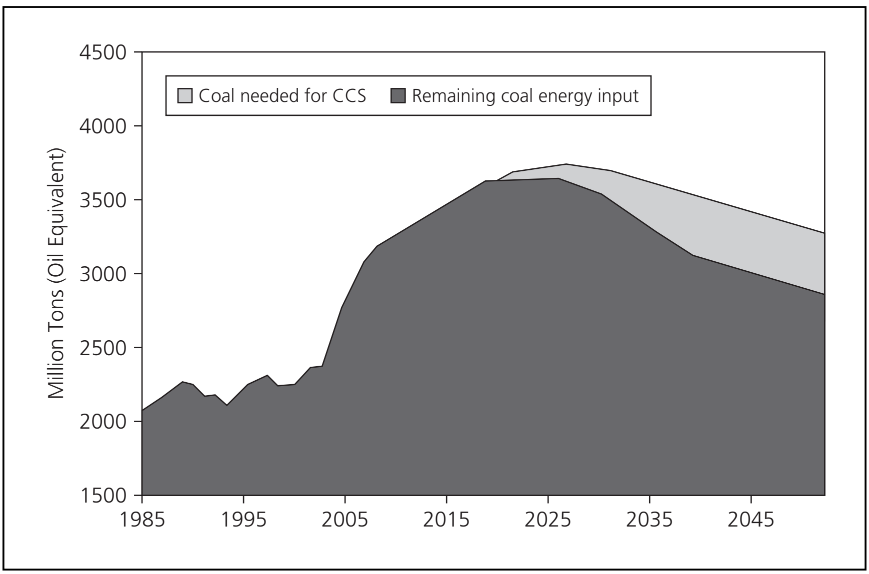

FIGURE 1.8 *Coal Production Scenario with Energy Input Costs for Carbon Dioxide Capture and Storage (CCS)*

Sources: Chart: Rembrandt Koppelaar, http://europe.theoildrum.com/node/2733; production scenario: Energy Watch Group, www.energywatchgroup.org/files/Coalreport.pdf.

Peak Nuclear

By now, you can probably guess what the story is with nuclear power: The best ores of uranium have been mined, leaving mainly low-quality ores left to exploit.

To the casual observer, this might seem at first like a ridiculous statement. Uranium is a very common element, found in about the same abundance as tin worldwide, in everything from granite to seawater. Almost all—99.3 percent—of the uranium found on Earth is uranium-238, an isotope of uranium containing 238 protons per atom. The remaining uranium—0.7 percent—is uranium-235, and that's what is used as fuel for our "light water" nuclear reactors.[21]

In a light water reactor, a chain reaction causes the fission (breaking apart) of the nuclei of the uranium-235 atoms, which generates an enormous amount of heat. (Some of the uranium-238 atoms also contribute, by converting to plutonium-239, of which about half is consumed in the process.) The heat is used to turn water into steam, which is then used to turn a turbine and generate electricity. Water is used as a moderator, to slow down the neutrons in the nucleus sufficiently to support the chain reaction.

The most common type of nuclear plant today, and the ones currently being planned, are pressurized water reactors, which use pressurized water as a coolant and neutron moderator. This type of reactor is generally considered to be the safest and most reliable.

In the early days of nuclear energy, it was assumed that the industry would quickly move beyond simple water reactors and develop *breeder* reactors, which can use the far more abundant uranium-238. Breeder reactors are so called because they generate more fuel than they consume, by neutron irradiation of uranium-238 and thorium-232 or plutonium. With breeder reactors, the initial fuel charge is gradually consumed and then the reactor runs on the fuel it has generated itself. Breeder reactors are cooled by liquid metal (such as sodium or lead) and have the advantage of being able to use depleted uranium-238 and uranium formerly used in weapons as fuel.[22]

After it is used, the fuel must be taken out of a breeder reactor and reprocessed in order to be reused. In this step, it is conceivable that some plutonium could be diverted from the reprocessing and fall into the hands of illicit weapons builders, which is why breeder reactors have aroused fresh fears of terrorists armed with nukes. Although reprocessing spent fuel is the foundation of France's robust nuclear energy program, concerns about safety, nuclear weapons proliferation, and economics have halted nuclear fuel reprocessing in the United States for over 30 years.[23]

There are actually dozens of different types of nuclear reactors, each with its own fuel needs and pros and cons. But all commercial nuclear reactors in use today are either water reactors or some type of fast breeder reactor.[24]

Limits to Nuclear Power As of 2007, there were 435 commercial nuclear reactors operating in 30 countries, providing 370,000 MW of capacity—that's 6.2 percent of the total energy produced worldwide, or about 16 percent of the world's base-load electricity.[25]

The United States supplies more commercial nuclear power than any other nation in the world, and currently has 104 commercial nuclear-generating units licensed to operate,[26] which constitute a mere 11.5 percent of the nation's energy needs.

