earth

THE OPERATORS' MANUAL

RICHARD B. ALLEY

COMPANION TO THE PBS DOCUMENTARY

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The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change,

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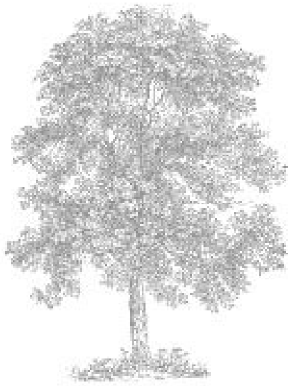
EARTH

The Operators’ Manual



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W. W. Norton & Company

New York • London

Printed in the United States of America
First Edition

Manufacturing by RR Donnelley, Harrisonburg, VA
Book design by Chris Welch
Production manager: Anna Oler
Ebook conversion by Erin Schultz, TIPS Technical Publishing, Inc.

Library of Congress Cataloging-in-Publication Data

Alley, Richard B.
Earth : the operators' manual / Richard B. Alley. — 1st ed.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-393-08109-1 (hardcover)
1. Energy development—Environmental aspects—History.
2. Renewable energy sources. 3. Global warming. I. Title.
TJ163.2.A43 2011
621.04209—dc22
2010054016

W. W. Norton & Company, Inc.
500 Fifth Avenue, New York, N.Y. 10110
www.wwnorton.com

W. W. Norton & Company Ltd.
Castle House, 75/76 Wells Street, London W1T 3QT

1234567890

To my wife, Cindy, and daughters, Janet and Karen,
with thanks and hope.

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PREFACE

Today, almost seven billion of us live side by side with whales and woodlands because we get almo all of the energy we use from oil, coal, and natural gas. If we suddenly quit using these fossil fuels ar returned to burning whale oil and wood, we wouldn’t come close to powering enough of our tractor trucks, and irrigation pumps to feed us all.

The good we get from fossil fuels is a mixed blessing, though. If we keep using them, and acce the risks of oil-well blowouts and mountaintop removal, for long enough, the fossil fuels will run o —we are burning them about a million times faster than nature saved them for us. We thus mu decide whether to burn most of the fossil fuels and then look for replacements, or to learn while v burn and while we still have a fossil-fuel safety net in the ground.

Our decision must be made under the shadow of global warming from the CO_2 released b burning fossil fuels. Sensors on heat-seeking missiles are affected by the interaction between CO_2 ar energy transfer through the air, and so is the climate. The atmosphere really doesn’t care whether v study it for warring or warming, and military as well as civilian physics research shows that CC matters. We thus have high scientific confidence that continuing to burn fossil fuels will cause larg climate changes, which will make life more difficult for poor people living in hot places now, and fo most people in future generations.

But if CO_2 emissions especially harm poor people, are we wiser to reduce emissions, or reduce poverty by helping people become wealthier? Not surprisingly, economics answers “Yes”—c some of each. How much of each may depend on national security, jobs, ethics, and insurance, as we as economics.

You will hear a lot of shouting from the wings that partially drowns out discussion of thes important issues, but this shouting is nothing new. President Abraham Lincoln’s administration foun ways to get good scientific advice through the noise, and following his example still works. I will t to stick closely to Lincoln’s example in giving you the best scientific insights. There are things th science doesn’t know, more things that I don’t know, and I am far from infallible, but much of th science really is solid, and I will tell you when it isn’t.

Lincoln also showed us part of the solution for powering the planet. Earth offers vast, sustainab energy resources with the potential to improve the economy and generate a lot of fortunes, includir the wind that so intrigued Lincoln on the Illinois prairie long before his presidency.

Being a truly honest broker on such complex topics may be impossible, but I will do my best f you. This could be easier for me than for most people: I enjoyed working for an oil company ar benefited from its largesse, my political registration is right of center, and I have won scientif awards for helping show just how bizarrely Earth’s climate can behave without any interference fro us. But I also helped the U.S. National Academy of Sciences and played a small role in the Nob Prize–winning effort of the United Nations Intergovernmental Panel on Climate Change (IPCC where my knowledge of Earth’s history and behavior contributed to the confident realization that th CO_2 from our fossil-fuel burning is highly likely to change the world in fundamental ways that wi increasingly make life harder for future generations. Our two lovely daughters give me a personal well as a professional stake in the search for a stable, sustainable world. Onward!

PART I.

THE BURNING QUESTION

1

Prepare to Come About

Synopsis. We humans have always used energy and always will. We now rely greatly on fossil fuels, which promise to make our lives much harder before they run out. But there are plenty of ways to get rich and save the world by remaking our energy system.

May you live in interesting times. —Old curse[1]

Power On

More and more of us are living better than ever before. In most of the world, an expectant moth can be reasonably confident that she will deliver a healthy baby, who will parent the next generatio and live long enough to help educate the generation after that. Wars continue, but the all-out disaste of World War II is ancient history for many of us, and a fading memory for the rest. We have used ou accumulated knowledge and wisdom, and the things we've built, to convert a world that might suppo a few million hunter-gatherers[2] into home for over six billion of us, heading for nine or ten billio When problems arise, we usually invent and cooperate to solve them. We have never fully agreed o the purpose of our existence (and we are not likely to agree in the near future), but if we approve any form of "The greatest good for the greatest number," then this really may be the best time history.

