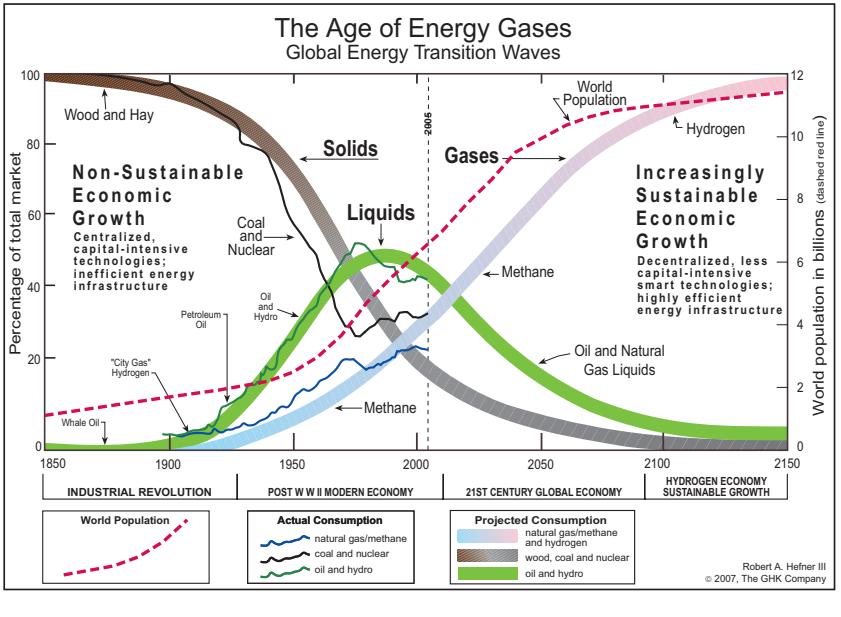
THE AGE OF ENERGY GASES

China's Opportunity for Global Energy Leadership

By Robert A. Hefner III
The GHK Company, 2007



The Age of Energy Gases

China's Opportunity for Global Energy Leadership

By Robert A. Hefner III, 2007
E-Mail: ghk@ghkco.com

The GHK Company
Oklahoma City, Oklahoma
USA

First printing, 2007

Introduction

We are living in a time when many of the world's scientists have concluded that global climate warming may be a direct result of human activities. Global carbon dioxide concentrations have recently reached unprecedented levels. Coal-fired power generation plants are the world's largest source of CO_2 emissions. Coal power produces about 40% of global CO_2 emissions[1]. Coal is the world's dirtiest and most inefficient source of power. Coal remains a 19th Century energy technology and its use imposes enormous external social, environmental and economic costs upon society. When these external costs are included, coal is not the cheapest source of power. Some scientists are saying that civilization, with "energy consumption as usual", can not be sustained. Britain's Stern Review on the Economics of Climate Change[2] estimated that the cost of "energy consumption as usual" could be equal to that of the Great Depression and both World Wars. Additionally, there are serious questions whether global oil production flows can continue to meet natural decline rates and increases in oil demand much past the end of this decade[3]. As a result, the price of oil will probably continue to be volatile and in its present price range or higher and thus the potential for disruptive geopolitical tensions and economic contractions will continue to increase.

This presentation will make the case that even if global climate warming is proven not to be of human origin, China's goal of Peaceful Rise will require a shift in its energy systems from coal and oil toward cleaner and greener 21st Century energy technologies, and that on the long-term march of progress civilization is once again poised for transformational and long-term changes of energy sources and energy technologies. In order to make informed choices, policymakers must keep in mind that the energy input to the economy may be of equal importance as money. Energy is not a neutral input to an economy but always has a positive or negative impact upon economic productivity and efficiency, and today there can be no question that the use of coal and oil creates huge and detrimental external costs that are paid by society as a whole in the form of higher taxes and a diminished quality of life. Informed policy decisions must be based upon the knowledge that the choice of the energy input can be transformational to an economy's potential for growth and its environmental impact. Thus, if the right energy choices are made, Asians in particular are poised for exponential growth in standards of living and quality of life. My presentation makes the case that the next great energy wave will be principally based upon the use of clean, chemically simple and globally abundant natural gases (methane and hydrogen) used in high technology, smart, efficient, distributed energy systems and that the winning nations of the 21st Century will be those that take up this challenge.

Now, to focus upon China. China's leaders have used the words Peaceful Rise to describe its path toward regaining its status as a global superpower. To achieve this goal over the coming decades will require that China successfully deal with many domestic and global challenges. Two of these challenges are essential to its success; first, China's need to maintain internal stability and second, the need to continue China's international participation as a responsible "stakeholder" in sustaining external peace and trade. To maintain long-term internal stability will require strong and sustained economic growth – including the development of a rising middle class as hundreds of millions of Chinese move to the cities

and rapidly increase their demand for more energy. As China's economy and demand for energy continues to rapidly grow over the coming decades, the maintenance of internal stability will require the reversal of environmental degradation caused principally by coal-fired power generation and the coal-powered side effects of higher health costs, lower levels of industrial and agricultural productivity and diminished quality of life. Many believe that the requirements of substantial increases in demand for power to provide for the massive migration to the cities and to sustain current rates of economic growth are in direct opposition to China's equally important need to begin to clean its environment. In fact, it seems that because China's forecast demand for electric power is so large, it has no option but to forge ahead with coal generation and hope for the best. I disagree, because natural gas power generation, supplemented with wind and solar, can solve the demand for cleaner power and quickly begin to reverse China's environmental degradation while lowering forecast CO_2 emissions substantially, as well as reducing the true costs of energy consumption. China's policymakers must accept the fact that the real costs of burning coal, including its large external costs, will be much higher than the costs of using natural gas to meet its increasing demand for power. If one believes that the World Bank's report[4] on environmental costs is basically correct, then China's external costs of coal use are more than US$100 billion annually.

If China is to be welcomed internationally as a responsible "stakeholder" in the maintenance of external peace and stability, then there must be a major shift in its domestic energy policy. Otherwise, with "energy business as usual," China's growing strategic need for oil, with oil's adverse geopolitical and strategic implications, will inevitably collide with the developed economies and their continuing addiction to oil. China's forecast monumental increase in coal use and CO_2 emissions[5] are already in direct opposition to the increasingly emotionally charged demand by more and more of the world's people, including growing numbers of Chinese, for relief from global climate warming. Once again, natural gas power, supplemented by wind and solar, can be both a near-term and long-term solution to this apparent dialectic.

Because the use, source and form of energy consumption will be a fundamental determinant of China's economic, environmental, foreign policy and defense directions as a nation and global player over the coming decades, China's choice of energy sources may well determine the success of its Peaceful Rise.

