Introduction

As oil prices climbed during 2007 and 2008, another and perhaps more serious energy 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 many instances, these blackouts are due to the lack of what is supposed to be the world's most abundant fuel — coal.

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

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

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

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

Great Britain experiences power shortfalls with ever-greater frequency, with analysts describing the nation's electricity-generating infrastructure as "crumbling" and "inadequate" for 21st-century use; the industry estimates that it will need to spend £100 billion building a new generation of power stations — more than has ever been spent before on any similar project in the country's history.[2] The British coal industry, once the world's largest and the main supplier of power to the national grid, is 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. And even energy-rich countries like Venezuela and Iran are not immune, suffering from electrical blackouts even as they export oil.

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

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

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

These problems are already of crisis proportions in many nations, though for most Western energy consumers they constitute merely an occasional annoyance or a vague worry. But if current trends continue, the likely consequences are difficult to overstate. Unless the world adopts a very different energy paradigm — and soon — problems with coal and electricity supplies can only spread and worsen year by year until, some time in the next two to three decades, human civilization approaches a 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 and declining availability would not be serious. Instead, however, coal is at the center of energy planning for many nations — especially the burgeoning Asian economies. Despite environmental concerns, coal is seeing the fastest percentage growth in usage worldwide of any of the principal fossil fuels, and 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 the end of the 19th century (when it supplanted wood) until the middle of the 20th (when it was overtaken by oil). More recently, natural gas has substituted for coal to some extent in electricity generation, partly because of growing concerns about greenhouse gas emissions (coal is the most carbon-intensive common fuel, natural gas the least); meanwhile oil has become the globe's most important fuel largely because of its role in transport.

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

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

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

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

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

World production of natural gas will likely peak somewhat later than that of oil; however, regional conventional natural gas supply constraints are already appearing, primarily in North America (the most intensive consumer of the resource), as well as in Russia and Europe. Because only a small proportion is traded globally in the form of liquefied natural gas

(LNG), this means it may not be 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 comparison appears suddenly attractive again. The industrial world has abundant experience with it, the technology for producing and using it is well developed, and there is purportedly an enormous amount of it waiting to be mined and burned. New technologies, such as integrated gasification combined cycle (IGCC) power plants and methods to capture and store carbon, promise to make coal cleaner (though not cheaper) to use. In addition, there is increasing interest in deploying methods to turn coal into a synthetic liquid fuel able to substitute for oil (we will explore each of these technologies in more detail in Chapter 7).

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

The shift in the world's economic center of gravity away from the United States and toward the great population centers of East and South Asia is being widely heralded as the primary economic trend of the new millennium. In recent years, China's economy has grown at an annual rate of 7 to 11.5 percent (a 7 percent constant growth rate implies a doubling of size every ten years: thus after 20 years the entire economy is four times its previous size, and after a mere 30 years it is eight times its 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 current decade, and will surpass US$20 trillion by 2020, making China's national economy then the world's largest. India's economic growth rate was 8.4 percent in 2006 and 9.2 percent in 2007. Currently, India is the world's fourth largest national economy, but at recent rates of growth it could advance to third 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 coal consumer, using nearly twice as much as the next country in line (the United States). The quantities are staggering: in 2007 alone, China added electrical generating capacity — nearly all of it coal-based — equal to the whole of France's or Britain's entire electricity grid. During 2007, China's installed electricity generating capacity grew 17 percent, reaching over 700 gigawatts, second only to the United States' 900+ gigawatts.

India is now the world's third-largest consumer of coal, which provides nearly two-thirds of the 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 an 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 during the 20th century, there were equally compelling environmental reasons.