And yet, we can easily believe we are cursed to live in these interesting times, with disaste waiting at every turn. Perhaps a billion or more people—one in six of us—exist in such poverty violence that they cannot reasonably expect their children to live long and prosper. Various accounti methods suggest that we are using, and often using up, nearly half of everything that the planet mak available to us and to all other species, with rising population and expectations pushing us rapid toward using 100 percent.

We have removed perhaps 90 percent of the large fish from the ocean; in fact, we have no ide what a natural ocean ecosystem looks like, because we fished out so many species before scientis learned to see what is going on.[3] Roughly one-third of the land surface not covered by ice sheets now used for cropland or grazing, with logging extending our impact.[4] Water is essential to us, but many places a large fraction of the water we use is not being replaced, as we pump it out of o deposits in the ground or melt it from old deposits in glaciers much faster than new rainfall snowfall supply more.[5] The soil that grows our crops is being washed away far faster than nature ca produce more,[6] so farming is becoming more difficult, especially as we use up the "easy" deposits phosphate for fertilizer.

With human population expected to increase, many of us not getting even the minimum th most civilized people believe is needed for a proper life, and almost everyone hoping to improve the lot, ~~it takes an optimist to believe that the demands on the planet will "only" double.~~ If our use already approaching half of everything supplied by Earth, where will the rest come from? And wh does our growing use mean for the other species that share the planet with us, and their ecosystems o which we rely?

A pessimist can easily look past our successes in advancing knowledge and skills an infrastructure and healthy people, and see the history of disasters, wars, environmental refugee starvation, and failure.[7] Humanity has had more than enough "wins" to show that success is possibl but more than enough failures to show that success is far from guaranteed.

If water runs out, we can desalinate and pump. If soil runs out, we can grow crop hydroponically without soil, or we might dig the dirt out of the reservoirs behind dams and spread back on the fields while adding key nutrients, much as a home gardener builds raised beds. phosphate becomes scarce, we can mine lower-grade ores and use our knowledge of chemistry enhance them.

But desalination uses energy, and lots of it. So does building a hydroponic system, and mining low-grade ore. So do plowing and shipping, heating and cooling, flying and driving, and so many oth things we do. We already rely heavily on energy use to solve our problems: powering pumps to pu water out of the ground to grow our crops, fueling huge shovels to dig phosphate and ships to send it- often great distances—to the farm fields, where fuel-filled tractors spread it, and much more. And ou energy use is arguably the most unsustainable part of our lives.[8] Roughly 85 percent[9] of the world primary-energy production today is from fossil fuels—oil, coal, and natural gas—with only 15 perce from nuclear, hydropower, wind, or other sources. We are using the fossil fuels approximately million times faster than nature saved them for us, and they will run out (see chapter 4).

We apply cheap energy to almost all of our problems, a "silver bullet" to slay the dragons th trouble us. But if we continue on our present course, we will run out of silver bullets. Our curre energy system cannot last. Worse, the by-products of that energy system threaten to change the plan in ways that will make our lives much harder—if we burn all of the fossil fuels before we learn how use new energy sources, we will have greatly increased the difficulty of our education.

Fortunately, we have a golden bullet in our pocket—our collective cleverness. The amount energy that Earth makes available, sustainably, dwarfs the amount that we now use, and dwar demand for the foreseeable future. Sunshine from just the desert floors of Arizona would power th whole United States, and from the Sahara could power the rest of the world's people, with hug amounts left over. The technologies required are not science fiction—in fact, they already exist soon will, and some of them are decades or centuries old.

But big projects take a long time to complete. In 1971, the then U.S. president Richard Nixo declared war on cancer. He proclaimed, "The time has come in America when the same kind concentrated effort that split the atom and took man to the moon should be turned toward conquerin this dread disease. Let us make a total national commitment to achieve this goal."[10] Almost for years later, although the goal remains elusive, huge progress has been made. But the first decade two of this "war" did not produce the heady victories we hoped for. Very simply, cancer proved to be hard problem.

Figure 1.1 *Karen Alley sailing: "Prepare to come about."*

I believe that our energy problem will prove easier to conquer than cancer, as I discuss in part I of this book. But the effort required is easy to underestimate. Our oil and coal companies are so goo at what they do that we easily forget the sheer immensity of their achievements. We occasionally ar reminded of the near impossibility of quickly containing the oil from even one spill when an oil we blows out or a supertanker runs aground in an ecologically sensitive area, but drill rigs and tankers a at work continuously. The efficiency with which some coal-mining companies change the very face Earth—removing the tops of mountains, filling valleys with the non-burnable rocks, and moving on- to extract the energy stored beneath is mind-boggling.

