NATURAL GAS ECONOMICS: AN UPDATE

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AN INTRODUCTION

In my first energy economics textbook, ENERGY ECONOMICS: A MODERN INTRODUCTION (2000), the title of the chapter on natural gas was *A Fuel of the Future: Natural Gas.* The purpose of that chapter (and some of the remainder of the book) was to convince readers that when oil and coal were on the downward slopes of their cumulative production curves – i.e. annual output was declining – natural gas would still be going strong. My goal was to demonstrate some useful aspects of economics to students and others, and my arguments apparently made sense to many readers. Unfortunately, all of them no longer make sense to me.

In the book I often refer to as *Energy Economics 101*, David Goodstein – professor of thermodynamics at the California Institute of Technology – suggests that the beautiful natural gas future I had in mind, but did not specify in detail, is unlikely to last much past the middle of the present century, even though shale natural gas (and oil) have made a dramatic appearance in the United States (U.S.), and large shale reserves are to be found elsewhere. (This might also be the place to note that natural gas or oil '*reserves'* are the amount of these resources that supposedly can be profitably extracted given current technological limitations.)

Professor Goodstein's logic is quite clear, and similar to the hypothesis that I always offer students when discussing items like crude oil: even if the *reserve-production ratio* – (RESERVES/PRODUCTION) = (Q/q) – for natural gas in the U.S. is about 100 years, which is an estimate quoted by the President of the United States on a number of occasions, there are excellent reasons to doubt that the present annual output could be made available for an entire century.

Before looking at this and similar topics, a few commonplace items need to be mentioned. The CIA Fact-book tells me what I want to know about natural gas reserves, and can also tell you if you turn to their site. For instance, the leading countries where natural gas reserves are concerned are Russia, Iran, Qatar, the United States, Saudi Arabia, Turkistan, the United Arab Emirates, Venezuela, Nigeria and Algeria, in that order. Remember this when the conversation turns from football or fashion to energy, and do not ignore some of the oddball talk about the U.S. exporting large amounts of energy resources, even though at the present time that country is a significant importer of natural gas and oil.

The importing roster for natural gas runs as follows. Germany and Japan are at the top, followed by Italy, the U.K., South Korea, France, the U.S., Russia, Turkey, Spain, China, and a long list of less prominent importers. If you examine a list of natural gas exporters, you will note that many countries are both exporters *and* importers. Geography and price explain this phenomenon.

I have the impression that a number of subjects have not received the attention they deserve in the teaching of energy economics, but as I explained to students in my course on oil and natural gas economics at the Asian Institute of Technology (Bangkok, Thailand), certain things should be learned perfectly, and a few of those items are in this contribution. For instance, reproducing the following diagram is an exercise that students will encounter on many of my examinations.