Can nuclear energy be substantially scaled up? According to the EIA's *International Energy Outlook, 2007*, nuclear power will remain a bit player. Figure 1.9 illustrates the EIA's projection.

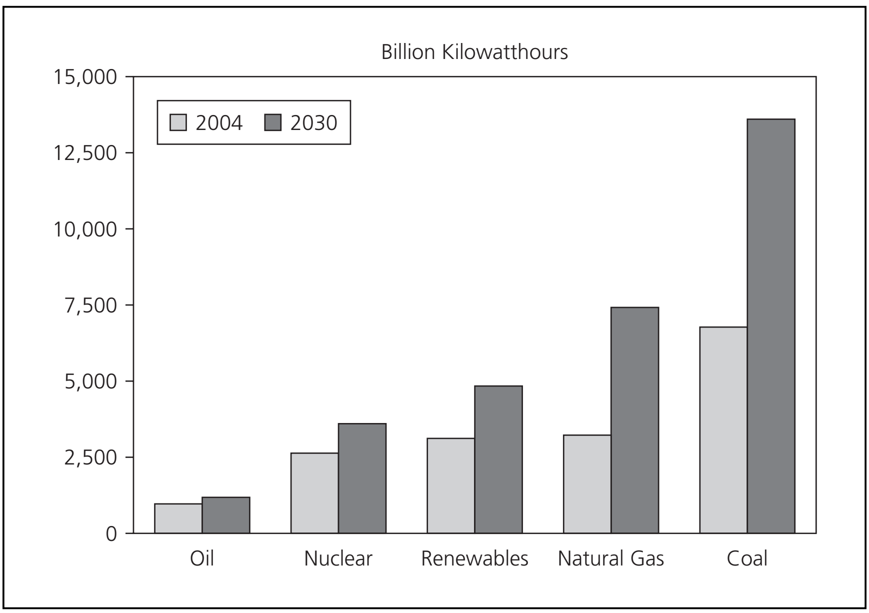

FIGURE 1.9 *World Electricity Generation by Fuel, 2004 and 2030*

Sources: www.eia.doe.gov/oiaf/ieo/pdf/electricity.pdf; 2004: derived from Energy Information Administration (EIA), *International Energy Annual, 2004* (May–July 2006), www.eia.doe.gov/iea; 2030: EIA, *System for the Analysis of Global Energy Markets* (2007).

The long lead times for nuclear plants, plus their high cost of construction and fuel production, necessarily limit their future. Part of the problem is shortages in building materials and skilled labor—the same limits that face the oil and gas industries. Coal and natural gas power plants, despite their environmental consequences, are far easier, faster, and cheaper to build, so the EIA is probably correct in this forecast.

But perhaps the most effective limit on the nuclear power industry is NIMBYism—that is, "Not in my backyard." It's nearly impossible, at least in the United States, to find any community willing to host a new nuclear plant or a nuclear waste storage site.

The last reactor built in the United States was ordered nearly four decades ago, took three decades to approve and build, and became operational in 1996. That's a very long lead time. Even if the political will can be mustered to grease the skids for new plants, it's hard to imagine that lead time being shortened by much, if at all, as environmental review requirements and community resistance are greater now than they were then.

Then there is the problem of just maintaining our current nuclear capacity. Of the 103 reactors currently operating in the United States, many are approaching the end of their intended life spans. Even with 20-year extensions of their planned life spans, all existing reactors will be decommissioned by the middle of this century. Just replacing them will require building two reactors a year for the next 50 years—in itself a dubious prospect.[27]

The aging of nuclear plants is a major factor worldwide. A 2007 paper by leading researchers at the Oxford Research Group suggests that over the next 25 years, nuclear power capacity is actually set to decrease, as many of the world's operational reactors are nearing the end of their lives. However, replacement reactors aren't forthcoming: There are only 25 new nuclear reactors currently being built, with 76 more planned and another 162 proposed but hardly certain. Even if all of them materialized in the next 25 years, we'd still be nearly 40 percent shy of replacing all of today's reactors.[28]

Peak Uranium

Life span and NIMBYism aside, however, the most unyielding limit to nuclear power is the prospect of peak uranium production. As new sources become harder and harder to find, the prospect of future nuclear growth becomes dimmer.

