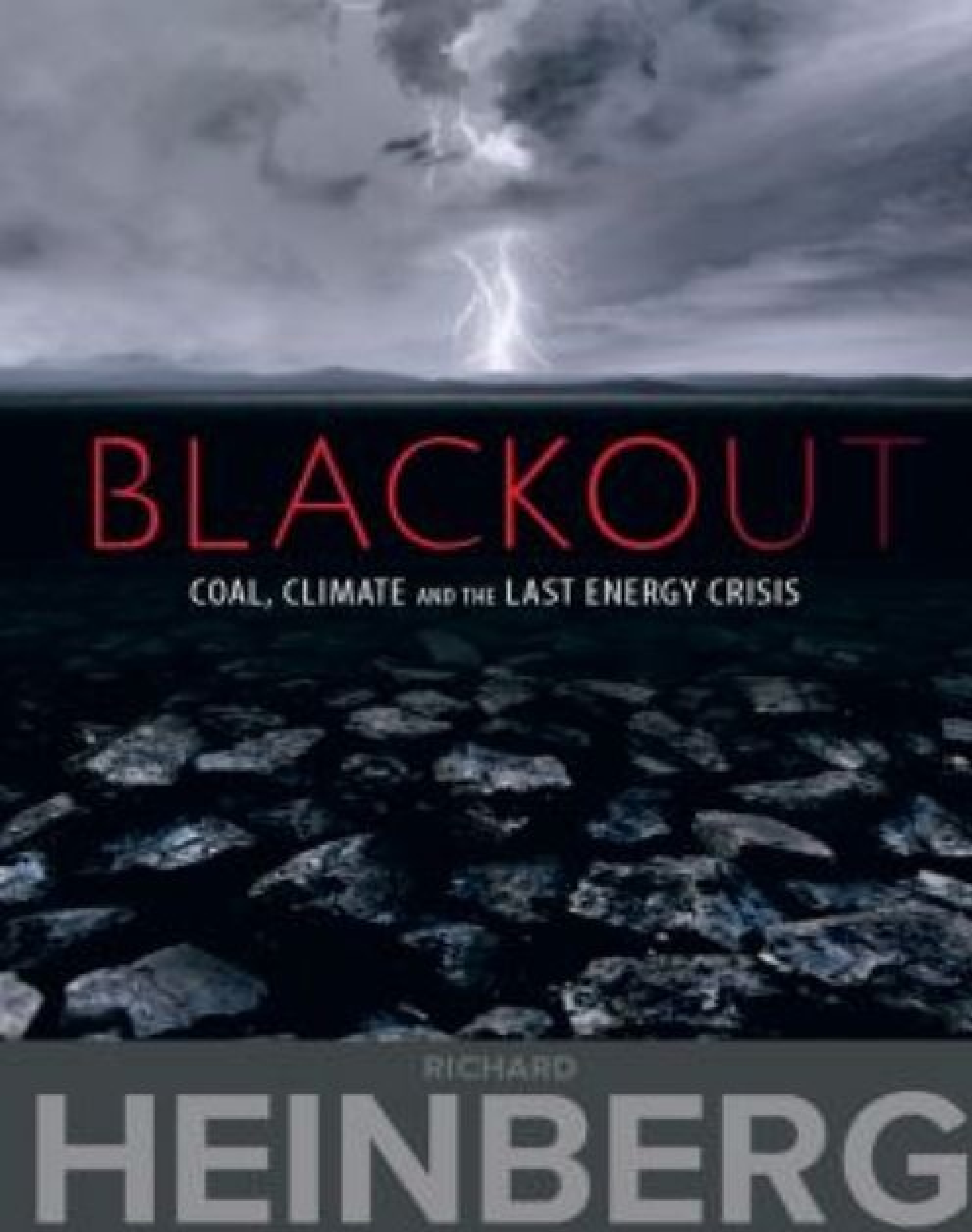
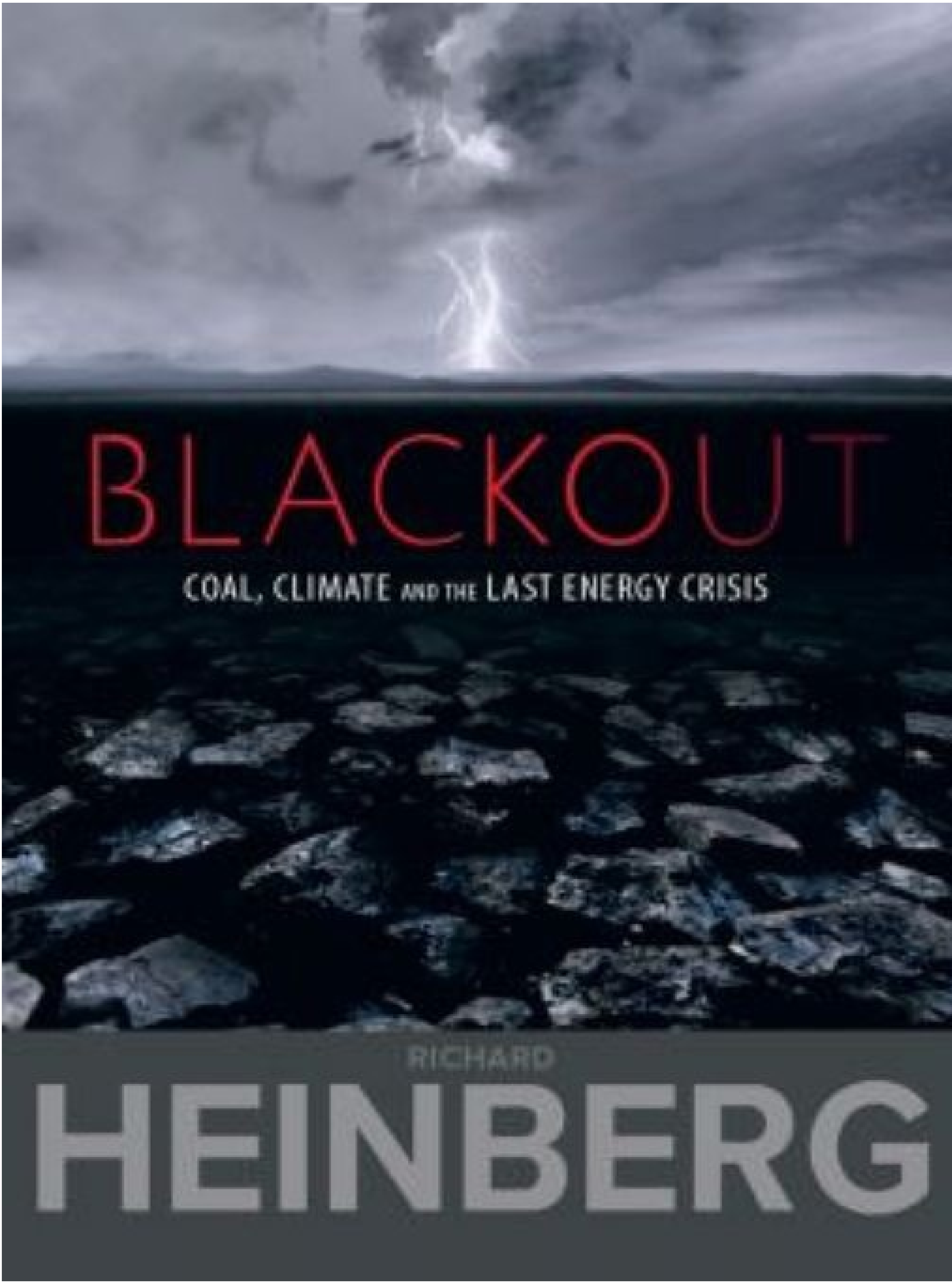