Changing the direction of an oil tanker, or any large ship, is a slow process. By the time the pil sees an obstacle ahead, mutters, "Oh, (very bad word)," and tries to make a correction, a collision ma be unavoidable. The inquiry into the sinking of the Titanic revealed that when the crew sighted th iceberg, it was already too late to steer to safety: "We had the order, 'Hard-a-starboard,' and she jus swung about two points when she struck."[11]

A remarkably wide range of thinkers, scientists, and engineers now see the ship of our energ use on a collision course that will seriously harm our future, unless a correction is begun soon. Th change is still possible—we are not the Titanic, doomed to hit and sink—but the longer we wait, th harder the change will be, and the more damage we will do as we sideswipe the unpleasant reality. A my younger daughter Karen says to her crew when sailing her Sunfish in much more pleasant time "Prepare to come about."

THE OPERATORS' MANUAL

When all else fails, read the operators' manual.[12]

I routinely board very large airplanes without having the vaguest idea of how they work or how to f them—I'm a passenger, and happy to ride along. I take buses, and taxis, and ride shotgun when othe drive, without sweating it. But put me behind the wheel of the car, and I suddenly need to know whole lot more. Manual or automatic? Mirrors adjusted right? Where is the knob for the headlight ~~Emergency brake, just in case? When I buy a new car, I actually do skim over the manual. And~~ whe the brakes went out on the geology van coming down the mountainside during my student day knowing what to do was a distinct comfort in a tight spot.

I'm educated as a geologist, with climate and ice and water and a bunch of engineering throv in. I have been an academic most of my professional life, but I worked for an oil company for a b and enjoyed both the money and the smart people doing interesting things there. My experience w similar to that of many geologists, who for more than a century have been getting good jobs to he people find valuable things in the Earth (oil, coal, diamonds, gold). Geologists also get jobs to he people avoid hazards (volcano! landslide!), and to be entertaining (dinosaurs!). Recently, however, w have been asked to take on another job.

Figure 1.2 Final assembly of the drill and protective dome for deep ice coring at GISP2 in central Greenland. Records from ice cores tell us the history of the atmosphere, including natural and human-caused changes.

I often have taught geomorphology, the science of why Earth's surface looks the way it does, ar the task has been getting harder. More and more, the processes that made Earth's landscape in the pa are not the processes that students observe today, because the dominant processes today are "us." W now move more rocks and dirt than nature does—all of the natural landsliding of hillsides and mu washing down rivers and dust blowing through the air are small compared to the work of o bulldozers and steam shovels.[13] Many home gardeners in suburbia are convinced that they have po soil, and most of them are right—builders often dig a hole for a foundation and perhaps a basemen spread the rock and clay to smooth the lot, throw a bit of "topsoil" on just thick enough to grow gras and call it a job well done. Digging a hole for a tomato plant then means tapping into a mess whatever came out to make room for the foundation or basement, plus some nails and shingle piec and other construction debris. A geomorphology student wanting to learn about nearby natural soi may have difficulty, because most of the easy-to-visit soils have been so greatly disturbed by human

A reporter called recently and asked how long it would take Earth to "forget" humanity if v suddenly disappeared. In some sense, we are now unforgettable—the human-caused plant and anim extinctions have emptied biological "jobs" that will be filled over many millions of years by creatur who will owe their existence to us wiping out the competition. We have pumped oil and gas out of th ground that had been there for hundreds of millions of years, through holes that may not be erod away for additional hundreds of millions of years. The human "layer" of plastic and aluminum fo and heavy metals may be recognizable in sedimentary piles hundreds of millions of years from now.

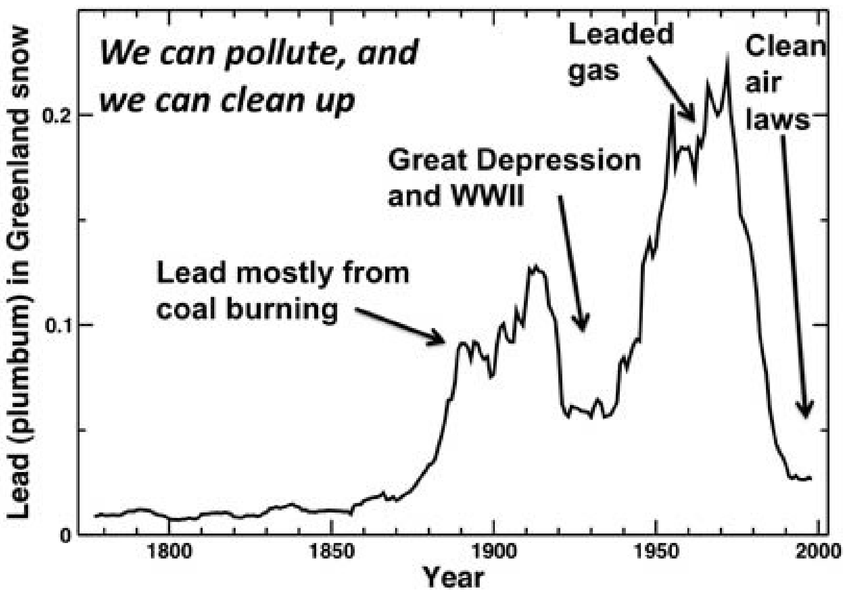

Figure 1.3 Recent history of concentration of lead pollution in Greenland snow.

