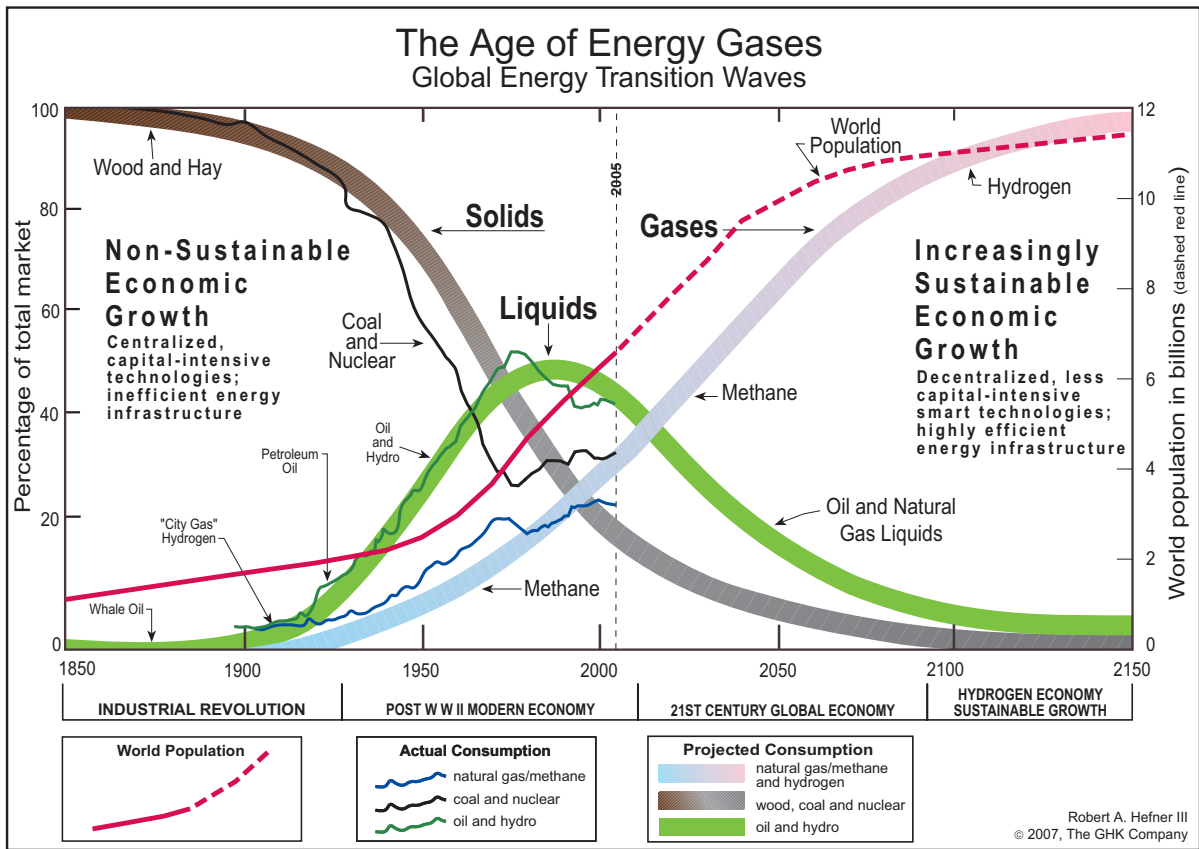


# The Age of Energy Gases

## Natural Gas Abundance



**Robert A. Hefner III**  
**Oil & Money 2007 Conference**  
*Shifting Power in the Global Oil Industry*  
 October 30 & 31, 2007  
 London

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I believe that 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 21<sup>st</sup> Century, a transition will accelerate toward totally clean hydrogen. In a climate-constrained world, natural gas is a positive step forward because when consumed it releases about one half or less CO<sub>2</sub> to the atmosphere as coal and about 30% less CO<sub>2</sub> than oil.

Hydrogen and the hydrogen economy should become civilization's energy endgame. Only within a hydrogen-based economy that produces virtually no energy pollutants and releases no CO<sub>2</sub> to the atmosphere 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.