BLACKOUT
COAL, CLIMATE AND THE LAST ENERGY CRISIS
RICHARD
HEINBERG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BLACKOUT

In *Blackout*, Richard Heinberg has made a major contribution to the coal debate. What is new is his focus on the question of how much minable coal there is. Governments have consistently over-estimated it, but the answer is critical for climate policy and for planning for alternative sources of electricity.

— David Rutledge, Tomiyasu Professor of Electrical Engineering Former Chair, Division of Engineering and Applied Science California Institute of Technology

Coal lies at the very center of our predicament as a civilization — it's the habit we must kick, and fast, as Richard Heinberg makes abundantly clear in this powerful volume. It's your program for understanding the drama now unfolding on the global stage.

— Bill McKibben, author Deep Economy

Blackout provides a startling wake-up call for energy optimists who believe our economic future is guaranteed by centuries worth of available coal — as well as for environmentalists who see "peak coal" as a salvation from climate hell. This clearly written and meticulously documented book provides a powerful case for a rapid global program to rewire the world with clean energy. Any other option puts the survival of our coherent civilization at risk.

— Ross Gelbspan, author, The Heat Is On and Boiling Point

Blackout reviews the most recent analyses of global coal reserves and concludes that peak coal production is likely much nearer than is commonly assumed. In the context of global warming, peak oil, and declining net energy, Heinberg argues cogently that the most rational strategy is to reduce consumption and to rethink our growth imperative.

— David Fridley, Scientist at Lawrence Berkeley National Labs

A great deal of the human future depends on how clearly and carefully we think about coal . . . Richard Heinberg is an insightful and reliable a guide to the subject and his conclusions are spot on. Should be required reading for those making energy policy everywhere.

— David Orr, Paul Sears Distinguished Professor of Environmental Studies and Senior Adviser to the President, Oberlin College; author, Down to the Wire: Confronting Climate Collapse and Earth in Mind; trustee of the Rocky Mountain Institute and the Bioneers.

BLACKOUT

COAL, CLIMATE AND THE LAST ENERGY CRISIS

RICHARD HEINBERG

NEW SOCIETY PUBLISHERS

Acknowledgments

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Introduction

A SOIL PRICES CLIMBED DURING 2007 AND 2008, another and perhaps more serious energ crisis loomed — one largely unnoticed by most Americans and Europeans.

A hundred or more countries are suffering, some acutely, from shortages of electricity; and in mar instances, these blackouts are due to the lack of what is supposed to be the world's most abundant fu — coal.

China has idled 50 of its coal-fired power plants for lack of fuel, and growing power outag threaten to undermine that nation's economy.

India's hydropower from the Himalayas is drying up due to global warming, and, though th country is pushing for more wind and solar power, its rapidly rising demand for coal is exacerbatin both climate change and international coal shortages.

Pakistan and Afghanistan, battlefronts in America's war on terrorism, are routinely plunged int darkness.

South Africa's mining industry is plagued by a lack of reliable electric power to run its coal, gol and diamond mining industries. In the rest of sub-Saharan Africa, nearly two-thirds of countri experience frequent and extended electricity outages,[1] and many are looking for coal to suppleme inadequate hydropower resources.

Great Britain experiences power shortfalls with ever-greater frequency, with analysts describing th nation's electricity-generating infrastructure as "crumbling" and "inadequate" for 21st-century us the industry estimates that it will need to spend £100 billion building a new generation of pow stations — more than has ever been spent before on any similar project in the country's history.[2] Th British coal industry, once the world's largest and the main supplier of power to the national grid, now virtually gone, largely due to the depletion of the country's once-vast coal reserves.

Some nations that can afford high oil prices don't have sufficient electricity to run refineries. Ar even energy-rich countries like Venezuela and Iran are not immune, suffering from electric blackouts even as they export oil.