In Greenland, I helped collect ice cores to learn the history of the atmosphere. The folks wh study the trace chemicals in the ice can see the clear signal of mining of lead—*plumbum*—used supply the plumbing of the Roman Empire. The post-Roman drop in lead level is followed by a ri beginning with the Industrial Revolution, a drop for the Great Depression, a huge rise with the use leaded gasoline and paint after World War II, and then a great drop when we became concerned abou lead poisoning and got serious about cleaning up.[14] The lead will be in the ice for a long time if v don't melt it out, and our lead will persist in the muds of lakes and the sea floor even if we do melt th ice.

With the amount of stuff we use, and the amount of the world we occupy, we are no longe passengers napping in the back seat of the car. We are everywhere, and changing everything. Henc many environmental scientists are now involved in figuring out what we are doing, how to operate remarkably complex and involved Earth system, and how to make the ride as enjoyable as possibl This ~~operators' manual is not finished yet—not even close—although we know an amazing amou~~ more than we did even a few years ago, with knowledge coming in rapidly. I am proud to have playe a small part in this effort. But I'm also concerned that a lot of people, including some of those who a making laws, still think that they are sitting in the back of the car, looking out the window ar enjoying the ride.

I can't possibly cover all of what we know about how the Earth system operates in this one boo Instead, I will focus on a few big ideas: 1) we humans have always used energy and always will, 2) th road we're on now will get us into trouble, and 3) there are plenty of ways to get rich and save th world by remaking our energy system. Along the way, we'll look in on some amazing moments i Earth's history, visit a few of our ancestors, and check in on some fortunes in the making.

Burning to Learn

Synopsis. Humans burn things, and burning was probably required to make us human. Despite many problems, burning has helped us, and the more we have burned, the better off we have been in the past.

The mind is not a vessel to be filled but a fire to be kindled. —Plutarch[1]

BRAIN POWER

Have you figured out how to get someone or something else to do most of your work for you?

If you answered yes, congratulations! You’re human!

Many things set us apart from most of the other creatures on our planet. Text-messaging ar tool-making are a lot easier with an opposable thumb. Baldness is not just about looking distinguishe (said the rapidly balding man . . .)—lack of hair over large expanses of our bodies lets us ru marathons without overheating, a useful ability for a hunter-gatherer chasing a meal or trying not become dinner for a pursuing jungle cat. Upright posture lets us wear ties to business meetings, b also lets us see what we’re chasing or what is chasing us, and lets us throw rocks or swing clubs predators or carry our tools and tots to the next meal. Our big brains allow us to develop language ar agriculture better than any other creatures on the planet.

But how do we afford those big brains? When we are resting, 25 percent of our energy use go to the brain, compared to just 8 percent averaged across the apes.[2] A resting newborn baby’s brai accounts for a whopping 60 percent of energy use. Our brains, like older desktop computers, use a l of energy even when idling.

How did our ancestors find the energy for their on-board computer power? One way is tha evolutionarily, they skimped on stomachs.

Hay for dinner, anyone? A cow can do it, but it takes four stomachs and a lot of chewing the cu in the evening. Much of the energy the cow gets from the grass goes to keeping those stomachs aliv and working, and keeping the cow alive and chewing to aid in the digestion.