Coal is the dirtiest of the conventional fossil fuels. Sulfur, mercury, and radioactive elements are released into the air when coal is burned and are difficult to capture at source. During the early phase of the Industrial Revolution, both the mining and the burning of coal generated legendary amounts of pollution. In cities like London, Chicago, and Pittsburgh, smoke and airborne soot reduced visibility to mere inches on some days. The following passage from *The Smoke of Great Cities* by David Stradling 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 "hell with the lid taken off," as he peered through a heavy, shifting blanket of smoke that hid everything but the bare flames of the coke furnaces that surrounded the town. During autumn and winter this smoke often mixed with fog to form an oily vapor, first called smog in the frequently afflicted London. In addition to darkening city skies, smoky chimneys deposited a fine layer of soot and sulfuric acid on every surface. "After a few days of dense fogs," one Londoner observed in 1894, "the leaves and blossoms of some plants fall off, the blossoms of others are crimped, [and] others turn black." In addition to harming flowers, trees, and food crops, air pollution disfigured and

> eroded stone and iron monuments, buildings and bridges. Of greatest concern to many contemporaries, however, was the effect that smoke had on human health. Respiratory diseases, especially tuberculosis, bronchitis, pneumonia, and asthma, were 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 an inherently dangerous and environmentally ruinous activity, and accidents (from asphyxiation by accumulated gas, as well as from explosions, fires, and roof collapses) were so common as to be an expected part of life in mining towns. Miners and their families often suffered from respiratory ailments — including pneumoconiosis, or black lung disease. Mining altered landscapes, often 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 industrialized countries. The large-scale mechanization of mining means that today fewer miners are required to produce an equivalent amount of coal; meanwhile, improvements in mining methods (e.g., longwall mining), as well as hazardous gas monitoring (using electronic sensors), gas drainage, and ventilation have reduced the risks of rock falls, explosions, and unhealthy air quality. Even with these improvements, mining accidents still claimed 46 fatalities in the United States in 2006; according to the Bureau of Labor Statistics, mining remains America's second most dangerous occupation (logging is the first).[8]

However, despite technical advances, coal mining continues to destroy landscapes, as is infamously the case with the method used in the Appalachian region of the United States called "mountaintop removal." This practice, which involves clear-cutting native hardwood forests, using dynamite to blast away as much as 1,000 feet of mountaintop, and then dumping the waste into nearby valleys, often burying streams, has been called "one of the greatest environmental and human rights catastrophes in American history."[9] Families and communities near mining sites must contend with continual blasting from mining operations and suffer from airborne dust and debris. Floods have left hundreds 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 been somewhat moderated in countries that industrialized early, in the nations where coal use is today the highest and is growing fastest, methods of mining and consumption often resemble the worst practices of the early 20th century.

Thousands of China's five million coal miners die from accidents each year (3,786 deaths were recorded in 2007). Meanwhile, acid rain falls on one-third of China's territory, and one-third of the urban population breathes heavily polluted air.[10] China's coal burning has put five of its cities in the 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 elements has been detected drifting around the globe in increasing amounts. In early April 2006, a dense cloud of coal dust and desert sand from northern China obscured nearby Seoul before sailing across the Pacific. Monitoring stations on the US West Coast found highly elevated levels of sulfur compounds, carbon, and other byproducts of coal combustion — microscopic particles that can work their way 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, they pale in comparison to what many regard as the greatest crisis of our time — global climate change due to carbon dioxide emissions from the burning of fossil fuels. While coal produces a little over a quarter of the world's energy, it is responsible for nearly 40 percent of greenhouse gas emissions. Those emissions consist principally of carbon dioxide (CO_2), though coal mining also releases methane, which is 20 times as powerful a greenhouse gas as CO_2 and accounts for nine percent of greenhouse gas emissions created through human activity.

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

Meanwhile, as deserts expand and climate zones shift, many species that are unable to move or adapt quickly enough find themselves on the precipice of extinction, and climate change-induced 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 carbon dioxide from the atmosphere) are losing their capacity. The net carbon uptake of northern forests is declining in response to autumnal warming. And evidence suggests that the oceans' ability to take up 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 water with carbon dioxide — are increasing at a rate a hundred times faster than the world has seen for millions of years. The oceans are naturally alkaline but, since the Industrial Revolution, sea surfaces have grown increasingly acidic. Many millennia will pass before natural processes can return the oceans to their pre-industrial state. The sea life expected to be worst hit include organisms that produce calcium carbonate shells — including corals, crustaceans, mollusks, and certain plankton species. Larger sea fauna such as penguins and cetaceans will not be directly affected, but changes to the rest of the food chain will eventually impact these larger animals as well (see the section, "Climate Sensitivity" in Chapter 6).