In the United States, energy experts forecast more frequent grid outages in years ahead due to lac of generation capacity and an aging grid infrastructure in need of thorough overhaul. America's co appears abundant — indeed, the domestic industry has begun exporting more coal recently due to hig international demand and soaring prices — but the quality of the coal that is being produced from U mines is declining, so America gets less energy from the resource even though more is being dug fro the Earth.

The world depends on coal for 40 percent of its electrical generation capacity (a greater share tha comes from any other single source), and coal has seemed endless in supply; yet the average price coal doubled during the two years from mid-2006 to mid-2008, and its availability in even the ne future is questionable in some countries that use large amounts.

Part of the coal supply problem arose from added transport costs and reduced reliability resultin ~~from tight oil supplies. But depletion of the world's highest-quality coal reserves also added~~ to th delays, the soaring electricity prices, and the power outages.

These problems are already of crisis proportions in many nations, though for most Western energ consumers they constitute merely an occasional annoyance or a vague worry. But if current trend continue, the likely consequences are difficult to overstate. Unless the world adopts a very differe energy paradigm — and soon — problems with coal and electricity supplies can only spread an worsen year by year until, some time in the next two to three decades, human civilization approaches universal, final Blackout.

Why Care About Coal?

1. The Economy

If coal were of declining importance in the world's energy mix, the problems of depletion an declining availability would not be serious. Instead, however, coal is at the center of energy plannin for many nations — especially the burgeoning Asian economies. Despite environmental concern coal is seeing the fastest percentage growth in usage worldwide of any of the principal fossil fuels, an the fastest growth, in terms of BTUs delivered, of any energy source.

This resurgence was mostly unanticipated.

Coal was the first fuel of the industrial age; it was the world's primary source of energy from th end of the 19th century (when it supplanted wood) until the middle of the 20th (when it was overtake by oil). More recently, natural gas has substituted for coal to some extent in electricity generatio partly because of growing concerns about greenhouse gas emissions (coal is the most carbon-intensiv common fuel, natural gas the least); meanwhile oil has become the globe's most important fu largely because of its role in transport.

The historic pattern was thus for industrial societies to move from low-quality fuels (wood contai an average of 12 megajoules per kilogram [Mj/kg], and coal 14 to 32.5 Mj/kg) to higher-quality fue (an average of 41.9 Mj/kg for oil and 53.6 for natural gas); from more-polluting to less-pollutin fuels; and from solid fuels to a liquid fuel easily transported and therefore well suited to a system global trade in energy resources.

During the 20th century, fuel switching yielded decisive economic and even geopolitical advantage In 1912, Winston Churchill, as Lord of the Admiralty, famously retooled Britain's navy to burn o rather than coal, thus helping ensure victory over Germany in World War I. [3] Throughout the secon half of the century, the US economy became less energy intensive (measured as the amount of energ required to produce each dollar of GDP) largely by switching away from coal toward oil and gas. diesel locomotive uses only one-fifth the energy that a coal-powered steam engine would consum pulling the same train; in addition, oil-burning systems generally need less attention and burn clean than coal-burning systems. As a result, oil and gas generate from 1.3 to 2.45 times more econom value per unit of energy than coal does.[4]

As nations learned to take advantage of physical and functional differences in fuels, and strained get more economic bang for their energy buck, coal was nearly always in the position of being t older, less-efficient, less-desirable source.

In short, the widespread assumption only a decade ago was that coal's moment in the energ spotlight had ended. While remaining an important fuel for electricity production, coal was in man people's minds an artifact of the 19th and early 20th centuries — the era of steam-powered loom majestic ocean liners, and smoke-spewing locomotives. Futurists in the 1980s and '90s assured that, with the dawn of the information age, energy would soon become "de-carbonized" as natio shifted to cleaner energy sources and more concentrated fuels.

However, during the past five years, global production of crude oil has remained static, despi demand growth — especially from Asian economies. And there is every indication that worldwi petroleum production will begin its inexorable, inevitable decline beginning around 2010. This is t often-discussed phenomenon of Peak Oil (explained, for example, in my book, *The Oil Depleti Protocol* [5]). In the quarter century from 1980 to 2005, world oil use grew at an average rate of rough 1.5 percent annually. During most of this period, prices were low — usually in the range of US$10 $20. However, in the three years following May 2005, the rate of extraction of conventional crude c stalled, while prices rose to an astonishing $147 before falling back substantially due to the impact the economic crisis that began in 2008. Many analysts believe that by 2015 oil production will *declining* at an annual rate of over two percent per year and prices may be in the multiple hundreds dollars per barrel. While more exploration prospects for conventional oil exist, they are mostly geographically remote or politically sensitive areas; meanwhile, shortages of drilling rigs and traine personnel are adding significantly to delays in bringing new projects on line. Enormous quantities non-conventional fossil fuels exist that could be turned into synthetic liquid fuels (the bitum deposits of Alberta, the heavy oil of the Orinoco basin in Venezuela, and the marlstone or "shale oi of Wyoming and Colorado); however, the rate at which these substances can be extracted an processed is constrained by physical and economic factors — such as the need for enormous quantiti of fresh water and natural gas for processing.

World production of natural gas will likely peak somewhat later than that of oil; however, region conventional natural gas supply constraints are already appearing, primarily in North America (t most intensive consumer of the resource), as well as in Russia and Europe. Because only a sma proportion is traded globally in the form of liquefied natural gas (LNG), this means it may not possible to avert regional shortages by resorting to seaborne imports.

In the face of these constraints for oil, gas, and unconventional fossil fuels, coal by comparis appears suddenly attractive again. The industrial world has abundant experience with it, t technology for producing and using it is well developed, and there is purportedly an enormous amou of it waiting to be mined and burned. New technologies, such as integrated gasification combin cycle (IGCC) power plants and methods to capture and store carbon, promise to make coal clean (though not cheaper) to use. In addition, there is increasing interest in deploying methods to turn co into a synthetic liquid fuel able to substitute for oil (we will explore each of these technologies more detail in Chapter 7).