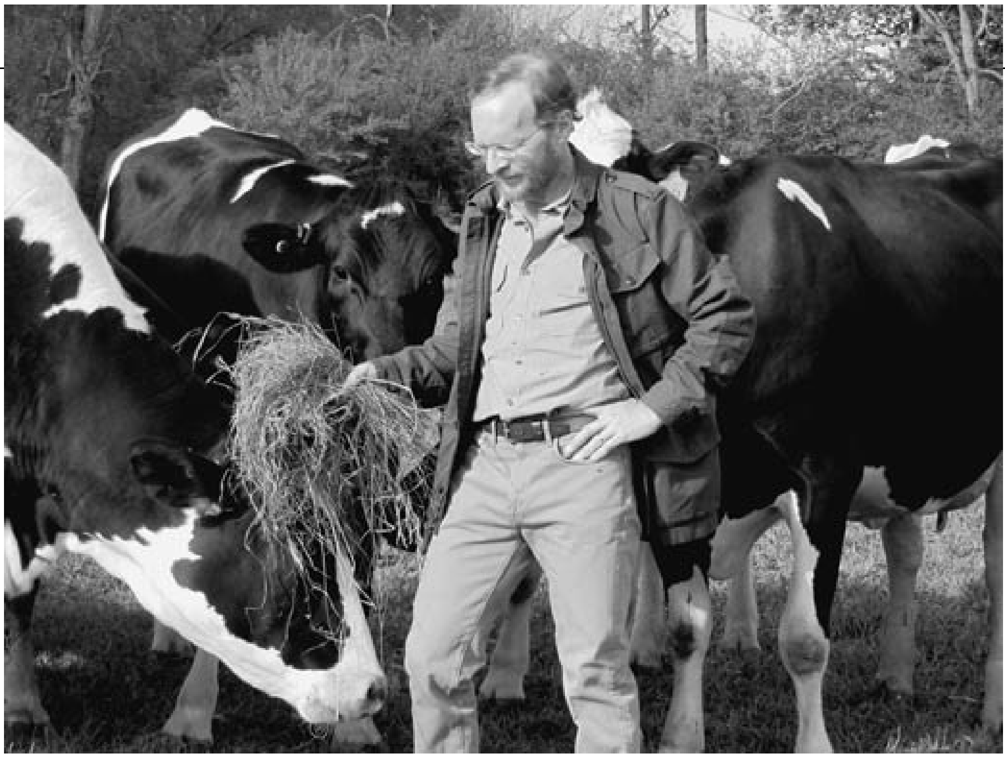

Figure 2.1 Cows can be curious creatures, as demonstrated by these Penn State Holsteins investigating the filming of Earth—The Operators' Manual. But cows are not the brightest lights in the intellectual firmament, with more stomach than brains, at least in part because of the difficulty of digesting their diet.

Our closer relatives, such as chimpanzees, eat a variety of things, and have relatively longer gu than we do. A chimp can successfully digest foods such as leaves that would pass almost unaltere through me. But some of the energy the chimp gets from digesting that food is used to keep th chimp's gut alive to do the digesting, leaving less to power the chimp's brain or other parts of th body. Adding a longer gut would allow more digestion, but with diminishing returns as that longer g used more energy itself.

Therefore, someone with a shorter gut, with fewer gut cells to keep alive, can divert the energ those cells would have used to power their brain. But a gut that is too short would allow undigeste food to be dumped out the rear end, wasting energy, so a shorter gut saves energy only if it is supplie with a more-digestible dinner.

Meat-eating is one solution. Let some other creature do the hard work of collecting and chewi and digesting vegetables and reassembling their parts into something more useful to an animal, a then eat that other creature. Our ancestors were clearly using tools and eating meat more than million years ago, and their brain sizes increased between about 1.9 and 1.6 million years ago, wh there is increasing evidence of increasing meat-eating.[3]

A fascinating new hypothesis links our very humanity to another way of improving digestibilit cooking. If our ancestors used fire to start digesting food outside their bodies, a shorter gut insi could finish up the job, allowing them to be well fed and smart at the same time.[4]

We know surprisingly little about the advantages of cooking, considering how much cooking w do, but recent research points to an important role for cooking in improving digestibility as well as killing diseases.[5] In one experiment, mice that were fed cooked meat gained almost one-third mo weight than those eating raw meat. In another study, switching pythons from a raw-hamburger diet a cooked-hamburger diet reduced the energy they used to digest their dinners by almost one-fourt Furthermore, people eating primarily raw foods tend to lose weight. Some paleoanthropologists ha speculated that cooking was a prerequisite for our spurt of brain growth beginning 1.9 million yea ago, ~~although evidence of organized, consistent fire use at that time remains sparse at best; perhap~~ more likely, fire contributed to the next big spurt of brain growth, within the last half-million year leading to the large size of our brains today.

Figure 2.2 Native American fire circle, Wind River Mountains, Wyoming. A skilled cook could use this to prepare food efficiently, conserving firewood, but the energy used in cooking was similar to the energy available to people in the cooked food.

Cooking thus looks like a great deal for people. Burn some trees, use the heat released to mal the food more digestible, and we get lots of energy from the food with a small investment supporting our guts. The extra energy powers our minds, and we’re human.

But what does this mean for the trees? Perhaps 10 percent or less of the heat from an ope cooking fire actually warms the food.[6] When I was on a field expedition to study the ice-age deposi of glaciers of the Wind River Range in Wyoming, the archaeologist Dave Putnam showed us nea small, efficient stone circles that native Americans had used, probably about 10,000 years ag Carefully tended, fires in such fire rings might have achieved 20 percent efficiency or more, muc closer to the efficiency of a modern stove. If you cooked grain on such an efficient fire ring, th energy you obtained from eating dinner might be slightly more than the energy used in cookin dinner.[7] For a sloppy fire, you might use twice as much energy in cooking as you obtain from eatin the cooked food. (Don’t even think about how inefficient cooking a marshmallow over a campgrou fire is.) And most of the energy from our food goes to the body, with only a little bit of the extr energy making our big brains possible. So, a lot of trees had to give their lives, and a lot of termit were deprived of their dead-wood dinner, to make us smart.

Some of the science discussed here is new, and research is ongoing. But it appears that bein human means relying on energy from outside—we learn because we burn. And our reliance on th energy of others, and the difficulty of supplying that energy from our traditional sources for billio of people, are daunting indeed.

WHAT IS ENERGY, ANYWAY?