From the human standpoint, the potential consequences of climate change for agriculture are particularly worrisome. According to the UN's World Food Program (WFP), 57 countries — including 29 in Africa, 19 in Asia, and 9 in Latin America — have been hit by catastrophic floods during the past few years. Harvests have been affected by drought and heat waves in South Asia, Europe, China, Sudan, Mozambique, and Uruguay. In 2007, the Australian government said that drought had slashed 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 never 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, as these other fossil fuels deplete and become more scarce and expensive, and as higher-quality coal depletes and nations turn to lower-quality coals, the climate situation will only grow worse — unless 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 could theoretically reduce the environmental burden from coal consumption, but there are snags and 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 greenhouse gas emissions, using cap-and-trade mechanisms to ration rights to emit carbon. This may turn out to be the most significant global policy discussion in world history, and it will have enormous implications for, among other things, the problem of global economic inequity — since national levels of per-capita energy consumption correlate closely with per-capita GDP.

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

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

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

These three great trends must inevitably interact and coalesce. How will this occur? Can current trends in coal consumption be sustained? If not, what does this mean for the global economy and for 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 will unpack during the course of this book.

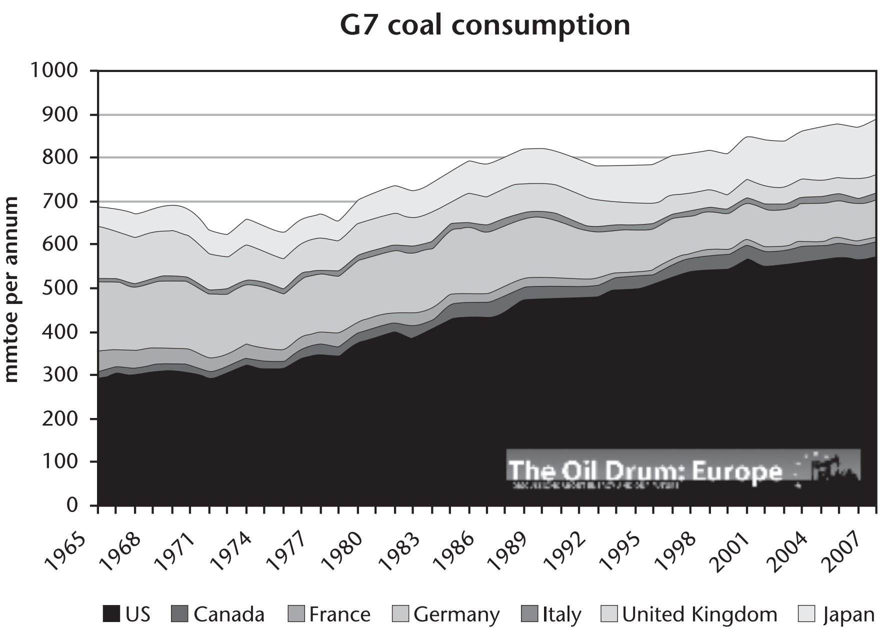
In Chapter 1, we will examine *how* coal supplies are estimated, and *why* new studies are challenging longstanding assumptions of abundance. As we will learn, estimating coal reserves is a complex task, and in many cases published figures are highly misleading.

Then in the four following chapters we will look in some detail at coal reserves in the United States, China, and the rest of the world, seeing why global supply shortfalls are likely within a mere two decades — in some nations, within just a few years; while in still others, coal supplies are already in trouble.

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

Chapter 7 explores technologies that the coal industry is counting on to increase production and 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 is 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, with all its economic and environmental implications, may ultimately pivot: *How do we know* how much coal we have?