Since economic growth generally implies more energy consumption, it should come as no surpri that nearly all of the current world expansion in coal consumption has occurred in the nations with th highest rates of economic growth — principally, China and India, but also Vietnam, South Korea, an Japan.

The shift in the world's economic center of gravity away from the United States and toward th great population centers of East and South Asia is being widely heralded as the primary econom trend of the new millennium. In recent years, China's economy has grown at an annual rate of 7 t 11.5 percent (a 7 percent constant growth rate implies a doubling of size every ten years: thus after 2 years the entire economy is four times its previous size, and after a mere 30 years it is eight times i original magnitude; at 11.5 percent annual growth, this eight-fold expansion comes in just 20 years According to most expectations, China's GDP will exceed US$10 trillion by the end of the curren decade, and will surpass US$20 trillion by 2020, making China's national economy then the world largest. India's economic growth rate was 8.4 percent in 2006 and 9.2 percent in 2007. Currently, Ind is the world's fourth largest national economy, but at recent rates of growth it could advance to thi place within a decade (current rankings according to the CIA *World Factbook* [6]).

China currently obtains nearly 70 percent of its energy from coal and is the world's primary co consumer, using nearly twice as much as the next country in line (the United States). The quantiti are staggering: in 2007 alone, China added electrical generating capacity — nearly all of it coal-bas — equal to the whole of France's or Britain's entire electricity grid. During 2007, China's installe electricity generating capacity grew 17 percent, reaching over 700 gigawatts, second only to th United States' 900+ gigawatts.

India is now the world's third-largest consumer of coal, which provides nearly two-thirds of th nation's commercial energy (compared to the world average of 26 percent).

It is entirely foreseeable that this enormous, rapid growth in coal consumption should entail a equally enormous environmental cost.

Why Care About Coal?

2. The Environment

If there were sound economic reasons for industrial societies to switch from coal to oil and gas durin the 20th century, there were equally compelling environmental reasons.

Coal is the dirtiest of the conventional fossil fuels. Sulfur, mercury, and radioactive elements a released into the air when coal is burned and are difficult to capture at source. During the early pha of the Industrial Revolution, both the mining and the burning of coal generated legendary amounts pollution. In cities like London, Chicago, and Pittsburgh, smoke and airborne soot reduced visibility mere inches on some days. The following passage from *The Smoke of Great Cities* by David Stradli and Peter Thorsheim conveys the experience of the inhabitants of these coal towns:

> One visitor to Pittsburgh during a temperature inversion in 1868 described the city as "he with the lid taken off," as he peered through a heavy, shifting blanket of smoke that h

> everything but the bare flames of the coke furnaces that surrounded the town. During autum ~~and winter this smoke often mixed with fog to form an oily vapor, first called smog~~ in th frequently afflicted London. In addition to darkening city skies, smoky chimneys deposited fine layer of soot and sulfuric acid on every surface. “After a few days of dense fogs,” on Londoner observed in 1894, “the leaves and blossoms of some plants fall off, the blossoms others are crimped, [and] others turn black.” In addition to harming flowers, trees, and foo crops, air pollution disfigured and eroded stone and iron monuments, buildings and bridges. C greatest concern to many contemporaries, however, was the effect that smoke had on huma health. Respiratory diseases, especially tuberculosis, bronchitis, pneumonia, and asthma, we serious public health problems in late-nineteenth-century Britain and the United States.[7]

The mining of coal was, in its early days, no less grim. Digging coal out of the ground is a inherently dangerous and environmentally ruinous activity, and accidents (from asphyxiation b accumulated gas, as well as from explosions, fires, and roof collapses) were so common as to be a expected part of life in mining towns. Miners and their families often suffered from respirato ailments — including pneumoconiosis, or black lung disease. Mining altered landscapes, ofte resulting in polluted water and air, as well as the destruction of forests, streams, and farmland.

From the standpoint of safety, coal mining has cleaned up its act, at least in the more industrialize countries. The large-scale mechanization of mining means that today fewer miners are required produce an equivalent amount of coal; meanwhile, improvements in mining methods (e.g., longwa mining), as well as hazardous gas monitoring (using electronic sensors), gas drainage, and ventilatio have reduced the risks of rock falls, explosions, and unhealthy air quality. Even with thes improvements, mining accidents still claimed 46 fatalities in the United States in 2006; according the Bureau of Labor Statistics, mining remains America’s second most dangerous occupation (loggin is the first).[8]

However, despite technical advances, coal mining continues to destroy landscapes, as is infamous the case with the method used in the Appalachian region of the United States called “mountainto removal.” This practice, which involves clear-cutting native hardwood forests, using dynamite to bla away as much as 1,000 feet of mountaintop, and then dumping the waste into nearby valleys, ofte burying streams, has been called “one of the greatest environmental and human rights catastrophes American history.”[9] Families and communities near mining sites must contend with continu blasting from mining operations and suffer from airborne dust and debris. Floods have left hundre dead and thousands homeless, and drinking water in many areas has been contaminated.

While the environmental and safety risks of both coal mining and coal consumption have bee somewhat moderated in countries that industrialized early, in the nations where coal use is today th highest and is growing fastest, methods of mining and consumption often resemble the worst practic of the early 20th century.

Thousands of China’s five million coal miners die from accidents each year (3,786 deaths we recorded in 2007). Meanwhile, acid rain falls on one-third of China’s territory, and one-third of th urban population breathes heavily polluted air.[10] China’s coal burning has put five of its cities in th top ten of the most polluted cities in the world, according to the International Energy Agency.[11]

Recently, very fine coal dust originating in China and containing arsenic and other toxic elemen has been detected drifting around the globe in increasing amounts. In early April 2006, a dense clou of coal dust and desert sand from northern China obscured nearby Seoul before sailing across th Pacific. ~~Monitoring stations on the US West Coast found highly elevated levels of sulfur compound~~ carbon, and other byproducts of coal combustion — microscopic particles that can work their wa deep into the lungs, contributing to respiratory damage, heart disease, and cancer.