We can usefully divide the universe into two categories: stuff, and the ability to make the stuff d something. You might call these “matter” and “energy.” Albert Einstein is famous in part because h showed that matter, or mass, and energy are really the same thing—wind up an old-style alarm cloc and you have made the spring a tiny, tiny, tiny bit more massive, and the extra mass will be turned i energy to move the clock’s hands and make the ticktocks over the next day.[8] Blow up an atomic bom and although you would have difficulty measuring the amount of mass lost, you will easily see th energetic effects of that loss. For most ordinary purposes, though, it is sufficient to treat mass an energy separately.

If you put the right chemicals together in the right pattern, you can make a diamond that loo pretty and scratches things really well, or a hammer that can break things. Use the hammer to brea the diamond into tiny bits, toss the dust out the window, and the diamond is no longer useful to yo The stuff is still there—mass is conserved, as the physicists say—but you have to gather the mass the right way to make it valuable.

Energy is much the same. If you store a lot of energy where you want it, you can use it to mak the stuff do what you want. Put a lot of heat energy in a small place, and you can cook a turkey. Or yo can let the heat drive the expansion of gases to drive a piston to drive a car to drive you across th country to visit grandma for a turkey dinner. When you are done, the energy is not gone, but it spread out—you heated the room while cooking the turkey, and then the heat from the warmer roo spread out into the outdoors and eventually was radiated to space. Once the heat energy is too sprea out, you can’t use it. Just like the dust from your broken diamond, the energy exists but it isn valuable any more.

MEASURING THE BURN

Comparing the energy used in a cooking fire to the energy contained in the cooked foods is easier we can put numbers on the energy amounts. But how do we measure energy? One way is to use o dining habits.

The U.S. Food and Drug Administration (FDA) suggests appropriate foods and nutrients that w should eat. These FDA recommendations are often given assuming a diet of 2000 calories per da “Calorie” is a measure of the energy available, and “calories per day” is the rate at which you use th stored energy, converting it to spread-out heat. How rapidly you use stored energy is also calle “power”—your personal power output is 2000 calories per day.[9]

Most other branches of modern science, and nonscientists in most other countries, don’t measu energy storage in calories, but in joules (named after an English physicist who started out as a brewe and who experimented with electricity in part by shocking his brother and letting his brother shoc him.)[10] The scientists who use joules for energy storage also use watts for power (abbreviated W, an named after James Watt, a Scottish inventor of steam-engine fame, who according to his epitap “enlarged the resources of his Country, increased the power of Man, and rose to an eminent plac among the most illustrious followers of science and the real benefactors of the World”).[11]

If you follow the FDA guidelines and burn 2000 calories per day inside of you, your person power output averages 100 W. Not that long ago, when almost all of us lit our houses with heat-unti they-glow incandescent lightbulbs, everyone understood what watts are—a big turned-on lightbu was using 100 W. (With modern compact fluorescents, 100 W is four or five bright lightbulbs.)[12] you ever touched a 100 W incandescent lightbulb that had been on for a while, you know that it w hot! So you shouldn't be surprised that you and the lightbulb are using energy at about the same rat You may use 150 or even 200 W during part of the day, then idle down while sleeping, but you average will be in the neighborhood of 100 W. A Tour de France bicycle racer may eat 10,000 calorie per day, to average a power output of 500 W. A whole lot of that energy goes into waste heat, but a the very highest level for a human, an elite bicycle racer may put close to 500 W into moving th bicycle up a mountain stage. The rest of us can only dream about that, so when we consider amoun of energy, just remember that the energy each of us generates is 100 W.[13]

Recently, total energy usage in the United States has been running notably higher than th personal burning inside of us. In fact, the total energy use in the United States in a day, divided by th number of people, gives approximately 240,000 calories per person per day, or somewhat more tha 10,000 W for each person.[14] This is the equivalent of each of us having more than 100 people doin our bidding—100 energy "servants" apiece. We are really better off than that, though. If each of u actually had 100 people to do our bidding, we wouldn't get this much work out of them, because mo of their time and most of their energy would be used to keep themselves fed and clothed and toilete and otherwise alive.

Some people become discouraged when they think about the huge energy and environment challenges facing us. Giving up is wrong, though. If you start to get discouraged, just remember thi Abraham Lincoln ran his mind and body on the same amount of energy as a single heat-until-it-glow lightbulb. You, and Einstein, and Beethoven, and Michelangelo, taken together, use or used les energy than a single chandelier. The careful mathematics of science yield the same answer that w teachers learn from our students—we have more than enough brainpower to figure out how to pow our brains!

BURNING TO EARN

Richer countries, and richer people, use more energy.[15] And using the energy helps the people. (I wi come back to the problems from the energy use later, and there really are problems, but the good fro energy use still outweighs the bad.)