As I see the future, China has only two energy choices; to be a *Follower* or to be a *Leader*:

- I believe it would be a tragic and long-term macroeconomic mistake for China to *follow* in the shadow of the West by continuing to build its energy infrastructure with old, inefficient and dirty 19th and 20th Century coal and oil technologies. To choose to *follow* would be a course that will increasingly limit economic growth and will increasingly pollute its people and lands. To *follow* the West is a path of increasing internal instability, and a path certain to reverse recently acquired global soft power as China becomes the world's largest polluter.
- Whereas the choice to *lead* the world in the development of 21st Century high-tech, smart, efficient, clean energy systems would provide for environmentally sustainable internal economic growth and simultaneously reduce global strategic tensions over long-term access to oil supplies. A *leadership* strategy will not only expand China's soft power, but create a vast new long-term external market for newly developed green energy technologies.

I believe it is unmistakably clear that China's best domestic and international interests are served by becoming a global energy *leader*. In spite of the fact that China is a developing nation and rightfully asserts that the industrialized nations achieved their current status without regard to CO_2 emissions and were largely responsible for bringing climate change to its current tipping point, China must not allow this fact to prevent it from choosing an energy path so fundamental to its achieving all the goals of its Peaceful Rise. China has an unprecedented commercial and political opportunity to once again establish itself as a global technological leader. China

has everything to gain both internally and internationally by global leadership in creating and developing the most fundamentally necessary technologies for civilization's future during the 21st Century and beyond. The technological leadership role is totally befitting a civilization that, as Cambridge University's renowned China scholar Joseph Needham asserted, invented and created at least half of the inventions and technology necessary for the modern world, including, I must say, the development of a natural gas drilling, production and distribution industry over 800 years ago [Fig. 1].

Early Natural Gas Drilling in China

Fig. 1: Circa 1041 A.D. – 1368 A.D.: This painting illustrates deep well drilling in China from the years 1041 to 1368 A.D. This deep well drilling was the precursor to the modern gas well. The main focus of the painting is the derrick and the "windlass" – the circular apparatus (rotated by oxen) which turns the winches on the derrick. The well is about 1000 meters deep. Oil painting by Chen Yanning.

The following dissertation is my advocacy that natural gases will be the principal fuel for the next great energy transition. I recommended

the natural gas path to China in 1984 at the first international energy exposition in Guangzhou. In 1985, I studied the potential for natural gas in China, and later reported to the National Natural Science Foundation, Ministry of Geology and Ministry of Petroleum, predicting China's natural gas resource potential to be similar to America's, and in the range of 30 to 40 trillion cubic meters[6] (1,059-1,412 Trillion Cubic Feet - TCF). Today, I remain equally certain of China's natural gas potential. Natural gas is an energy resource that I believe is abundant in vast quantities, both within China and globally. However, let me recognize immediately that many energy experts have historically doubted, and continue to doubt, the abundance of natural gas both within China and globally. I will make my case for natural gas abundance later.

An energy path based upon natural gas will immediately begin to reduce coal's CO_2 emissions and, possibly more important for China, natural gas will eliminate the deadly sulphur, mercury and ash pollutants that continue to limit economic growth and deteriorate the quality of life. These are the deadly coal pollutants that reduce visibility, create dense fogs, poison fish and crops, reduce human productivity, add to healthcare costs and are killing the grasslands of inner Mongolia, spawning severe dust storms that choke Beijing, and that have recently been found as faraway as the west coast of America[7].

To understand my long-term thinking about the Age of Energy Gases, we must first look at how society in the past has viewed the waves of energy transitions through history, principally the transitions from wood to coal to oil as shown on the following figure.

The origin of civilization began around the fire. Wood fueled the first power plant - the open pit fire. Forests were plentiful so wood was inexpensive and easy to use. But over thousands of years, environmental and resource considerations arose. As early as about 1200 A.D., a Chinese literati said that if China didn't find a new source for carbon black, it would end up with no forests. As cities began to grow, trade went to the seas and navies were built, concerns grew about the adequacy of the forest resource worldwide. However, as always, beginning in the 1700's, human ingenuity found a better

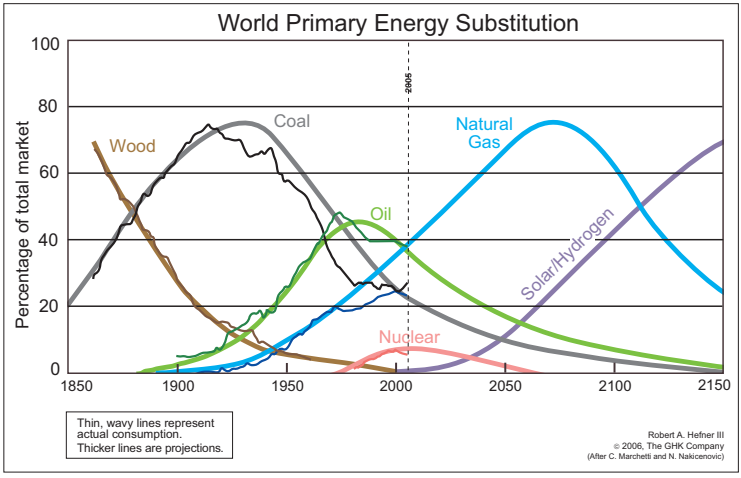


Fig. 2

alternative. In 1769, James Watt patented the steam engine and coal technology created the Industrial Revolution. Coal, a more mobile, higher density fuel began to replace wood in the 1800's. A new, transforming, 19th Century energy system was born and England became the birthplace of the Industrial Revolution. Coal technology increased efficiency in the manufacturing and transportation sectors by orders of magnitude and produced an exponential growth in the standard of living for the nations that participated in the Industrial Revolution. Based largely upon these new transforming energy technologies, England rode this great energy wave to the zenith of the British Empire. Unfortunately, this coal based wave also brought England to the zenith of its environmental degradation that included "pea soup" fogs, coal encrusted buildings, homes filled with coal dust, and enormous losses of economic and agricultural productivity, as well as rising health costs and diminishing life spans for the average Londoner. China faces the very same environmental degradation and economic limits today that England faced in the 1800's. The World Bank estimates that pollution is costing China between 8% and 12% of its annual GDP[8] or about US$160 – $240 billion each year.

China's environmental agency has estimated 3% or US$60 billion per year, but whatever the real costs, it is certain they will continue to rapidly increase. These high external costs show that China can, indeed I daresay, must, afford to build a new 21st Century energy infrastructure. China today has the opportunity to avoid locking itself into the developed economies straitjacket of dirty, inefficient 19th and 20th Century energy technologies.