But as bad as all of these mostly longstanding environmental, health, and safety problems are, the pale in comparison to what many regard as the greatest crisis of our time — global climate change du to carbon dioxide emissions from the burning of fossil fuels. While coal produces a little over quarter of the world's energy, it is responsible for nearly 40 percent of greenhouse gas emission Those emissions consist principally of carbon dioxide (CO_2), though coal mining also releas methane, which is 20 times as powerful a greenhouse gas as CO_2 and accounts for nine percent greenhouse gas emissions created through human activity.

During the past decade, as a scientific consensus has solidified that global warming is due to huma activity, the actual signs of climate change have often surpassed even the most dire forecasts. Durin the 2007 summer, Arctic sea ice reached a minimum extent of 4.13 million square kilometer compared to the previous record low of 5.32 million square kilometers in 2005.[12] This represented decline of 22 percent in just two years; the difference amounted to an expanse of ice roughly the si of Texas and California combined. Moreover, the average thickness of the ice has declined by abo half since 2001. Altogether, taking into account both geographic extent and thickness, summer Arct sea ice has lost more than 80 percent of its volume in four decades. At current rates of melting, th Arctic could be ice-free during summer months by 2013. While sea levels will not be directly affect by the total melting of the northern icecap, since it floats on and thus displaces ocean water, that eve will severely destabilize Greenland's ice pack — whose disappearance would cause sea levels to ri by several meters, inundating coastal cities around the globe that are home to hundreds of millions people.

Meanwhile, as deserts expand and climate zones shift, many species that are unable to move adapt quickly enough find themselves on the precipice of extinction, and climate change-induce drought or changing monsoon patterns are sweeping every continent.

The crisis is being exacerbated by the fact that carbon sinks (forests and oceans that soak up carbo dioxide from the atmosphere) are losing their capacity. The net carbon uptake of northern forests declining in response to autumnal warming. And evidence suggests that the oceans' ability to take u atmospheric carbon is also slowing, and perhaps even reversing.[13]

Meanwhile, the seas are acidifying as levels of carbonic acid — produced by the reaction of wat with carbon dioxide — are increasing at a rate a hundred times faster than the world has seen f millions of years. The oceans are naturally alkaline but, since the Industrial Revolution, sea surfac have grown increasingly acidic. Many millennia will pass before natural processes can return th oceans to their pre-industrial state. The sea life expected to be worst hit include organisms th produce calcium carbonate shells — including corals, crustaceans, mollusks, and certain plankto species. Larger sea fauna such as penguins and cetaceans will not be directly affected, but changes the rest of the food chain will eventually impact these larger animals as well (see the sectio "Climate Sensitivity" in Chapter 6).

From the human standpoint, the potential consequences of climate change for agriculture a particularly worrisome. According to the UN's World Food Program (WFP), 57 countries — includin

29 in Africa, 19 in Asia, and 9 in Latin America — have been hit by catastrophic floods during th ~~past few years. Harvests have been affected by drought and heat waves in South Asia, Europe,~~ Chin Sudan, Mozambique, and Uruguay. In 2007, the Australian government said that drought had slashe predictions for the coming winter harvest by nearly 40 percent, or four million tons.[14]

Altogether, human-induced climate change constitutes environmental impact on a scale nev witnessed during the period of human civilization — i.e., the past 10,000 years.

Because coal produces higher carbon emissions per BTU of energy yielded than does oil or gas, these other fossil fuels deplete and become more scarce and expensive, and as higher-quality co depletes and nations turn to lower-quality coals, the climate situation will only grow worse — unle other sources of energy are developed quickly, or unless total energy use declines.

Efforts to capture carbon at power plants and sequester it in deep geological deposits cou theoretically reduce the environmental burden from coal consumption, but there are snags ar tradeoffs to that solution, as we will see in Chapter 7.

There is currently an enormous push underway to develop a global agreement to reduce greenhou gas emissions, using cap-and-trade mechanisms to ration rights to emit carbon. This may turn out be the most significant global policy discussion in world history, and it will have enormou implications for, among other things, the problem of global economic inequity — since national leve of per-capita energy consumption correlate closely with per-capita GDP.

Such a policy could also significantly impact the development of coal industries worldwide, ar entire national economies that depend on coal.

But if size of the coal resource base is smaller than is generally believed, this would have enormou implications for climate science, economic planning, and government policy.

In short: two of the defining trends of the emerging century — the development of the Asia economies and climate change — both center on coal. But coal is a finite, non-renewable resourc Thus, a discussion of the future of coal must also intersect with a third great trend of the new centur resource depletion.

These three great trends must inevitably interact and coalesce. How will this occur? Can curre trends in coal consumption be sustained? If not, what does this mean for the global economy and f the environment? If such trends *cannot* be sustained, how *will* our energy future unfold?

These are, of course, enormously complex problems with vast implications — which we wi unpack during the course of this book.

In Chapter 1, we will examine *how* coal supplies are estimated, and *why* new studies are challengin longstanding assumptions of abundance. As we will learn, estimating coal reserves is a complex tas and in many cases published figures are highly misleading.

Then in the four following chapters we will look in some detail at coal reserves in the United State

China, and the rest of the world, seeing why global supply shortfalls are likely within a mere tw ~~decades — in some nations, within just a few years; while in still others, coal supplies are already~~ trouble.

In Chapter 6 we will examine the implications of this new information for our understanding of th crisis of climate change.

Chapter 7 explores technologies that the coal industry is counting on to increase production ar electricity generation efficiency, and to reduce carbon emissions.