Gerald Grandey, the president and CEO of Cameco Corporation, the largest uranium producer in the United States, believes that demand for uranium will exceed supply for the next eight or nine years, forcing utilities to depend on inventories for fissionable fuel rather than new production. In a June 2007 press conference, he indicated that he expects demand to grow at 3 percent annually for the next decade, but doesn't see uranium mining being able to keep pace with demand. Nor does he see much in the way of opportunity to acquire smaller producers in order to increase his company's output: "There isn't a whole lot out there to acquire that's meaningful," he said.[29]

This is a complex topic, but essentially, like coal, uranium comes down to a question of *energetics*. Only the highest-quality ores are net energy positive when used in a typical fission reactor. And like coal, we may be past peak uranium in terms of energy content.

According to independent nuclear analyst Jan Willem Storm van Leeuwen, when the uranium-235 content of the ore is under 0.02 percent, more energy is required to mine and refine the uranium than can be captured from it in a nuclear reactor, so it's not worth doing.

In a 2002 paper by van Leeuwen and Philip Smith, "Can Nuclear Power Provide Energy for the Future; Would It Solve the CO2-Emission Problem?," the authors predict that the diminishing availability of high-grade uranium ores will pose a hard limit to the future growth of nuclear energy: "Another way of putting it is to say that if all of the electrical energy used today were to be obtained from nuclear power, all known useful reserves of uranium would be exhausted in less than three years."[30]

Naturally, as they are consumed, the world's reserves of high-grade ore are dropping. The vast majority of the remaining uranium, and the largest deposits of it, have ore grades lower than 0.1 percent. That is 100 to 1,000 times poorer a fuel than the ore used today, making it uneconomical to mine.[31] (See Figure 1.10.)

As Figure 1.10 shows, van Leeuwen estimates that at current rates of consumption—again, not anticipating any massive upscaling of nuclear energy usage—high-grade uranium ore will last only to about 2034, and nuclear energy will become a net energy loser by 2070.[32]

The remaining sources of uranium, from lower-quality ores to seawater, are ultimately net energy losers because it takes so much energy taken from fossil fuels to mine and produce the fissionable material that it would be pointless to use those fuels for mining and processing uranium to drive a reactor. It would be far better just to burn them.

The Oxford Research Group paper supports the conclusion that there are adequate reserves of high-grade uranium ores for only about another 25 years of operation, and that any increases beyond that point will have to come from breeder reactors, which primarily use the much-more-abundant plutonium for fuel.[33]

A 2006 study by the Energy Watch Group (the same group that did the coal report), "Uranium Resources and Nuclear Energy," indicates that even

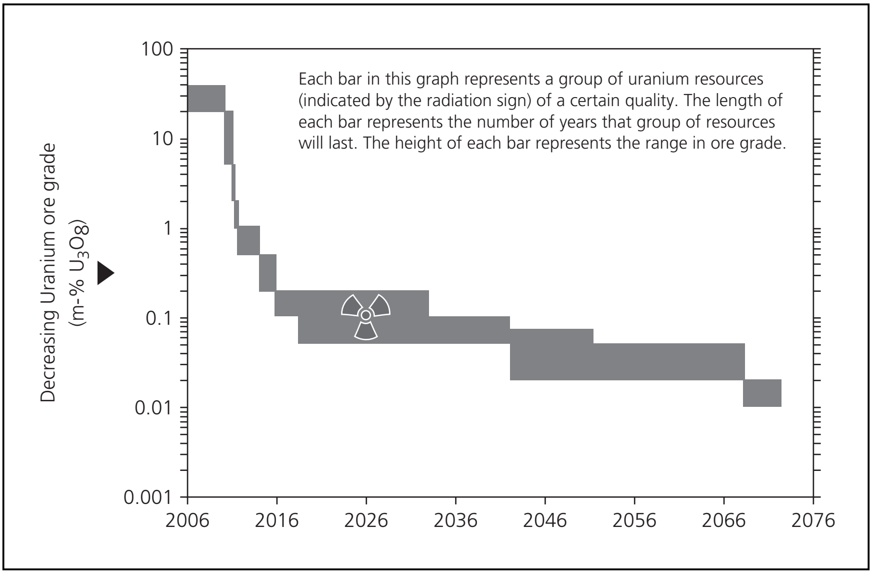

FIGURE 1.10 *Uranium Ore Grade, 2006–2076*
Source: Jan Willem Storm van Leeuwen, Oxford Research Group.

under the best-case estimates of uranium resources, production will peak before 2050, assuming today's relatively minuscule rate of use.[34] Increase the rate of use, or use a less optimistic reserve number, and that date moves forward quickly.