Returning to Fig. 2, we can see that as coal use began to produce unsustainable environmental and economic limits, beginning early in the 20th Century human ingenuity gave birth to the next great wave of energy transition. A new fuel appeared that packed even more energy in a smaller, more portable package - oil. Churchill first saw the enhanced value of oil to fuel the British Navy in 1912, and by the end of WWI oil began to emerge as the primary fuel for a cleaner and more efficient 20th Century energy technology. Oil technology built what is called the modern world, and along the way fundamentally changed the geopolitical and geostrategic balance of the world. Oil technology built a transportation sector that once again increased global mobility by orders of magnitude, and this time the development of aircraft further shrank the relative size of the world. Oil technology, coupled with the information revolution, connected and globalized the economies of the world as the 20th Century closed. America rode this great energy wave to global dominance, both militarily and economically. But as we enter the 21st Century, we can clearly see limits to the age of oil.

However, as with all resources, the global economy will never run out of oil, but we are likely reaching the commercial limits to add new oil production flows at rates needed to overcome both natural rates of production decline and increases in demand over the coming decades in a "business as usual" scenario for several reasons:

- a scarcity of new places to explore and limited potential for new giant oil discoveries;
- very large financial requirements to meet the need for massive capital investment[9]; and
- worldwide shortages of energy knowledgeable people, energy equipment and industry services.

Even if oil production keeps pace with increasing demand, the oil "business as usual" scenario will create increasingly unsustainable global economic imbalances and political friction or wars. If world demand for oil is not met, severe and volatile economic dislocations and contractions will occur, and the likelihood of war is increased. The winner nations will be those that have made progress pursuing alternate energy paths. I believe that the most compelling and least costly alternative path will be natural gas.

The Age of Energy Gases

Natural gases will fuel the next great energy wave. This wave will begin with clean methane, commonly called natural gas, and during the second half of the 21st Century, a transition will accelerate toward totally clean hydrogen. Hydrogen and the hydrogen economy should become civilization's energy endgame. Only within a hydrogen-based economy that produces virtually no energy pollutants can forecasted levels of global population and its required increases of economic growth be sustained environmentally. The path toward civilization's ultimate goal is clearly marked by a series of energy waves that have decarbonized our energy sources over the past 150 years by shifting from wood, composed principally of carbon, to coal, with a little less carbon, to oil, again, less carbon and also containing hydrogen, to methane, that is composed of only one carbon and four hydrogen atoms. The transition to natural gas will be a "giant step for mankind" toward hydrogen itself, with no carbon, that when used as a fuel is environmentally benign, producing only heat and water.

Now, to return to the issue of natural gas availability: The discovery of more and more very large natural gas fields around the world is making the global abundance of natural gas more and more apparent every day. However, in order to fully appreciate and understand the abundance of natural gas, we must abandon the historic misconception that "oil and gas" are one energy source and one energy industry. My life's work as a geologist and natural gas, not oil, explorationist has led to my belief that global natural gas resources are much more abundant than oil and at least as abundant as coal. As you contemplate the abundance of natural gas, keep in mind

that wherever coal is found natural gas is present and wherever oil is found natural gas is also present and often in equal or larger quantities and, even more important, the largest natural gas fields in the world have little or no oil. I have met many experts in China who mistakenly believe that because China is a relatively small global oil producer, that China should not expect much natural gas.

We must abandon the long-held concept of "oil and gas" where "gas" comes second, as a little-valued by-product of oil or, in the case of coal mining, a dangerous and often deadly nuisance. Natural gas is different from oil in most every way except how it is generally explored for and even then success in natural gas discovery requires thinking outside of oil exploration. Natural gas is lighter than air and cannot be seen; oil is a viscous liquid easily seen and difficult to clean up when spilled. Oil spills devastate vast stretches of oceans and beaches whereas huge and yet unmeasured quantities of natural gas have been leaking from the Earth's land masses and oceans for millenniums and, although a so-called greenhouse gas[10], without apparent adverse environmental impact. Natural gas is compressible and oil is not, allowing a natural gas reservoir of identical size but at deeper depths to hold twice or more as much natural gas as the same reservoir at a shallower depth. Natural gas is chemically simple, with four hydrogen atoms and only one carbon. Oil is chemically complex and contains much more dirty carbon. *One of the most significant differences is that natural gas is commercially produced from many reservoir rocks that could not commercially produce one drop of oil (tight sandstones, coal, shale).* For example, shale reservoirs that have historically produced no oil have recently become the number one target for natural gas development in the U.S. as a result of new real time 3-D seismic, massive fracturing and horizontal drilling techniques. Over the last decade natural gas resources from shale reservoirs have increased America's natural gas potential by more than 50%[11], and the technologies to produce these shale reservoirs are continuing to improve each day [Fig. 3]. Natural gas is pervasive around the world, whereas about 65% to 70% of all oil reserves[12] are located under a relatively small and concentrated area of the earth's surface. Natural gas requires a significantly different infrastructure than oil and is cleaner and generally more efficient.

American Shale Gas Deposits

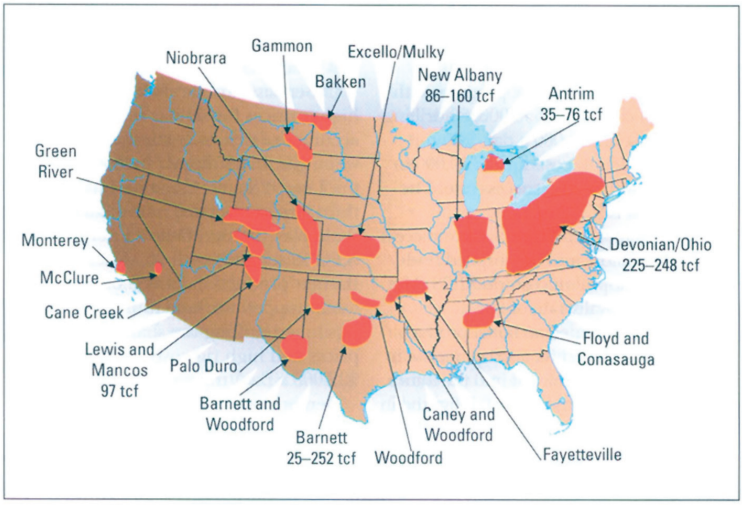


Fig. 3: Gas shale deposits appear in basins from the east to the west coast across the United States. Although recovery percentages are low, total volumes are high. (Map courtesy of Schlumberger)

Nonetheless, most people today think of "oil and gas" as one industry. My grandfather and father were in the oil industry, but I separated myself from the "oil industry" while at the University of Oklahoma. Unfortunately for natural gas understanding, the world's universities continue to teach "petroleum" geology and "petroleum" engineering; the dictionary defines "petroleum" as hydrocarbon *liquids*, not *gases*. Most of the natural gas available for consumers today was found by oil geologists searching for oil with capital budgets targeted toward expanding oil supplies. International comparative measurements of natural gas and oil are most often expressed in "Barrels of Oil Equivalent (BOE)." Yet, during the last decade or so the world's "oil and gas" exploration results passed into the era of natural gas *followed* by oil. By studying the world's "giant oil and gas fields"[13] found between 1990 and 1999, we learn that 37 giant oil fields were found containing 36,800 million barrels of oil equivalent (BOE) and 40 giant gas fields were found containing 119,387 million

BOE – over three times as much natural gas as oil found in the giant fields. An even closer look shows that about 30% to sometimes as much as 40% or more of the BOE in the giant *oil fields* were actually *natural gas*. So, in reality, at least five times more natural gas was found as oil. This is a clear indication that the future is natural gas, not oil.