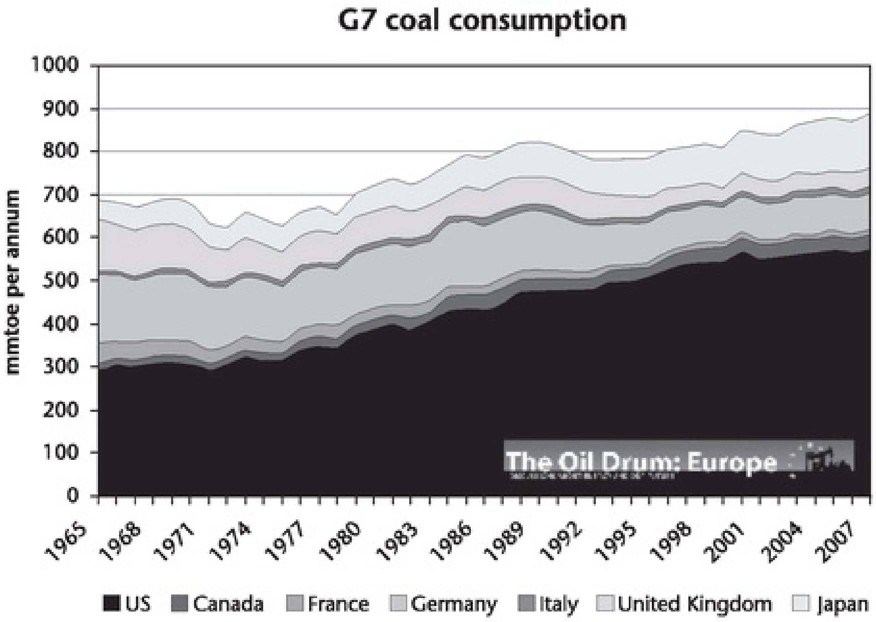

Fig. 1

Finally, in Chapter 8 we will examine three scenarios for the future, hinging on how much coal consumed and whether the carbon from coal is captured and stored.

We begin with a rudimentary and somewhat technical question upon which our energy future, wit all its economic and environmental implications, may ultimately pivot: *How do we know* how muc coal we have?

CHAPTER 1

How Much Coal Do We Have?

> *"It has been estimated that there are over 984 billion tonnes of proven coal reserves worldwide. ...This means that there is enough coal to last us over 190 years."*
>
> — *The Coal Resource, World Coal Institute, 2005*

THE FIRST SCIENTIFIC FORECAST FOR FUTURE BRITISH COAL SUPPLIES, published b Edward Hull in 1864, promised a 900-year abundance.[1] Subsequent estimates stayed above 500 yea for about a century. By 1984, the official forecast for British coal was down to 90 years' supply. As o 2008, Britain's coal industry, once the world's largest, is virtually gone.

The first scientific survey of US coal supplies, undertaken by the US Geological Survey in 190 concluded that the nation had 5,000 years' worth of coal. Today, the US Department of Energy say that the country has a 200-year supply.

Somehow Britons evidently misplaced about 750 years' worth of coal, while Americans lost staggering 4,700 years' worth. What happened?

Future supplies of coal are often discussed in terms of the reserves-to-production (R/P) ratio — i.e the resource base estimated to be recoverable at current prices and with current technology, expresse in terms of annual consumption. This ratio is frequently stated as if it were a forecast of supply ov time, as in, "the world has 190 years' worth of coal at current rates of consumption," or "China has 100-year supply."

This sounds both reassuring and reasonable — simply a matter of common sense, easily illustrate with a homely metaphor to which we will return several times in the following paragraphs.

Imagine that you were in the habit of eating a can of soup for lunch every day and you looked your cupboard and counted ten cans. You would correctly conclude that your daily reserves-to consumption ratio for canned soup was 10/1, and that you have ten days' worth of soup.

It makes perfect sense. Why shouldn't the situation be similar for coal?

In fact, supply forecasts for nonrenewable natural resources based on R/P ratios are *always wron* and often dramatically so. This may seem like an unreasonably sweeping statement (surely suc forecasts are correct at least once in a while?), but the evidence is clear: for practical purposes, re experience *never* conforms to forecasts based on R/P ratios.

There are three main reasons for this.

1 . *Rates of consumption for energy and materials are never constant.* In most cases,

populations increase and economies expand, consumption continually grows. Let us say th demand for a given mineral is growing at 3.5 percent per year; in that case, a resource base th would have lasted 100 years at an initial, constant rate of consumption would be exhausted only about half that time.

In our canned-soup example above, the initial ten-day supply forecast will be dashed if yo soup-loving brother shows up to stay for a week, and will have to be scaled back even furth when your sister from Florida drops by for a few days, with her hungry teenage son in tow.

2. *It is physically impossible to maintain a constant or growing rate of extraction of any no renewable resource until the moment when the resource is exhausted.* In the real world, tim based extraction profiles for non-renewable resources tend to conform to a modified be curve. Extraction starts slowly, increases as demand grows and exploration efforts expan reaches a peak when the most easily-accessed portion of the resource has been depleted, ar declines gradually thereafter as only the more remote and lower-quality deposits are able to b found and produced.

   Again, back to our example: Suppose your soup cans aren't stacked nicely in the cupboar but have been randomly concealed around the house by a deranged former housekeeper, som in plain sight and others hidden in walls and under floor boards (this more closely resembl the actual situation with non-renewable natural resources, which must be located throug prospecting efforts). You will find the cans that are in plain sight right away and exhaust ther fairly quickly; after your brother has shown up and the two of you have polished off those fir few, you may have to spend considerable time and effort taking the house apart, combing th wreckage for more. Perhaps many days or even weeks later, after your famished sister ar nephew have joined in the search, will you discover the last can.