The EWG study's conclusion was sobering:

> *The analysis of data on uranium resources leads to the assessment that discovered reserves are not sufficient to guarantee the uranium supply for more than thirty years.*
>
> *Eleven countries have already exhausted their uranium reserves. In total, about 2.3 Mt of uranium have already been produced. At present only one country (Canada) is left having uranium deposits containing uranium with an ore grade of more than 1%, most of the remaining reserves in other countries have ore grades below 0.1%, and two-thirds of reserves have ore grades below 0.06%.*[35]

The Energy Watch Group estimates that the uranium peak would be around 2025 for "probable reserves" and 2030 for "possible reserves,"[36] the latter being more or less in line with van Leeuwen's estimate.

Figure 1.11 is their chart of *possible reserves*—in other words, their best-case scenario.

As shocking as this projection is, if the world significantly expands its use of nuclear power, the reality could be worse. EWG's assumptions about the rate of use were based on the nuclear plants and uranium mining operations currently in existence, plus those that were planned or under construction at the end of 2006. If the ambitions of government leaders to radically increase nuclear-generating capacity are realized, then the rate of use will be higher, and the peak sooner.

To put a final nail in the nuclear coffin, the authors of the EWG report note that alternative reactor designs won't substantively affect their calculation, saying, "At least within this time horizon, neither nuclear breeding reactors nor thorium reactors will play a significant role because of the long lead times for their development and market penetration."[37]

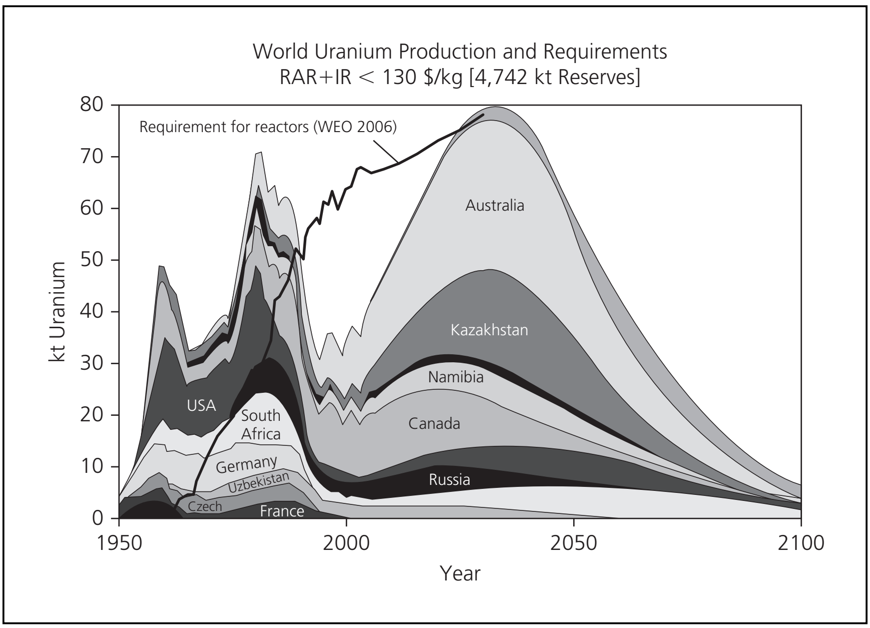

FIGURE 1.11 *Future Production Profile of Uranium—All Possible Reserves*

Source: Energy Watch Group, "Uranium Resources and Nuclear Energy," December 2006, EWG Series No. 1/2006, www.lbst.de/publications/studies__e/2006/EWG-paper_1-06_Uranium-Resources-Nuclear-Energy_03DEC2006.pdf.