In order for my theory of The Age of Energy Gases to be credible the global supplies of natural gas must be large. The large or even vast supplies of natural gas around the world are becoming more apparent each year as more and more very large natural gas fields are discovered. 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 and sometimes no oil.

We must abandon the long-held concept of "oil and gas" where "gas" comes second, as a little-valued by-product of oil. 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 the parameters of oil exploration. Natural gas is lighter than air and cannot be seen or smelled; oil is a viscous smelly 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 over geologic time for million of years and, although a so-called greenhouse gas<sup>1</sup>, 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 between oil and natural gas is that natural gas is commercially produced from many reservoir rocks that could not commercially produce one drop of oil.* Because natural gas can be commercially produced from all the volumes of rocks that contain oil, as well as vast volumes of rocks, particularly tight sandstones, shales and coals that contain no oil, the global volumes of sediments capable of producing natural gas are at least twice and probably closer to several times the volumes of rocks capable of oil production. Additionally, because natural gas is a lighter than air gas, it flows naturally from its reservoir to the surface. Because oil is a viscous liquid it generally does not flow to the surface unless assisted by natural gas contained in the oil. As a result, most natural gas fields produce 70% to 80% of the natural gas originally in place while most oil fields only produce 30% or less of the oil in place unless secondary or tertiary recovery methods are used that will increase many oil field recoveries to about 50% to 60%.

*A second significant difference between oil and natural gas is that in most sedimentary basins of the world very little oil is produced below a depth of 15,000 to 18,000 feet, yet very large and giant natural gas fields exist below these depths.* Because throughout its history natural gas has been priced at a discount to oil, very little exploration of the vast quantities of potential reservoir rocks at these depths have been explored, yet sedimentary basins exist to depths of at least 50,000 feet and potentially commercial quantities of natural gas have been found below 30,000 feet. As a result, there are hundreds of thousands, if not millions, of cubic miles of deep sediments within the world's hydrocarbon producing basins that remain unexplored. The point here is that as the price of natural gas rises to a parity with oil, very large supplies of natural gas exist that will be discovered and developed, often within large consumption areas of the world such as the USA and China. By including the vast quantities of deep sediments and the equally vast quantities of sediments at shallower depths that commercially produce natural gas but not oil, there are at least several times the volumes of rocks capable of producing natural gas than those that produce oil and with natural gas recoveries from those reservoirs averaging about twice those of oil, it becomes a reasonable assumption that the global supplies of natural gas are at least twice those of oil. A recent, important and good example of large volumes of rocks that have historically produced virtually no oil are shale reservoirs that have 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%<sup>2</sup>, and the technologies to produce these shale reservoirs are continuing to improve each day [Fig. 1]. Natural gas is pervasive around the world, whereas about 65% to 70% of all oil reserves<sup>3</sup> 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. And the U.S. is blessed by the existence of a million mile pipeline system that provides natural gas distribution to most Americans. For this reason, to displace the use of coal and oil in America is relatively inexpensive and easy to accomplish.