3. *Reserves are not static, but can increase as a result of new discoveries, higher prices (whic make lower-quality deposits more attractive), and new technologies that facilitate exploratio and production.* Our soup metaphor has so far assumed a fixed supply, but in reality you a unlikely to be confined solely to the food stocks you have in your house at any given tim Instead, you will periodically go to the supermarket to buy more. If you have a car or even bicycle, you can get there more easily, and also carry home larger quantities.

Obviously, the first two mitigating factors work to make the initial R/P forecast too optimisti while the third trends in the other direction. Which factor carries the most weight? In the practic experience of resource extraction industries, the answer is rarely simple. Much depends, for exampl on how fast demand is growing, or on how much of the resource remains to be discovered. It is on th latter point that our canned-soup metaphor breaks down: when it comes to non-renewable resource there is no supermarket with groaning shelves being regularly replenished from trucks, canneries, ar farms; instead, there are finite quantities endowed by nature. As a result, one thing is certain — th third factor can only overcome the first two for a limited time; unless demand is rapidly *declining*, th resource will run out.

A low-hanging-fruit syndrome constrains both the discovery and production of most non-renewab resources. Deposits of minerals are continually being found; but, as exploration history lengthens, th tendency is to find only minor deposits that were missed the first time around. Meanwhile, productio continues to grow, perhaps for decades, until (as we have already noted) the difficulties of recoverin the remaining resource force a peak and subsequent decline in extraction rates. With energy resource ~~production ultimately must cease when the amount of energy required to produce the resource~~ equa the energy content of the resource being produced.

Some of the resource will always be left in the ground — and this often amounts to a majority what was originally in place.

Therefore the world's coal reserves will not last 190 years. In fact, they will last much longer, a there will surely still be some recoverable coal left many centuries from now. But that truism actual tells us nothing useful. For economic planning purposes, what is far more useful to know is *the timin of the point when it will no longer be possible to increase yearly production rates.* The shape of th depletion profile is far more informative than the R/P ratio.

It may be helpful to consider a couple of examples in order to gain some understanding of just ho misleading R/P forecasts can be.

During the 1970s, exploration geologists identified enormous oil deposits under British-controlle regions of the North Sea. As discoveries accumulated, reserves grew. With low initial production, th R/P ratio was high. As production ramped up, the largest fields that had been found early on graduall became depleted. By 1999, it was no longer possible to increase the aggregate rate of extraction, an British oil production began to falter. By 2008, total production from all fields combined had decline to about half its peak level. But paradoxically, because reserves figures have remained fairly consta (since some discoveries are still taking place in the North Sea while production is falling), R/P ratio have actually *increased* in recent years. If one were looking to the oil R/P ratio as the main index o the health of Britain's petroleum economy, this could only be encouraging. Yet Britain has recentl been forced to become a net oil importer for the first time in 30 years.

For the past 25 years, the R/P ratio for oil produced in the United States has been between 9 and 1 years. On one hand, this seems cause for worry, if it means that America could run out of oil in only decade; on the other hand, the fact that the ratio hasn't changed in a quarter-century is encouragin because it implies that reserves are being constantly replenished. However, that appearance o replenishment is itself misleading, because it is mostly due to America's extremely conservative o reserves reporting rules. Meanwhile, US oil production has generally been declining since 1970, an the nation — which was formerly the world's petroleum powerhouse — now imports two-thirds of i oil. In other words, there is little or no useful correspondence between what has been happening wi oil reserves and R/P ratios for the United States and what has been happening with actual production.

Net Energy

Net energy is the amount of useful energy delivered to society from energy-harvesting effort after all energy expenditures associated with those efforts have been subtracted.[2] This sometimes expressed as the ratio of energy returned on energy invested (EROEI). Socie depends upon maintenance of a positive net energy balance. However, energy harvesting fro non-renewable sources is subject to the law of diminishing returns, such that EROEI tends decline as the resource is depleted. Fossil fuels in place become useless as energy sourc when the energy required to extract them equals or exceeds the energy that can be derived fro burning them. This fact puts a physical limit to the portion of resources of coal (or oil or ga that should be categorized as reserves.

The graph shows a theoretical depletable resource that follows the "best first" (or "low hanging fruit") policy of resource extraction. The vertical axis is quantity and the horizontal is time. The gross energy resource "X" is the entire area under the curve ("X" = "A"+ "B"+ "C"+ "D"). Direct energy costs are "D." Indirect energy costs (like tractors and highways and medical insurance and such) are "C." Environmental externalities (in energy terms) are "B." "A" represents the total net energy of the resource after costs have been subtracted. At any given point in time the energy returned on energy invested (EROEI) can be calculated by taking a ratio of the total area divided by the costs (depending on the boundaries). As can be seen, net energy peaks and goes to zero long before the total gross energy is depleted.

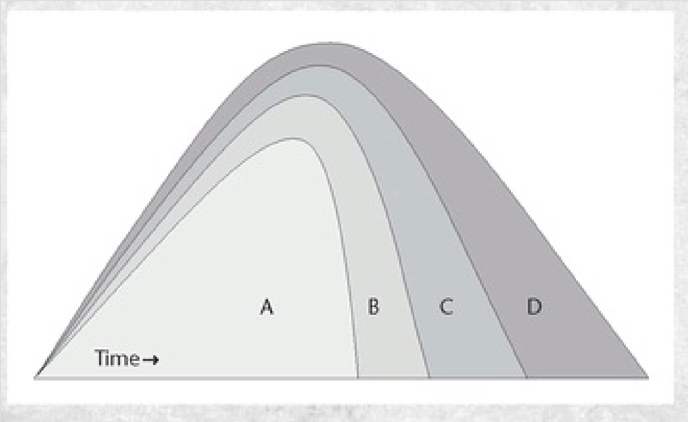

Fig. 2

From all of this it seems fair to conclude that, as a tool for forecasting future supplies of nonrenewable resources such as coal or oil, the R/P ratio is utterly worthless. We use it to try (always unsuccessfully!) to answer the wrong question — *When will reserves be exhausted?*, when what we really need to know is, *When will the rate of production begin to decline despite continuing efforts to increase it?* Nevertheless, official agencies such as the Energy Information Administration of the US Department of Energy still prominently list current world and national coal R/P ratios, while making no effort to forecast peaks of production.[3]

Part of the appeal of the R/P ratio is its simplicity. However, the real world is complicated. With regard to coal, part of that complexity has to do with the extremely variable nature and quality of the resource. So any serious attempt to grasp the future supply situation must begin with an effort to incorporate that variability.