Natural gas is not part of the oil industry. The natural gas industry is only now beginning to exist as an integrated global industry. Historically, natural gas has at best been priced as a cheap by-product of oil, or worse, flared away as a nuisance. For decades, the brightest spots on earth at night have been the giant natural gas flares from "oil" fields in Siberia, Saudi Arabia and West Africa.

Only in the last few years has the market begun to price natural gas as an important commodity at a price roughly equivalent but still mostly discounted to oil. Likewise, only in recent years have capital budgets begun to target the expansion of natural gas reserves and natural gas infrastructure. A good example is Qatar that is on its way to building the first truly integrated global natural gas company. And in China, large new natural gas fields are being developed in Sichuan and new discoveries in the South China Sea, Inner Mongolia and deeper levels below Daqing are soon to be developed.

The natural gas market is only now in its infancy as a global commodity. So, when you hear people talk about oil and gas in one breath, remember that they are "oil" people and are limited in their understanding of natural gas by their long held views of oil.

The western world and its producer nations will certainly remain focused on oil for decades to come. Why? Because oil fuels such a large segment of the world transportation sector which is fundamental to globalization, particularly in the developed economies; because oil is vital to political stability in most of the major oil producing nations; because oil trade represents the largest piece of the global economy; because the great multinational oil companies and, more recently, the state owned oil companies, have an enormous capital investment in oil infrastructure. Unamortized capital investment in "downstream" infrastructure such as transportation, storage, refining and distribution to the world's automobiles far exceeds that of exploration and production. Also consider the invested capital of the automobile

companies so closely linked to oil through the internal combustion engine, not to mention the world's fleet of autos. The automobile is the foundation of America's mobile way of life with most of its population living far from work as a result of vast subsidized highway systems and subsidized, inexpensive gasoline. To be realistic, one must also consider the suburbs as part of the capital investment in vast, extremely inefficient oil and coal based energy infrastructure. Consider the staggering inefficiency of a single American being transported by an automobile (1% of its fuel actually moves the driver[14]) for an hour each way to and from work, or America's absurdity of a single Domino pizza being delivered to a customer across town by automobile. I must question the wisdom of China following America by building a subsidized highway system the size of America's[15] and meeting the forecast demand for a fleet of about 250 to 300 million automobiles[16] (America has about 240 million[17]) over the next three decades that will be fueled with price controlled and subsidized low-cost petrol. As to coal, consider the almost indescribable inefficiency, not to mention needless environmental degradation, of mining coal in Wyoming and transporting trainloads across America to Texas to fuel a power station that must then transport its electric power over hundreds of miles of resistive wires to a suburb often located 30 to 100 miles or more from the point of power generation.

As inefficient as these practices are, oil and coal will remain the primary energy sources of the developed economies for some time to come. Because of the current boom in coal-fired generation, particularly in the U.S. as a result of the Bush Administration easing environmental restraints, and China, where two coal generation plants a week are added[18], natural gas may have a long way to go before it will surpass coal and oil in global market share. However, in the past decades natural gas has been the fastest growing primary energy and I believe this trend will resume as policymakers begin to recognize the real external costs of coal and oil. What is needed now is to alleviate the fears of insufficient natural gas resources and to begin the task of understanding natural gas in its own right as the next primary energy source. I believe this calls for an appropriate international institution that can organize a global effort for the collection of natural gas

resource and production data and mount a well financed program for research and study of natural gas and natural gas technology.[19] Natural gas resource estimates must no longer be limited by oil thinking. To understand natural gas we must begin the task of analyzing the significance of many recent natural gas facts and discoveries before realistic, unbiased global natural gas estimates can be formulated. We must recognize such natural gas facts as:

- the non-biologic origin of natural gas becoming more probable by the discovery of vast quantities of methane on Titan, one of Saturn's moons [Fig. 4], as well as on Jupiter, Saturn itself, Uranus and Neptune. And here on Earth, methane venting from the 40,000 mile long mid-oceanic rift system [Fig. 5]. Natural gas should not be thought of as just another "fossil fuel," as we are learning that there is an increasing possibility that large quantities of natural gas may not be of biologic origin and may even be continuously forming as part of the great continental subduction movements occurring on earth today;

Titan – Methane Atmosphere, Lakes

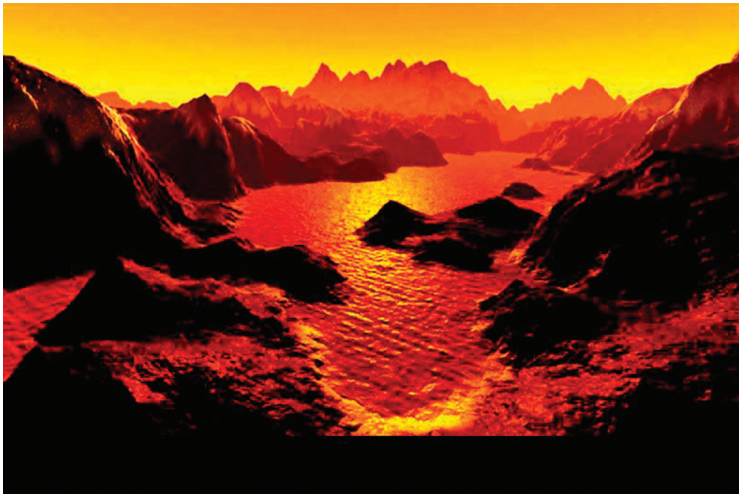


Fig. 4: A lake of liquid methane surrounded by mountains of solid ice on Titan.
Source: Huygens probe, ESA. (Courtesy of Jesse Ausubel)

Global Oceanic Rift System

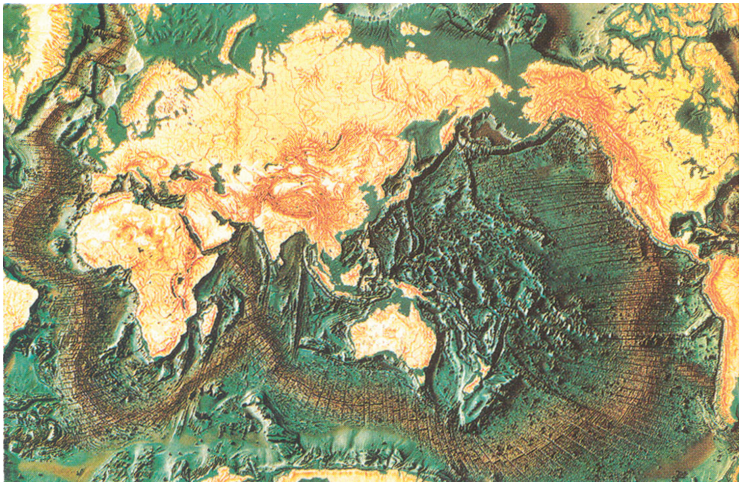


Fig. 5: 40,000 mile mid-oceanic rift system. *Discover Magazine*, June 2007.