### American Shale Gas Deposits

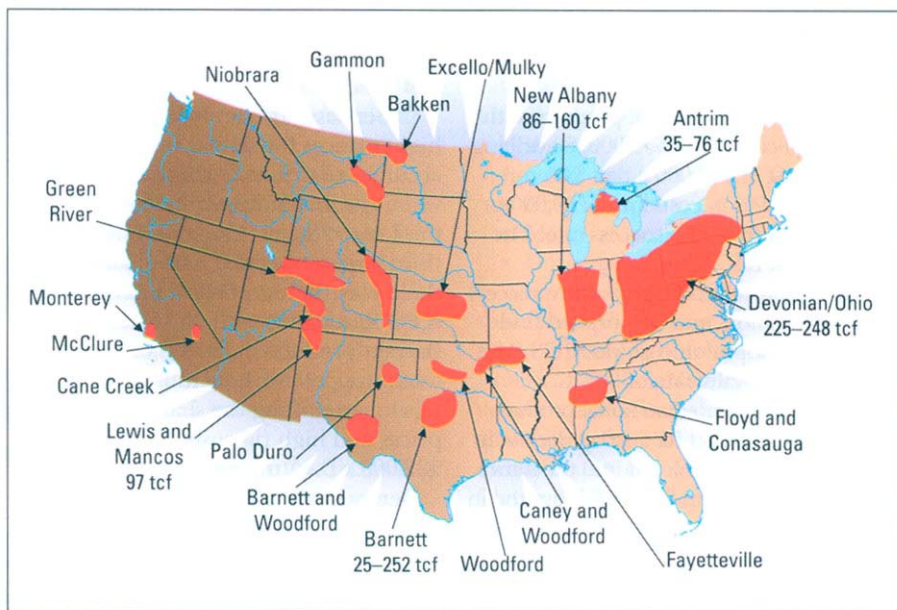


Fig. 1: Gas shale deposits appear in basins from the east to the west coast across the United States. Although recovery percentages are low, total volumes are high. (Map courtesy of Schlumberger)

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* and the “petroleum” courses follow the name, with students learning basically about oil, not natural gas.

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”<sup>4</sup> 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 in spite of its environmental and security of supply advantages, 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.

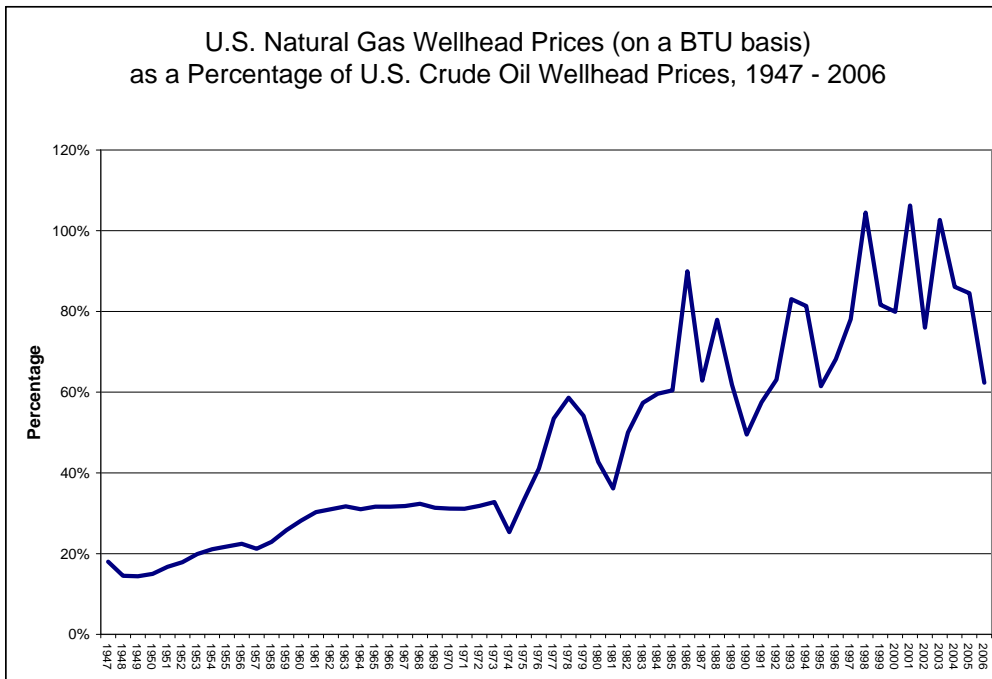


Fig. 2: Natural gas price, on a BTU basis, as a percentage of oil.

Only in the last few years has the market begun to price natural gas as an important commodity but at a price 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. However, an excellent example of the oil bias, that I highlighted in the 1970’s, was Exxon’s 1976 study that said the U.S. natural gas resource base was about 287 trillion cubic feet<sup>5</sup>. As a result of Exxon’s unrealistically low estimates for U.S. natural gas supply, Gordon Zareski, Chief of the Resource

Evaluation & Analysis Division, Bureau of Natural Gas, of the Federal Power Commission, testified before Congress in 1977 that: “The basic underlying cause of the natural gas shortage is the simple fact that the nation is running short of economically recoverable gas resources that can be readily converted to producible reserves.”<sup>6</sup> Also in 1977, John O’Leary, Administrator of the Federal Energy Administration said often that “natural gas has had it.”