Across the countries of the world, those that use more energy per person generate mo economic activity per person. There are notable variations, with countries such as Russia, Sau Arabia, and Canada using more energy to make a dollar (or a euro or a ruble) of economic activi than countries such as Japan, Italy, and the United Kingdom. These differences matter, but they a not huge, with the less efficient countries usually using no more than about twice as much energy p dollar as the more efficient countries. We all know that the correlation between energy use an economic activity does not necessarily tell us that using energy helps the economy. The wor economy has grown over the same time that my hair has fallen out, but the extra sunscreen I buy cover my expanding forehead during soccer games is not economically significant globally, so m spreading baldness is not responsible for the rising wealth of nations. But overall, we know that th wealthy use more energy, and serious thinkers typically find that the good things obtained from th energy help create the wealth.

Suppose that I keel over from a heart attack while sitting at my computer. My neighbor will us a phone powered by electricity to call a hospital, which will dispatch an ambulance powered b gasoline. A machine powered by electricity might keep me breathing and keep my heart beating unt a doctor can fix the problem. The knowledge and dedication of my neighbors are essential to save m life, but so are the machines and the energy they use. My recovery would be aided by the plentif food in the climate-controlled hospital, with the air-conditioning or heating, the food refrigeration ar cooking and trucking, the plowing and planting and fertilizing, all relying on energy sources that g far beyond the 2000 calories per day that I actually eat.

In an economic sense, the wealthy are not using more energy because they are wasteful.[16] general, the wealthier you are, the more dollars of economic activity you get from a given amount energy. As an example, in the United States from 1973 to 2008, economic activity (the gross domest product, with the effects of inflation removed) more than doubled, while energy use increased by on one-third. Thus, the people of the United States in 1973 used slightly more than twice as much energ to earn a dollar as the people in 2008. The effects of inflation have been removed, so energy efficienc really went up. But energy use still rose, because the economy grew even faster than energy efficienc grew.

There are lots of ways to “spin” these sorts of data in public discourse, and you should have r difficulty finding people spinning this discussion many different ways. Because the wealthy genera more dollars of economic activity per barrel of oil, you could argue that the wealthy are more efficie than the poor. Because the wealthy use much more energy, and much more stuff per person than th poor, you could argue that the wealthy are much less efficient. Both are correct in some sense. Th best interpretation of the data probably is: 1) energy use helps increase wealth, which increases energ use; 2) the wealthy energy users find ways to improve efficiency; but 3) the effects of item 2 are n large enough to offset the effects of item 1.

I will come back to facts and figures later. But first, to explore the role of energy in our lives, th ways we have gotten it, the costs and benefits, let’s first look at some of the history of our energy us I will tell you a few stories that interest me, without in any way subjecting you to a comprehensiv treatise.

3

Peak Trees and Peak Whale Oil

Synopsis. Our ancestors moved to new energy sources in part because the old sources were running out. Much of the natural world we enjoy now owes its survival to our use of fossil fuels instead. We cannot go back to our old ways as the fossil fuels are exhausted.

A king's head is solemnly oiled at his coronation, even as a head of salad. . . . Think of that, ye loyal Britons! We whalemen supply your kings and queens with coronation stuff! —Herman Melville[1]

The Sinking Rock

One of the many attractions of the Cape Cod National Seashore, in Eastham, Massachusetts, near th old Coast Guard station, is a giant boulder that was delivered long ago by ice-age glaciers (see chapt 11). Climbing to the top of Doane Rock is a rite of passage for youngsters—if you can scramble all th way up and back down safely by yourself, you're a big person. My wife's family has been visiting th region for over a century, and those good people have been kind enough to include me over the la few decades. My father-in-law, Niel Richardson, likes to joke that Doane Rock has been sinkin When he was a lad during the 1930s, he would sit atop the rock and watch the waves breaking on th beach, half a mile away. Now, the pitch pine and scrub oak are much taller than the rock, and a ki perched on top can barely see Doane Road, 100 feet (30 m) away.

Of course, Niel knows that sinking has nothing to do with it—instead, the trees grew. The Ca Cod that the Pilgrims found in November of 1620 was "so goodly a Land, and wooded to the brinke the sea."[2] The Pilgrims, and those who followed them, then set about deforesting the Cape. Buildi ships and homes consumed many of the best trees. The 1700s-era Doane House, where we sometim stay, has irregular-width oak boards in the floor, including some of such remarkable size that nothi similar could be made from Cape trees today.

Figure 3.1 Doane Rock, Cape Cod National Seashore, was deposited by a glacier during the ice age and is the largest such "erratic" boulder on the Cape.

Early New Englanders didn't need ocean-going boats for whaling; they could launch small boa from the shore, especially to hunt right whales (possibly so-named because they are the "right whale to hunt, since they swim close to shore where they can be killed, and they float after being killed Shore whaling may have begun as early as the 1620s off Cape Cod, and was economically importa during the latter 1600s and into the 1700s. Boiling the blubber in the "try works" to extract t valuable oil was started by burning wood for heat, although the cooked-out whale pieces could later added to fuel the fire, giving a reportedly strong and very unpleasant odor.

Figure 3.2 The view from Doane Rock. In the early twentieth century, this photo would have showed a treeless plain sloping

down to the ocean half a mile away.