- the discovery of methane hydrates in all the world's oceans and their potential for commercial production. The world may contain more energy in the form of natural gas hydrates[20] than all the energy contained in the world's coal and oil combined [Fig. 6-on next page], and only in the last several years have very limited experiments begun to test how natural gas hydrates can be produced;
- the recent commercial development of shale gas in the USA that may well have doubled America's natural gas resources, yet shale gas has not been explored for and commercially developed in the other continents of the world. China will most certainly have large deposits of shale gas possibly in the range of 10 to 20 trillion cubic meters (350-700 TCF).

Policymakers commit a tragic mistake when they dismiss natural gas as simply another "fossil fuel," because doing so ignores that natural gas is considerably environmentally cleaner than oil and coal; natural gas has the potential to significantly reduce global

Global Natural Gas Hydrates

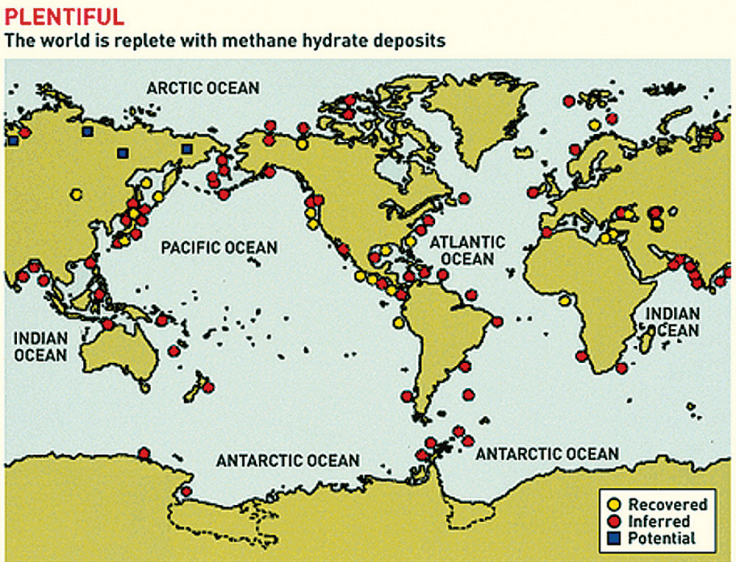


Fig. 6: Source: U.S. Geological Survey.

CO_2 emissions by its use for power generation; global natural gas reserves are potentially massive; and large quantities of natural gas may have non-biological sources and may even be renewable. We need to learn to distinguish between natural gas – a principal solution to global energy problems – and coal and oil, which are the principal problems.

Computer projections of natural gas[21] forecast that natural gas will move toward supplying about 80% of the world energy market, as did coal in the 19th Century. But how could that be realistic, particularly recognizing that oil never attained 50% of the world's energy marketplace? Oil peaked in 1973 at 48% and has subsequently declined to about 36% of today's global demand for energy[22]. That fact fascinated me. I wondered why a fuel as efficient and competitive as oil, when compared to coal, only managed to achieve just less than

50% of the global energy market. It dawned on me that possibly the big picture of energy transitions may well be elegant simplicity. In the big picture, matter in the universe exists principally in two forms – solids and gases. Liquid is a transitional and minimal state of matter. There is not much liquid in the universe, in our solar system or on earth. If one drained all the water and oil from the Earth it would become a little ball of water with an oil film less than the size of the end of your thumb as compared to a two foot diameter earth.[23]

The earth is mostly solid, saturated and surrounded by gases. As liquid is a transitional and minimal state of matter, it could therefore be a clear indication that oil, a liquid, may be a comparatively limited global energy resource as compared to coal, a solid, and natural gas, a gas. If you think of it this way, the energy sources that fueled civilization from the beginning through the Industrial Revolution were Solids, then a Liquid transition took us to the "modern world." Then what would be the future? I call it The Age of Energy Gases, as depicted in the next figure [Fig. 7], which has the capacity for the first

Global Energy Waves

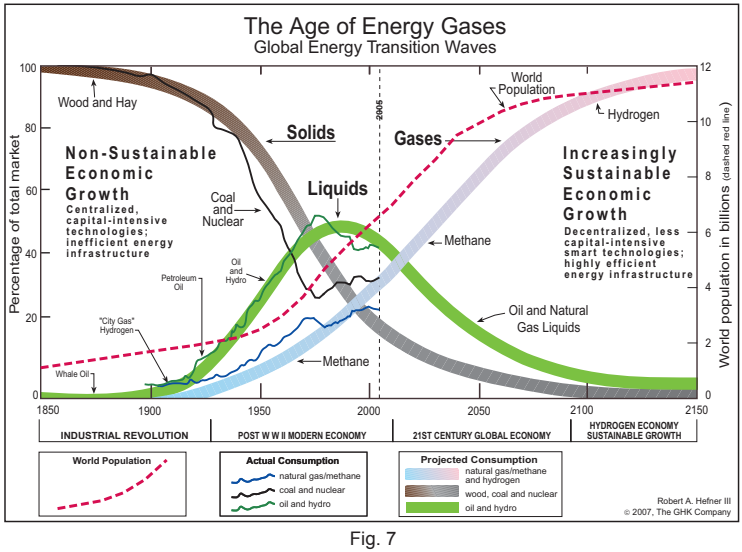


Fig. 7

time in human history to transition civilization to fully sustainable growth for millenniums to come.

The Age of Energy Gases begins with a common natural gas, methane or CH_4 – only one carbon and four hydrogen atoms. Further out in the wave of energy gases, say 2050, after the natural gas infrastructure based upon the use of gas, not solids or liquids, is in place, we will accelerate a transition through a similar and largely in-place methane infrastructure, to a hydrogen (also a gas) based economy. By studying Fig. 7 we can see that as we move across these energy waves over time we have been de-carbonizing or we might say we have been "hydrogenising" our energy consumption. Indeed, the past 150 years has seen a greening and cleaning of our energy sources.