Exxon’s 287 Tcf number compared to the 1,500 to 2,000 Tcf I forecast in my presentation “The Future for Conventional U.S. Natural Gas Supply” at the Aspen Institute’s 1978 energy forum<sup>7</sup> and the 584 Tcf actually produced in the U.S. since 1975<sup>8</sup>. Today most “expert” natural gas resource estimators have caught up to my 1978 estimate of 1,500 to 2,000 Tcf, but, because of recent price increases and technology improvements, my estimate for the U.S. is now at least in the range of 3,000 to 3,500 Tcf.

Although the natural gas market is only now in its infancy as a global commodity, the past few decades have seen natural gas to be the fastest growing primary energy. 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. However, in spite of the heavy oil bias that I believe keeps the natural gas reserve and resource estimates at less than half of what they realistically must be, the consensus of world natural gas supplies are certainly adequate to provide significant increases in global natural gas consumption. The International *Petroleum* Encyclopedia (my emphasis) estimates between 6,686 Tcf to 9,708 Tcf have been discovered<sup>9</sup> and with an annual consumption rate of about 100 Tcf<sup>10</sup> that gives us 67 to 97 years of natural gas at current rates of use. The key is what are the remaining undeveloped supplies? It is not surprising that there is very little information about global natural gas resources. So, what I believe is needed today to differentiate natural gas understanding from oil and to alleviate the fears of insufficient natural gas resources is 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.<sup>11</sup> 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. 3], 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. 4]. 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. 3: 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

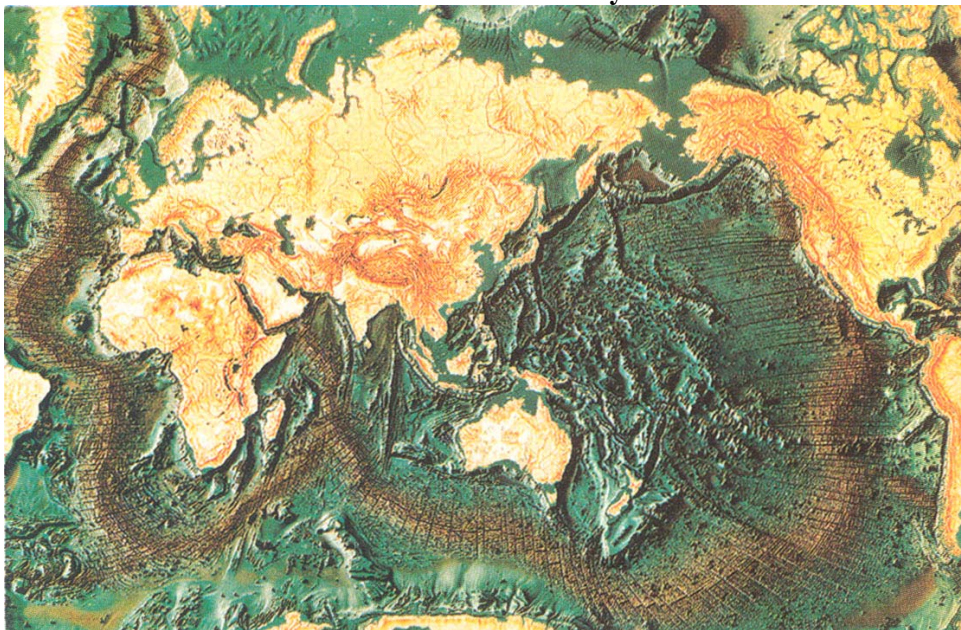


Fig. 4: 40,000 mile mid-oceanic rift system. *Discover Magazine*, June 2007.