Nuclear energy has other challenges, too, apart from the availability of fuel. The true cost of building nuke plants, from planning all the way through decommissioning, are never accounted for, nor paid, by the operators of the plants. The decommissioning costs are invariably externalized, or foisted onto the public, while we have yet to deal with the past 60 years' worth of toxic spent fuel, some quarter of a million tons of it, now scattered around the globe. Once all costs are taken into account, nuclear energy may in fact be a net energy loser.

To conclude, alternative reactor designs are not ready for prime time, and for traditional reactors, the world has 30 years or less of uranium reserves left, at current rates of usage. The global peak of uranium production will likely be around 2025 to 2030, perhaps 5 or 10 years after peak coal.

CRISIS OR OPPORTUNITY?

We have now seen a few scenarios for peak oil, peak gas, peak coal, and peak uranium, which together account for 98 percent of today's energy usage. These scenarios, built on objective and peer-reviewed data and research, illustrate the urgency of a complete overhaul of our energy economy. Within the next century, most of our conventional power-generating resources will fade or simply become too expensive to find, extract, produce, and consume. This leaves the entire global community with a significant challenge to rapidly develop new energy technologies and a new energy infrastructure. Because, as you can see below, the global fossil fuel production and forecast does not look good.

Putting them all together (with slightly different forecasts), it might look something like the image depicted in Figure 1.12. That's why we call peak energy a crisis. Given that the bell curves of production for all of today's dominant fuels tail off to perhaps one-quarter of the peak supply by the end of the century, we presume that we'll have to accomplish the renewable-energy revolution in perhaps 75 years' time—a breathtaking challenge.[38]

With peak energy occurring by 2025, where does that leave us? It leaves us with an incredibly huge gap to fill with renewables. Consider today's overall energy mix by referring to Figure 1.13.

The largest renewable energy source in the world is hydropower, but there is very little hydroelectric power left to exploit worldwide, and many of the existing plants have struggled to continue operating in the last few years due to reduced rainfall—a phenomenon that has been tied to global warming.

Therefore, with 98 percent of today's fuels in irreversible depletion by 2025, we're going to have to start growing that 1.4 percent wedge of "Geothermal and Other" as fast as we possibly can, starting yesterday, until it takes over

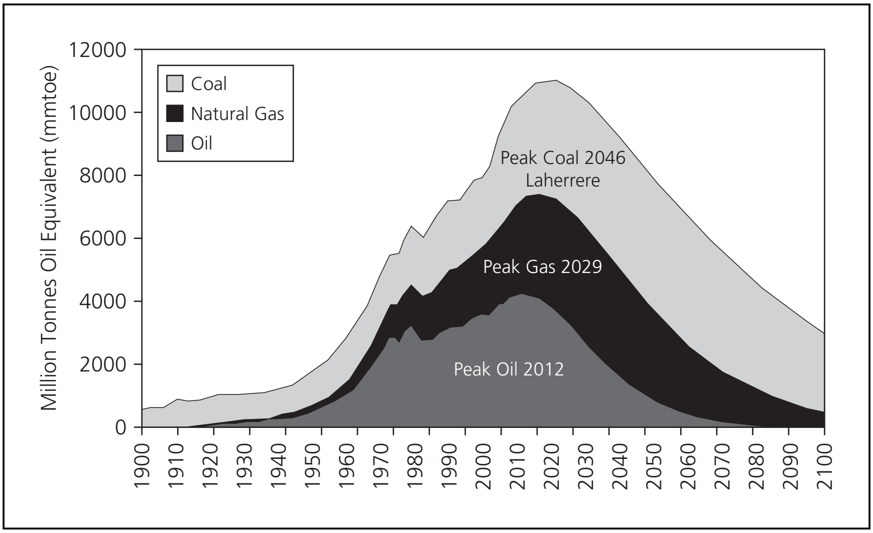

FIGURE 1.12 *Global Fossil Fuel Production and Forecast*
Source: Euan Mearns and Luís de Sousa.