It is my long-term concept that for millenniums civilization existed with only the basic technologies, then grew with waves of accelerating technological innovation originally fueled by dirty, inefficient solid fuels, mostly wood and coal. Then, in the 20th Century, a rapid and what will become a relatively short lived liquid oil transition began that once again provided the fuel for another exponential technological pulse that began at the close of WWII and spurred the creation of the modern connected and globalized society that we live in today. This technological pulse, fueled by cheap energy, allowed for the exponential growth in population that also began at the close of WWII[24]. We have been caught in a conundrum where low-priced energy, resulting from decades of supplies far in excess of demand, provided for exponential population growth that must be fueled by more energy consumption. As long as the energy input was cheap, the cycle accelerated. But now, because of large increases in the price of energy as a result of supply and demand balances, and even more important, the dramatic acceleration of external costs of coal and oil, human creativity will once again seek technological innovation that will be fueled by a less costly (including externalities) primary energy source at an exponential rate of growth. This time the principal source will be gases, beginning with methane. And this time the transition will once again last for millenniums because the hydrogen economy will allow the earth to sustain its forecasted population growth as well as the economic growth created by waves of technological innovation to come.

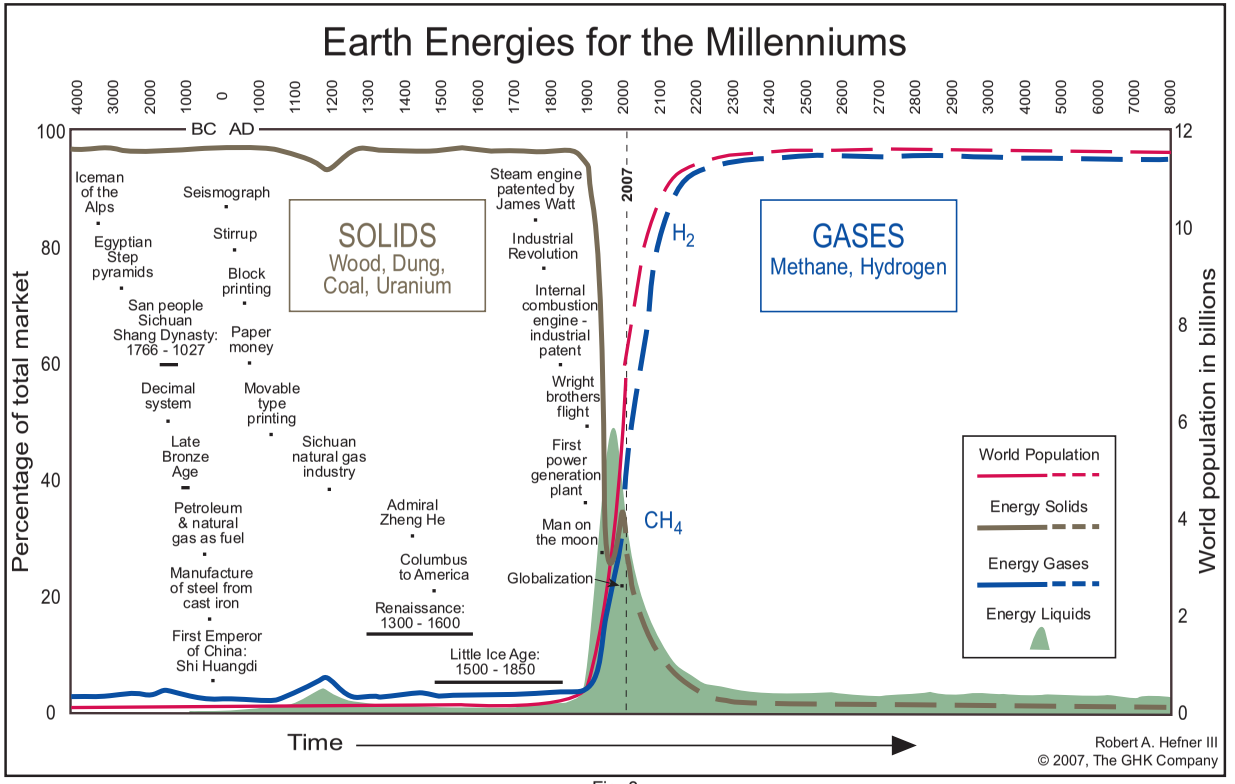

Earth Energies for the Millenniums
4000 3000 2000 1000 0 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 4000 5000 6000 7000 8000
BC AD
Percentage of total market
World population in billions
100 80 60 40 20 0
12 10 8 6 4 2 0
2007
SOLIDS
Wood, Dung, Coal, Uranium
GASES
Methane, Hydrogen
H_2
CH_4
Iceman of the Alps
Egyptian Step pyramids
San people Sichuan Shang Dynasty: 1766 - 1027
Decimal system
Late Bronze Age
Petroleum & natural gas as fuel
Manufacture of steel from cast iron
First Emperor of China: Shi Huangdi
Seismograph
Stirrup
Block printing
Paper money
Movable type printing
Sichuan natural gas industry
Admiral Zheng He
Columbus to America
Renaissance: 1300 - 1600
Little Ice Age: 1500 - 1850
Steam engine patented by James Watt
Industrial Revolution
Internal combustion engine - industrial patent
Wright brothers flight
First power generation plant
Man on the moon
Globalization
World Population
Energy Solids
Energy Gases
Energy Liquids
Time
Robert A. Hefner III
© 2007, The GHK Company

Fig. 8

Hydrogen is a totally clean and fully sustainable form of energy. Hydrogen, one of the basic elements of nature, is the universe's simplest and most abundant element, accounting for more than 90% of the observable universe. Hydrogen bound in water and organic forms accounts for more than 70% of the Earth's surface.[25] When hydrogen is burned with oxygen only heat and water are produced[26]. The hydrogen economy is technologically possible today; cars, planes, boats, power plants and towns have already been fueled with hydrogen, so the technology is basically in hand and is not something that is yet to be invented. What is needed is a *long-term* commitment by governments to provide research and development funding for natural gas, hydrogen and hydrogen technology, with incentives like those given in the past to coal, oil and nuclear, and commitments by nations equal to the one that put man on the Moon.

Today's emotional rush to biofuels, nuclear and "clean coal" are not solutions but rather only unsustainable attempts to continue along the "business as usual" scenario by adding some modern but generally uneconomic, inefficient solid and liquid technologies that will increasingly be subsidized by governments and paid for by society in the form of increased taxation. Biofuels are already driving up food costs that literally hit the poor "where they live." If subsidized and mandated by policymakers, biofuels are likely to continue to push up core inflation, causing central bankers to raise interest rates, and we will all suffer the macroeconomic consequences of higher costs and fewer jobs. So why move to biofuels, particularly when they are not that good at reducing pollution and in many cases require nearly as much energy to make as is produced?