- 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<sup>12</sup> than all the energy contained in the world's coal and oil combined [Fig. 5], and only in the last several years have very limited experiments begun to test how natural gas hydrates can be commercially produced;

### Global Natural Gas Hydrates

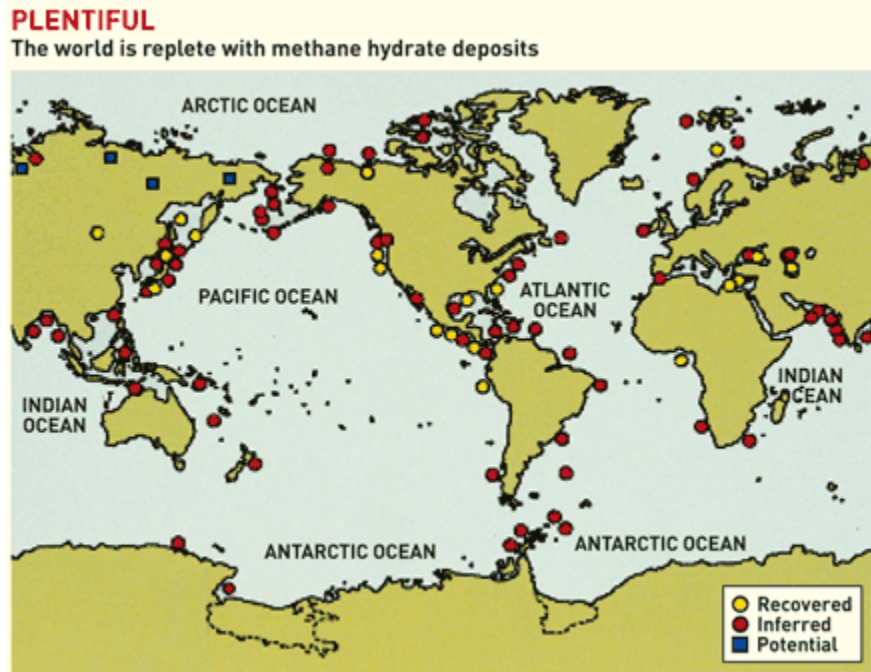


Fig. 5: Source: U.S. Geological Survey.

- 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.

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 CO<sub>2</sub> 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<sup>13</sup> 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<sup>14</sup>. That fact fascinated me, particularly because energy transitions are better defined by the *percentage* of the market the individual fuel holds and tend to be obscured by the quantities of the fuel consumed. 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 [Fig. 6].<sup>15</sup>