What Kind of Coal?

Coal is a fossil fuel and therefore non-renewable. A combustible, sedimentary, organic rock composed mainly of carbon, hydrogen, and oxygen, it was formed from vegetation consolidated between other rock strata and altered by the combined effects of pressure and heat over millions of years.

While oil and gas were formed primarily from enormous quantities of microscopic plants (algae) that fell to the bottoms of prehistoric seas, coal is the altered remains of ancient vegetation that accumulated in swamps and peat bogs (peat currently covers three percent of Earth's surface; i previous geologic eras, that percentage was much higher). While oil and gas were formed during tw relatively brief periods of intense global warming roughly 150 and 90 million years ago, co formation started much earlier and occurred during much longer time spans, with the first prima formation period occurring during the late Carboniferous period (roughly 360 to 290 million yea ago), another in the Jurassic-Cretaceous (200 to 65 million years ago), and a third in the Tertiary (6 to 2 million years ago).

All fossil fuels vary in quality. For example, oil from some geological sources is more viscous an may have more impurities as compared to oil from other sources. Natural gas likewise varies b chemical composition: its main ingredient, methane, may be accompanied by larger or small amounts of sulfur dioxide, hydrogen sulfide, carbon dioxide, or other impurities; if the latter a present in too great a degree the gas is considered uncommercial and is not extracted.

Coal's variability is in some respects even greater than that of oil or gas: the range of energ density between and among hard and soft coals is wide, as is the range of impurities in coals fro differing regions. (Much of this variability has to do with the degree of alteration undergone by th original plant material, a process known as *coalification.*) At the high end of the coal spectrum anthracite — a hard, black coal that has more carbon, less moisture, and produces more energy p kilogram than other coals. At the low end are lignite and subbituminous coals, which are brow friable, and have more moisture, less carbon, and a lower energy content. Again, coal that contai high amounts of mineral impurities (especially sulfur) may be unusable.

The qualities of coal determine its uses. Generally, only anthracites and some high-carbo bituminous coals are suitable for making coke for steel production, a process that requires hig temperatures; these are therefore often referred to as "metallurgical coals" or "coking coals." Sinc anthracite is much less abundant than other coals, it sells for higher prices; it also therefore tends to b mined preferentially. Other coals are used mainly for electricity generation and are therefore known "steam coals," but this category includes a wide variety of coal types, from bituminous to lignite. A the lowest end of the spectrum are coals that are barely distinguishable from peat.

Even a thick seam of high-quality coal may be unrecoverable if it happens to lie beneath a tow school, or cemetery. Accessibility is also an important factor: lack of nearby transport infrastructur can pose a serious economic hurdle, since the transportation of coal can account for over 70 percent its delivered cost.[4] The cheapest mode of transport for coal is by water; thus, coalfields nearest coast areas are most likely to be tapped for the global export market. While the oil industry has learned access offshore petroleum and gas, coal that is buried in marine environments is difficult to extra economically with current technology, although there are instances where this is done (undersea co has been mined in Britain since the 18th century, and is currently mined also in Chile, Japan, Chin and Canada).

The location of coal varies greatly in depth, from surface outcrops to seams buried thousands of fe down. In most instances, underground mining is practical only to a depth of about 3,000 feet (1,00 meters), although the world's deepest coal mine, in England, reaches 5,000 feet (1,500 meters Obviously, the costs of mining at great depth are much higher than those of working at the surfac and the danger to miners increases as well. Worldwide, 40 percent of produced coal is surface mine (in the United States, about 60 percent of produced coal is surface mined).

Coal seams also vary in thickness, from only a few inches to well over 100 feet. Unless they a ~~very close to the surface, seams less than 28 inches in thickness are likely to be uneconomic to mine.~~

These variations in energy density, quality, location, depth, and thickness all must figure in calculations when geologists and energy analysts attempt to answer the question, “How much usef coal exists?” Cutoff points for whether coal is judged economical to produce tend to be vague ar changeable. Two variables capable of affecting such decisions are price and technology. If the price c coal rises, producers may find it economical to dig deeper, to exploit thinner seams, or to mine lowe quality deposits. And with new machines for mining, coal that was uneconomic to extract in the pa may become profitable.

Total world reserves (at end of 2002):	
bituminous coal + anthracite	479 billion tons
subbituminous coal	272 billion tons
lignite	158 billion tons
Each coal class has a different energy content:	
anthracite	30 MJ/kg
bituminous coal	18.8-29.3 MJ/kg
subbitiminous coal	8.3-25 MJ/kg
lignite	5.5-14.3 MJ/kg
wood	12 MJ/kg
coal	14-32.5 Mj/kg
oil	41.9 Mj/kg
natural gas	53.6 MJ/kg

On one hand, as more coal is discovered, as the price goes up, or as new mining machines a developed, coal reserves expand. On the other hand, as we extract and use enormous amounts of co each year, we draw down those reserves.

One might expect that overall reserves figures would change fairly slowly and in a predictab fashion. In fact, as we will see, reserves figures for several nations have collapsed in recent years; an over the past few decades, centuries’ worth of coal has disappeared from global reserves. Given th the world’s economy depends so heavily on coal, this trend is hardly reassuring. If we wish t understand how and why such downward reserves revisions are happening, it is essential that we loo