Nuclear works; however, we do not yet know what the real cost of nuclear waste storage will be, nor can we measure the potential cost to society of accidents or dirty bomb attacks as a result of nuclear proliferation, so one way or another, nuclear energy will need to be subsidized by the taxpayer. Today, there are 442 nuclear plants in operation worldwide[27] that produce about 17%[28] of the world's electric power demand and even if over the coming three decades the 29 nuclear plants now under construction and the additional 100 planned plants[29] are actually built, nuclear energy would only then supply about

22% of the world's electric power. Nuclear will be increasingly capital intensive, difficult to license, site and finance and a new plant will take most of a decade from decision to build to completion. Realistically, I cannot see nuclear becoming a principal energy source of the world's demand for electric power in the next 30 years.

The words "clean coal" are nothing more than a dirty trick used by a 19th Century industry willing to do almost anything to keep from going out of business. The only so called "clean coal" will require sequestration – underground storage, a technology whose cost cannot be yet realistically measured. Nor do we know if there are sufficient sub-surface geological reservoirs to store all the CO_2 and once there, if the CO_2 will stay in place. To sequester 60% of America's CO_2 emissions from coal-fired power plants, 20 million barrels a day of liquid CO_2 would need to be pumped into the ground[30]. To physically and economically pump these volumes will be no easy task as they equal about four times America's daily crude oil production[31]. And, even if the CO_2 is sequestered, what will happen to the toxic pollutants of sulphur, mercury and ash? Suffice to say there is no such thing as "clean coal." Totally clean power can only be produced from solar, wind, hydro, tides, and hydrogen, and, unfortunately, although solar and wind will continue to grow rapidly and be supported by policymakers, solar and wind will not be capable of providing to humankind a principal energy solution. Additionally, because natural gas fueled power emits only half the CO_2 as coal and none of the other pollutants, there is a reasonable possibility that natural gas power sequestration could become commercially feasible. If so, then natural gas can be added as a source of totally clean electric power generation.

Instead of heading off in so many different energy directions believing in the need for all forms of energy and energy diversification, as has recently been the case, what we must rather do as we enter the 21st Century is to "*follow the technology."* Technology is clearly leading us from complex chemistry of dirty, carbon rich solids (coal: $C_{135}H_{96}O_9NS$), through a carbon rich liquid transition (oil: C_5H_{12} to $C_{36}H_{74}$), to simpler and simpler chemistry (natural gas: CH_4) with less and less carbon, and pointing us toward the simplest chemistry and

cleanest source, with no carbon at all, hydrogen itself (H_2). *We are going from centralized, highly capital intensive, inefficient power plants that burn dirty, chemically complex solids toward decentralized, less capital intensive, highly efficient, smaller, smart power systems that burn chemically simple, clean natural gases.* Our future will have smaller and smaller forms of energy converters, located closer and closer to energy demand and decision making. We will have smart energy technology with computers moving toward nanotechnology implanted throughout the energy system from production through transportation to consumption. And possibly most important to the efficiency of consumption, we will move from regulated and bureaucratic, centralized, top-down highly inefficient energy decision making to flexible, cost saving smart systems efficiently controlled by the individual, family or neighborhood and tailored to meet continuously changing local needs. These new technologies will spawn new waves of efficiency, conservation and savings that will once again increase productivity within our economic systems by orders of magnitude. Consumption itself will become vastly more efficient. But, none of this is possible without basically a new energy infrastructure built for The Age of Energy Gases.

The Age of Energy Gases is the path that will move civilization away from coal-fueled non-sustainable growth, as was the case during the Industrial Revolution in England, the Pittsburgh killer fogs in the 1940's in America and in most of China today, toward fully sustainable economic growth. In the case of oil, we will be moving from a fuel with impending limitations that is largely concentrated in politically less stable regions to a fuel – natural gas – that, unlike oil, is abundant and more widely distributed globally. Once again, those who think of "oil and gas" as one industry also think because Russia, Iran and Qatar currently have the largest measured quantities of natural gas[32] that we will be jumping from an oil OPEC frying pan into a natural gas OPEC fire. I doubt this because natural gas's widely spread global abundance will provide for significantly more diversification of supplies than is the case with oil. The natural gases wave will move us away from strategic instability, unsustainable CO_2 emissions, polluted cities, degraded environments and global climate

warming to less and less CO_2 emissions with more sustainable and secure growth. The barriers to entry into The Age of Energy Gases will not be issues of supply, technology or economics, but the lack of natural gas understanding and the will of policymakers to end our unsustainable and addictive use of coal and oil.

I believe that the next great wave – The Age of Energy Gases – will be the wave that Asia rides. The western economies have two major impediments to becoming energy *leaders* in the 21st Century: 1) the existence of a largely coal and oil based energy infrastructure with enormous unamortized capital investment, and 2) democratic political systems and cultures that are based on short-term policy needs and are not well suited for the creation of fundamental long-term policy adjustments. Long-term transformational energy planning is not going to happen in America without a catastrophic crisis. It took the Cold War and Sputnik to spur the U.S. to a decade-long plan to put a man on the Moon. So for at least the near-term, the West will remain stuck in the straitjacket of 19th and 20th Century energy infrastructures.

An indication of Asia's energy future may be the fact that along with Asia's wave of recent economic and technological rise, there has also been significant growth in Asia's natural gas discoveries and use. As has often been the case, Singapore is leading the way by fueling more than 80% of its power generation with natural gas and has plans to become a globally important natural gas physical and financial trading center. Singapore already has in place two hydrogen filling stations used by a number of cars and buses.

China, as the driving force in the rise of Asia, has before it a superb opportunity for global energy *leadership* in the development of clean and green natural gas and hydrogen based energy technologies. By choosing a 21st Century natural gas path, China will be able to economically develop an energy infrastructure over a comparatively short time that will provide environmentally sustainable and increasingly efficient internal economic growth necessary to sustain and enhance its internal stability. Externally, over the long-term, this path will reduce global pressures related to increasing oil use and will also significantly reduce global CO_2 emissions. And over the short-term, an energy *leadership* commitment by China toward a clean

energy path would enhance its position in the world as a responsible "stakeholder" in the maintenance of external peace and, at the same time, add substantially to its Soft Power. The path of energy *leadership* will not only create a giant new global market for green energy technology but will be fundamental to China's Peaceful Rise. As Chou En-Lai said, "The helmsman must guide the boat by using the waves, otherwise the boat will be submerged by the waves."

Endnotes

[1] U.S. Department of Energy, Energy Information Administration, *International Energy Outlook* 2006, p. 96.

[2] *Stern Review on the Economics of Climate Change*, 700-page report released October 30, 2006 by economist Nichols Stern for the British government.

[3] "Mathematical model forecasts year conventional oil will peak," *Oil & Gas Journal*, May 7, 2007; "The Looming Oil Crisis Could Arrive Uncomfortably Soon," *Science*, Vol. 316, April 20, 2007.