### Water Planet?

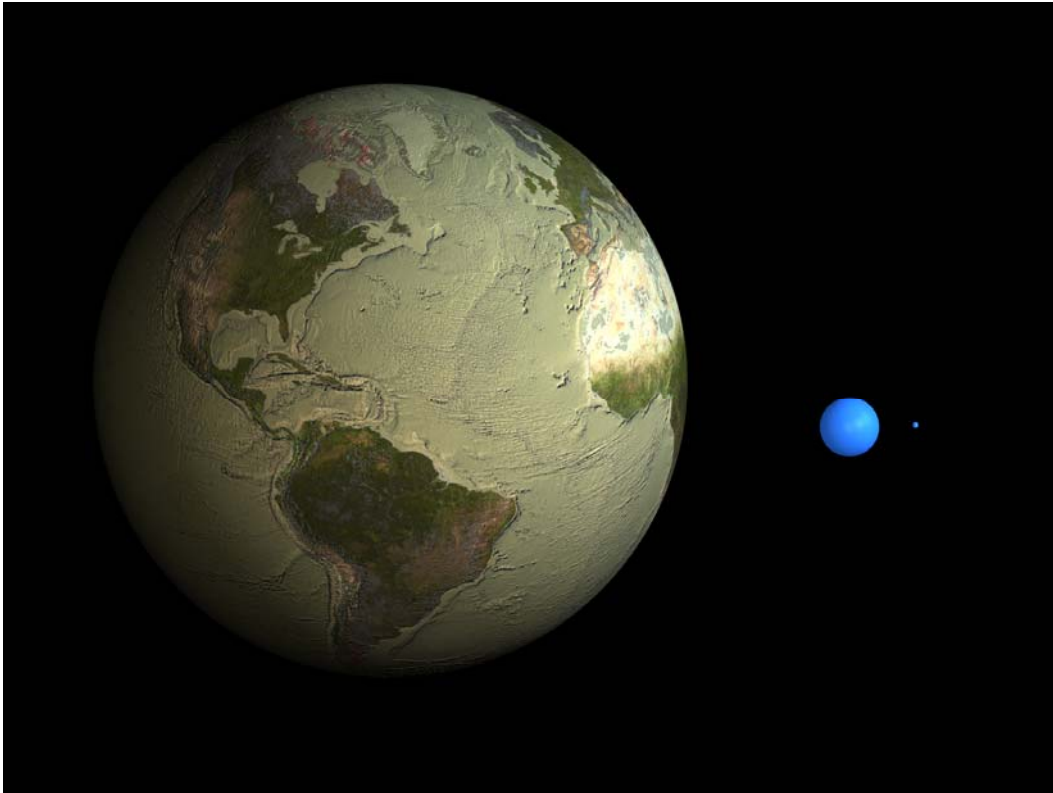


Fig. 6: Water Planet? We frequently hear that more than 70% of the world is covered by water. But how much is there really? On the left is an image of the Earth with all water removed. On the right is a sphere representing all the water on Earth (oceans, icecaps, glaciers, lakes, rivers, groundwater etc.). To the far right (tiny sphere) is the FRESH water that is readily available to humanity to sustain life. Courtesy of Woods Hole Oceanographic Institution.

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

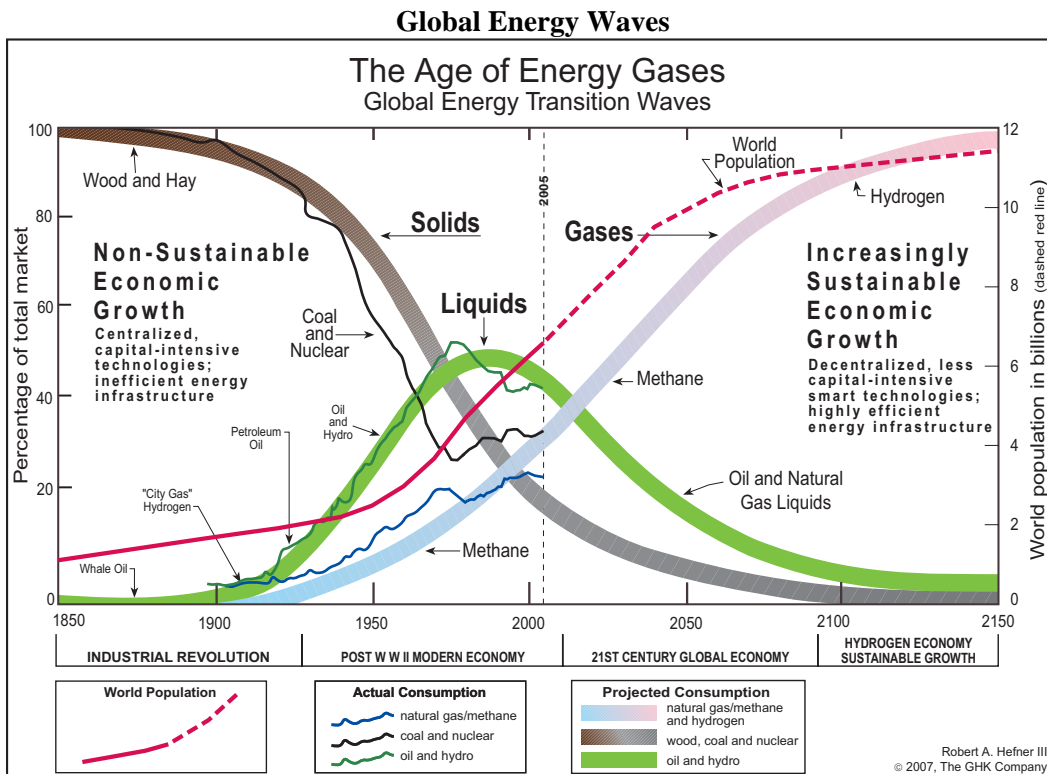


Fig. 7

The Age of Energy Gases begins with a common natural gas, methane or  $\text{CH}_4$  – only one carbon and four hydrogen atoms. Further out in the wave of energy gases, say 2050 or even later in the 21<sup>st</sup> Century, 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<sup>16</sup>. 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. This wave has already begun, as can be clearly seen on The Grand Energy Transition chart [Fig. 8]. 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.