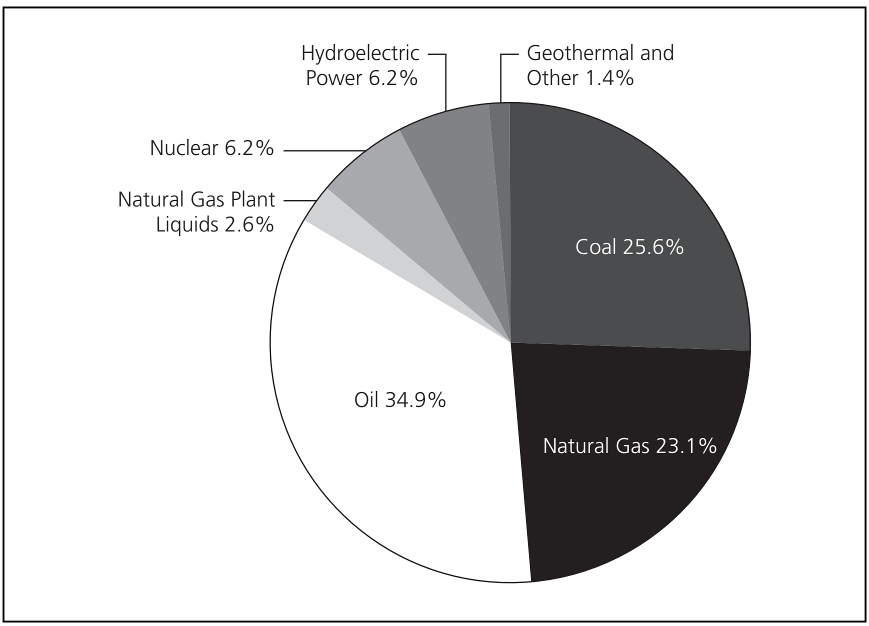

FIGURE 1.13 *World Energy Production by Source, 2004*
Source: EIA, "World Primary Energy Production by Source, 1970–2004," www.eia.doe.gov/emeu/aer/txt/stb1101.xls.

nearly the whole pie. Unless some amazing, unexpected, paradigm-changing breakthrough happens in the meantime, it is literally our only choice (after reducing consumption).

This raises an important question: Since the foregoing analysis suggests that peak oil will occur in the next two years (if it hasn't already) and that the peak of all energy production is a scant 17 years off, do we have enough time to pull it off?

One of the most well-respected studies on how long it will take to prepare for peak oil was published in February 2005 by veteran energy analysts Robert L. Hirsch, Roger Bezdek, and Robert Wendling, in a report titled "Peaking of World Oil Production: Impacts, Mitigation, and Risk Management,"[39] which they did for the U.S. Department of Energy.

Their approach was elegantly simple: First, they determined how much oil could be offset by various mitigation strategies. They made some reasonable assumptions about the future potential of all exploitable sources of energy, and about the amount of savings that might be achieved through conservation and higher efficiency, and charted each as a wedge on an aggregate chart. Then they charted that against what they considered to be a reasonable forecast of world oil production under three different scenarios, in which intensive mitigation begins at the peak, 10 years before the peak, and 20 years before the peak.

Their conclusion was blunt: Only if we commence our efforts a full 20 years before the peak can we manage a smooth transition. If peak oil is truly only two years off, then we are already facing an inevitable, roughly 20-year shortfall in supply, simply because it takes that long to replace infrastructure and make other necessary adjustments to live within a reducing, rather than expanding, energy budget.

In their words:

> *If mitigation were to be too little, too late, world supply/demand balance will be achieved through massive demand destruction (shortages), which would translate to significant economic hardship. . . . The world has never faced a problem like this. Without massive mitigation more than a decade before the fact, the problem will be pervasive and will not be temporary. Previous energy transitions (wood to coal and coal to oil) were gradual and evolutionary; oil peaking will be abrupt and revolutionary.*[40]

The lead author of the report, Robert Hirsch, a longtime energy consultant for Science Applications International Corporation (SAIC), sums up the situation simply: "Peak oil: the more you think about it, the uglier it gets."[41]

The paucity of alternative fuels, and the relative immaturity of renewable energy and of strategies for reducing energy consumption, prompted noted peak oil analyst and oil investment banker Matthew Simmons to remark, “There are no magic bullets, only magic BBs.” Rather than pursuing some single new source of energy, like the ever-elusive cold fusion, we need to be thinking about a thousand small solutions that together can solve the energy-depletion dilemma.

THE SOLUTIONS

In the next 11 chapters, we will discuss many of these “small solutions.” We will review the various renewable energy technologies that are at the forefront of transitioning our energy economy, we will show you the companies that got an early lead in the renewable energy sector, and explain why they delivered for investors and why they’re now some of the most important energy companies operating today. But most importantly, we will show you how you can profit from the next generation of renewable energy companies that are poised to take over where fossil fuels leave off.