[4] "Clear Water, Blue Skies: China's Environment in the New Century," The World Bank, September 1997.

[5] "China: Developed Nations Should Take Lead in Emissions Fight," *Wall Street Journal*, April 26, 2007, saying China is predicted to overtake the United States as the world's biggest source of greenhouse gasses this year.

[6] "Proposal for Cooperation Between the People's Republic of China and GHK (China) Limited," Robert A. Hefner III, The GHK Company, 1985.

[7] The EPA has estimated that on some days, about 25% of the pollution in Los Angeles comes from China. "The Greening of Geopolitics," by Thomas L. Friedman, *The New York Times Magazine*, April 15, 2007.

[8] "Clear Water, Blue Skies: China's Environment in the New Century," The World Bank, September 1997; "Economic Boom, Environmental Bust," by Elizabeth C. Economy, *National Post*, October 22, 2004; "New China, New Crisis," *The Observer*, January 7, 2007. China's State Environmental Protection Administration (SEPA) uses a figure of 3%.

[9] To meet global demand for oil in a "business as usual" scenario, the International Energy Agency's *World Energy Outlook 2006* says the oil industry needs to invest a total of US $4.3 trillion (in 2005 dollars) over the period 2005-2030 in capital expenditure.

[10] "Because the atmosphere is rich in oxygen, any methane released into it will spontaneously transform into carbon dioxide and water on a time scale of about ten years." From *The Deep Hot Biosphere*, by Thomas Gold, published 1999 by Springer-Verlag New York Inc., pg. 15.

[11] "Shale gas plays expand," *E&P* magazine, March 2007; "When your gas reservoir is unconventional so is our solution: Shale gas," Schlumberger white paper, October 2005.

[12] *BP Statistical Review of World Energy*, June 2006.

[13] AAPG Memoir 78, *Giant Oil and Gas Fields of the 1990's*, 2003.

[14] "A typical recent-year production car gets about 28 EPA adjusted mpg on level city streets. Where does the energy in that fuel go? About 85-87% is lost as heat and noise in the powertrain – engine, pollution controls, the mechanical drivetrain transmitting torque to the wheels – or in idling at 0 mpg (which wastes 17%). Only ~17% reaches the wheels in EPA testing, or ~12-13% in actual driving using accessories; ~6% accelerates the car. Since ~95% of the mass moved by that ~12-13% of the fuel energy is the car, not the driver, the car uses less than 1% of its fuel to move the driver." *Winning The Oil Endgame*, by Amory Lovins, E. Kyle Datta, Odd-Even Bustnes, Jonathan G. Coomey and Nathan J. Glasgow; published 2005 by the Rocky Mountain Institute

[15] "China and The Price of Gas," *Parade* magazine, *The Oklahoman*, April 1, 2007.

[16] "Things to Come" commentary by Arnaud De Borchgrave, UPI Editor at Large, November 9, 2006: "China is expected to field 170 million cars and trucks by 2020 and 400 million by 2030."

[17] *Highway Statistics 2005*, Publication No. FHWA-PL-06-009, pg. II-3.

[18] "The Future of Coal," an interdisciplinary MIT study, summary report, 2007, pg. ix: "China is currently constructing the equivalent of two, 500 megawatt, coal-fired power plants per week and a capacity comparable to the entire UK power grid each year."

[19] The Gas Technology Institute (GTI) spends about $25 million per year on natural gas research.
[20] "Potential Supply of Natural Gas in the United States," Report of the Potential Gas Committee, Potential Gas Agency, Colorado School of Mines, published September 2005, page 111; "Methane on Ice", *Chemical & Engineering News*, August 22, 2005, Volume 83, Number 34, pp. 16-17; E-Mail communication from Arthur H. Johnson, Hydrate Energy International, May 21, 2007: "The best global estimates of gas hydrate in place come from the USGS World Energy Assessment. The estimates span three orders of magnitude: 100,000 to 270,000,000 tcf."
[21] Cesare Marchetti and Nebojsa Nakicenovic, 1979, "The dynamics of energy systems and the logistic substitution model," RR-79-13, 73 p. and Nebojsa Nakicenovic, 1986, "Patterns of change: Technological substitution and long waves in the United States," WP-86-12, 32 p., International Institute for Applied Systems Analysis, Laxenburg, Austria.
[22] *BP Statistical Review of World Energy*, June 2006.
[23] Woods Hole Oceanographic Institution; Dave Gallo.
[24] "World Population Estimates and Projections by Single Years: 1750 – 2150," Population Reference Bureau.
[25] "Hydrogen Futures: Toward a Sustainable Energy System," Worldwatch Institute Paper 157, August 2001.
[26] "Hydrogen as an energy carrier," www.hydrogenassociation.org/general/faqs.asp, April 10, 2007.
[27] "Nuclear energy is resurgent," *Washington Post*, January 6, 2007.
[28] "Nuclear Energy to Power China," PRLog.Org, June 1, 2007.
[29] "Nuclear energy is resurgent," *Washington Post*, January 6, 2007.
[30] "The Future of Coal," an interdisciplinary MIT study, summary report, 2007, page ix.
[31] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, March 2007.
[32] *BP Statistical Review of World Energy*, June 2006.

About the Author

Robert A. Hefner III is Founder and Owner of The GHK Company (www.GHKCo.com), a private natural gas exploration and production firm with offices in Oklahoma City, Oklahoma, USA. Hefner founded GHK in 1959 and from the 1960s through the 1980s, GHK led in the development of technology necessary to successfully drill and produce many of the world's deepest and highest pressure natural gas wells. Hefner was also a leader in the industry's successful efforts to deregulate the price of natural gas and he appeared 18 times before Congressional committees testifying on energy matters in the 1970's and 1980's. In 1997, Hefner discovered one of America's larger onshore natural gas fields. GHK continues as one of Mid-Continent America's active natural gas exploration and production companies. Hefner is a member of the Dean's Councils at Harvard's John F. Kennedy School of Government, is a Member of the International Council at Harvard's Belfer Center for Science and International Affairs, is on the Council of Advisors at the National Geographic Society, is a Fellow of the Royal Geographical Society of London, and is a Fellow National in the Explorers Club. For over two decades, Hefner has actively pursued his interest in China in the areas of energy, foreign affairs, and art. His collection of contemporary Chinese oil paintings (www.HefnerCollection.com) is amongst the world's most important. Recently, he and his wife, MeiLi, established the Hefner China Fund at the National University of Singapore's Lee Kuan Yew School of Public Policy and Harvard's Kennedy School of Government. The Fund financially assists up and coming Chinese working in government to further their education.

THE GHK COMPANY

6305 Waterford Boulevard, Suite 300
Oklahoma City, Oklahoma 73118-1116 USA
Telephone: 405/858-9800 • Telefax: 405/858-9898
E-Mail: ghk@ghkco.com