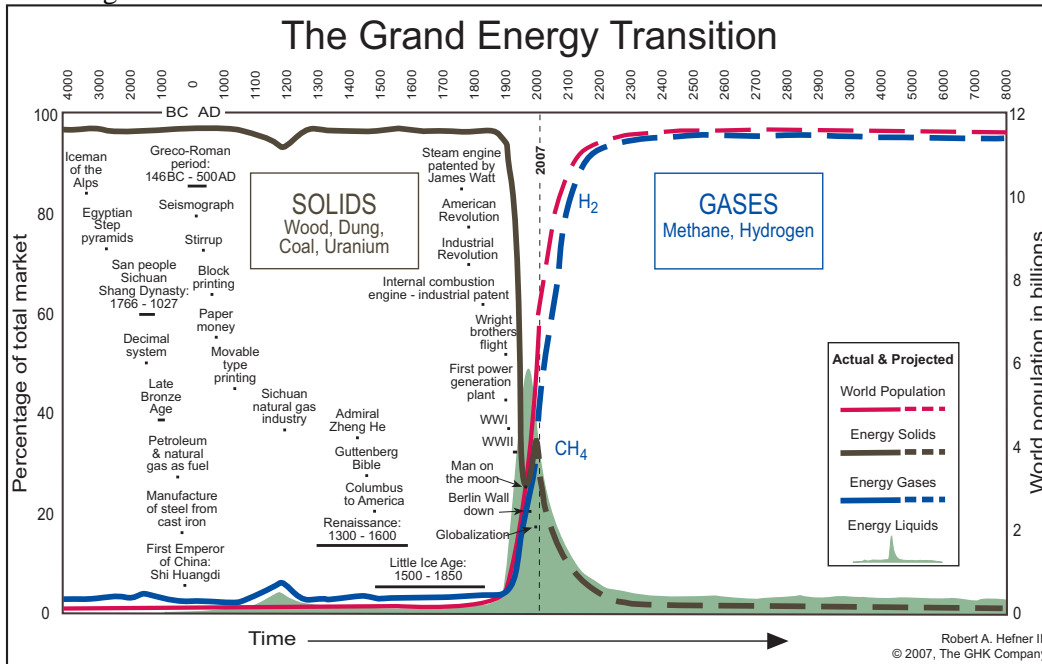


Fig. 8

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.<sup>17</sup> When hydrogen is burned with oxygen only heat and water are produced<sup>18</sup>. 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<sup>19</sup> that produce about 17%<sup>20</sup> 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<sup>21</sup> 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<sub>2</sub>, and once there, if the CO<sub>2</sub> will stay in place. To sequester 60% of America's CO<sub>2</sub> emissions from coal-fired power plants, 20 million barrels a day of liquid CO<sub>2</sub> would need to be pumped into the ground<sup>22</sup>. To physically and economically pump these volumes will be no easy task as they equal about four times America's daily crude oil production<sup>23</sup>. And, even if the CO<sub>2</sub> 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<sub>2</sub> as coal and almost 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<sub>135</sub>H<sub>96</sub>O<sub>9</sub>NS), through a carbon rich liquid transition (oil: C<sub>5</sub>H<sub>12</sub> to C<sub>36</sub>H<sub>74</sub>), to simpler and simpler chemistry (natural gas: CH<sub>4</sub>) with less and less carbon, and pointing us toward the simplest chemistry and cleanest source, with no carbon at all, hydrogen itself (H<sub>2</sub>). *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, neighborhood or office building 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<sup>24</sup> 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<sub>2</sub> emissions, polluted cities, degraded environments and global climate warming to less and less CO<sub>2</sub> 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.