The howling winter winds on Cape Cod can be bone-cutting cold, so the fireplace in the Doan House, and similar fireplaces in houses up and down the Cape, provided a welcome relief for th people. But the fireplace burned wood—perhaps an acre of trees (0.4 hectare) per year for a house[3]— which came from the rapidly dwindling forest. In 1690, the town of Eastham, home of Doane Roc enacted a rule to prevent logging on the common lands except for export to make money. This wa extended to all lands in 1694, and even export logging was banned in 1695, but the trees seem to hav been gone by 1700.[4] The Cape was almost completely deforested, and then kept bare into the ear 1900s, when fossil-fuel burning became important and the demand for trees dropped. My father-i law grew up with the returning forest of the Cape, a forest that really owes its existence to fossil fuel

Very simply, the land of the Cape was capable of growing lots of trees that were big enough t use for construction as well as fuel, but the human demand between the 1600s and about 1900 f outstripped the ability of the land to grow those trees; rising use of fossil fuels eventually reduced th demand for Cape Cod trees so greatly that they are now growing back, blocking Niel's view of th ocean from the great rock but providing a beautiful cover to the Cape, which is allowing wildlife return and eroded soils to re-form. Before the Civil War, scarcely more than 30,000 people kept th Cape nearly treeless; 150 years later, 200,000 more people live on a tree-covered Cape.[6] Th difference? Fossil fuels.

THE GREAT PENNSYLVANIA DESERT

I live in Pennsylvania—Penn's Woods. I am fortunate to teach at a great university, Penn State. Afte class, our students walk off campus into a town that is younger than the university. The university wa founded in 1855 far from any city, up the hill from an iron furnace. That furnace still guards the ma road out of town. Of the thousands of people who pass each day, I suspect few even notice the furnac and fewer realize that they are there because of the furnace.

Much of the infrastructure of the U.S. East Coast in the early 1800s was built of Juniata iro which was mined, smelted, and forged in and near the valley of the Juniata River in centr Pennsylvania. Beginning in the late 1700s, entrepreneurs converted the rusty soils of the region in pig iron, which was then forged into other useful items. Place names such as Pennsylvania Furnac Lucy Furnace, Harmony Forge, and the older and more easterly Valley Forge of Revolutionary Wa fame testify to the influence of the iron industry. Iron-making grew in central Pennsylvania becaus the region offered the iron-rich deposits, limestone, water power, and timber needed for iro manufacture in those days.

Later, use of coal allowed the iron industry to focus in a few places such as Pittsburgh, but th iron-making of the Juniata Valley was done in widely scattered furnaces fueled by charcoal. Th making of the charcoal is a fascinating chapter in history, oddly romantic now but decidedly n romantic to the people who did it.

A single iron furnace needed about six hundred bushels of charcoal per day to operate.[7] As man as one hundred men and boys worked, mainly in the autumn and winter, to cut the wood for th charcoal. Wood was cut into four-foot lengths, and anything thicker than about six inches had to b split to make the conversion to charcoal work better. The four-foot-long logs (just over one mete were stacked four feet high in eight-foot-long cords; a good cutter could supply three of these cords a single day.

[Figure 3.3](#) Preparing for charcoaling, June 1942, Wayne National Forest, Ohio. C. A. Masie (left) and David Daniels putting wet leaves and then dirt over the wood to restrict oxygen so that burning will produce charcoal. An immense amount of wood was used to make charcoal.

After a winter of cutting, the colliers took over, doing the "coaling" to make charcoal during dr times in spring and summer. An experienced collier and assistants would set up a camp on a flat, dr spot near the cut wood, and live there for several weeks while tending the coals. Thirty or more cor of wood would be stacked carefully in a "pile" fifteen feet high and twice that wide. This pile was th covered with dirt and sod, but leaving strategically placed holes and a central vent. Then the pile w burned beneath the dirt for up to two weeks. The dirt cover slowed the supply of oxygen, while t holes let in just enough air so that the fire smoldered rather than going out. Such a smoldering fi heated the wood sufficiently to drive off or burn up its water, oxygen, and other volatile materials. T pile shrank as it lost these materials, so workers were forced to walk around on top and pack the so cover back down, lest the holes get big enough to let in enough oxygen to burn up the valuab charcoal. These workers surely walked carefully, knowing they were one misstep from plunging in the glowing hot pit. Eventually, after enough of the original wood was lost, the holes in the soil cov were blocked completely, the fire slowly went out, and the charcoal—now almost all carbon—w separated, cooled, and hauled by mule cart to the furnace.

A lot of other activities were going on around the furnace as well, including mining the iron o and the limestone, "flatting" the charcoal so that there were no big chunks to clog the furnac charging the furnace, blasting air in to raise the temperature high enough to melt out the iron a allow the impurities to combine with the limestone flux, and eventually producing the valuable "pig of iron and a vaguely attractive blue or green glass slag. Anyone walking near one of the old furnac today, or kayaking a river downstream of a furnace, is still likely to find pieces of the slag. If you're history buff, this is a fascinating corner of our heritage.