### **About the Author**

Robert A. Hefner III is Founder and Owner of The GHK Company, a private natural gas exploration and production firm with offices in Oklahoma City, Oklahoma, USA. Mr. Hefner founded GHK in 1959 and, from the 1960's through the 1980's, 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. Mr. 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, Mr. 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. Over the past three decades, Mr. Hefner has authored numerous articles concerning natural gas and its abundance, natural gas's difference from oil, and the importance of natural gas for sustainable long-term economic growth. He is currently writing a book on his theory of "The Age of Energy Gases." For over two decades, Mr. Hefner has actively pursued his interest in China in the areas of energy, foreign affairs, and art. Mr. Hefner a Member of both the Dean's Councils and the International Council at the Belfer Center for Science and International Affairs at Harvard's Kennedy School of Government, is on the Council of Advisors at the National Geographic Society, is a Fellow of the Royal Geographical Society in London, a Fellow National in The Explorers Club. He and his wife, MeiLi, have a collection of contemporary Chinese oil paintings that are amongst the world's most important ([www.hefnercollection.com](http://www.hefnercollection.com)). Mr. Hefner received his B.S. degree in geology from Oklahoma University.

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<sup>1</sup> "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.

<sup>2</sup> "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.

<sup>3</sup> *BP Statistical Review of World Energy*, June 2006.

<sup>4</sup> AAPG Memoir 78, *Giant Oil and Gas Fields of the 1990's*, 2003.

<sup>5</sup> Paper "U.S. Oil and Gas Potential" by Exxon Company, U.S.A., Exploration Department, March 1976: "Exxon's new study says that the 'attainable potential' – the part of the resource base that might actually be found and produced under currently foreseeable technology and economics – is about 287 trillion cubic feet of natural gas." Also, J.D. Langston, Vice President, Exxon Company, U.S.A., paper "A New Look at the U.S. Oil and Gas Potential," presented to The Sixteenth Annual

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Institute on Petroleum Exploration and Economics, The Southwestern Legal Foundation, Dallas, Texas, March 10, 1976: “287 trillion cubic feet of gas are thought to be undiscovered and attainable.”

<sup>6</sup> Gordon K. Zareski, Chief, Resource Evaluation & Analysis Division, Bureau of Natural Gas, Federal Power Commission, at Hearings before the Subcommittee on Energy & Power of the Committee on Interstate & Foreign Commerce, U.S. House of Representatives, 95<sup>th</sup> Congress, First Session on Long-Term Natural Gas Policy Issues & Questions, March 24, 25 and April 5 1977.

<sup>7</sup> Aspen Institute Workshop on R&D Priorities and the Gas Energy Option, June 25-29, 1978, Aspen, Colorado.

<sup>8</sup> DOE/EIA *Monthly Energy Review*, December 2001 and May 2007.

<sup>9</sup> *International Petroleum Encyclopedia 2005* with charts indicating estimates of future recovery of natural gas to be between 6,686 Tcf and 9,708 Tcf.

<sup>10</sup> *BP Statistical Review of World Energy*, June 2007.

<sup>11</sup> The Gas Technology Institute (GTI) spends about \$25 million per year on natural gas research.

<sup>12</sup> “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.”

<sup>13</sup> 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.

<sup>14</sup> *BP Statistical Review of World Energy*, June 2006.

<sup>15</sup> Woods Hole Oceanographic Institution; Dave Gallo.

<sup>16</sup> “World Population Estimates and Projections by Single Years: 1750 – 2150,” Population Reference Bureau.

<sup>17</sup> “Hydrogen Futures: Toward a Sustainable Energy System,” Worldwatch Institute Paper 157, August 2001.

<sup>18</sup> “Hydrogen as an energy carrier,” [www.hydrogenassociation.org/general/faqs.asp](http://www.hydrogenassociation.org/general/faqs.asp), April 10, 2007.

<sup>19</sup> “Nuclear energy is resurgent,” *Washington Post*, January 6, 2007.

<sup>20</sup> “Nuclear Energy to Power China,” PRLog.Org, June 1, 2007.

<sup>21</sup> “Nuclear energy is resurgent,” *Washington Post*, January 6, 2007.

<sup>22</sup> “The Future of Coal,” an interdisciplinary MIT study, summary report, 2007, page ix.

<sup>23</sup> U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, March 2007.

<sup>24</sup> *BP Statistical Review of World Energy*, June 2006.