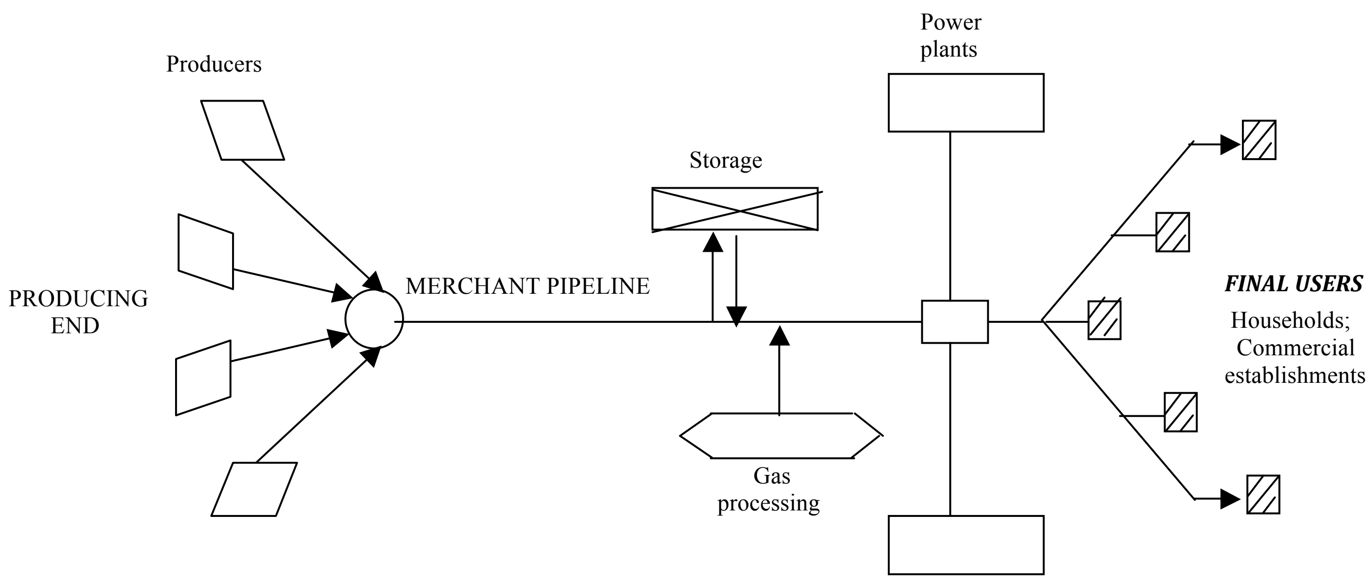


Figure 1

Sadly, my skill with a computer goes no further than basics, because the block in the above diagram that says *power plants* should also indicate that that designation applies to the box of similar size directly below, and is intended to denote *large consumers* of natural gas (like power plants). At the producing end of this scheme the intention is to show gas from various 'wells' going into what are called (large) 'merchant' pipelines, and eventually – after perhaps some processing and storage – reaching large and small consumers. In addition it should be understood that there is a difference between the size of the merchant pipeline and smaller pipelines taking gas to homes and small businesses.

The exact nature of that difference is unknown to me, and I have never been sufficiently curious to alleviate this shortcoming, but such is not the case with the following diagram that deals with the gas transmission process. Here I can mention that

most of my students at the Asian Institute of Technology were graduates in some branch of engineering, however a full comprehension of the next topic requires only some elementary economic theory, or the willingness to acquire a fraction of that background, especially the part outlined in the pages on production theory that you can find fairly early in a textbook on Economics 101.

As you might be aware, the first course in economics is composed of consumption and production theory, with the emphasis on the first. When I complained about this arrangement to Professor Paul Samuelsson, the first American winner of the Nobel Prize in economics, and probably the most respected American economist of the 20th Century, he informed me that anyone who had an intense preference for the latter should study engineering.

That may or may not be good advice, but the opinion here is that the production theory taught in an introductory book like Lancaster (1974) should and does provide more than enough background to make it possible for readers to comprehend what comes in the remainder of this section, beginning with Figure 2.

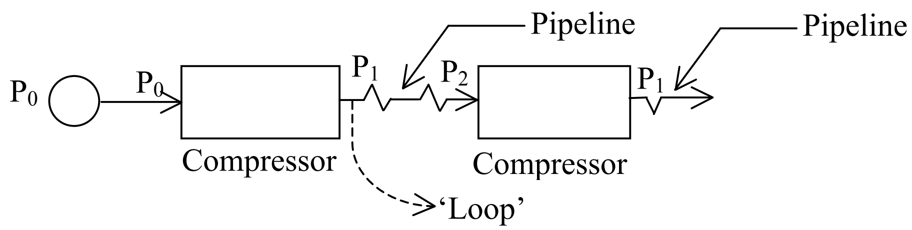


Figure 2

In this figure the P's are pressures, and we begin with gas coming out of the ground at a pressure of P_0, and soon after going into the first compressor at about the same pressure, which is definitely possible, but is not always the case. It would not be likely if the compressor were some distance from the gas well, because in its passage to the first compressor, the gas loses some of its momentum as a result of friction in the pipe. In any event, continuing with the approach shown in the diagram, the compressor raises the pressure to P_1, and in the next stretch of pipe it declines to P_2, following which the compressor boosts it again to P_1…and so on and so forth, assuming also that the pipe lengths are equal.

As for the loop in the diagram, its purpose is to raise the capacity of the pipeline, and sometimes looping is called "twinning". Check GOOGLE on this!

In order to obtain a paper suitable for an economics as compared to an engineering journal (1949), Professor Hollis B. Chenery of Harvard University constructed a model emphasizing the diameter of a pipeline (with equal lengths between

compressors), and the energy required to transmit the gas, where the latter is obtained from sophisticated equipment called compressors that transfer mechanical energy from e.g. the compressor's motor to the gas that is to be transported. It is also the case that the gas could provide fuel for the compressor.

I discussed much of this in my natural gas book (1987), beginning with the implicit equation q = f(P,D), where P is pipeline pressure, and D is the pipeline's diameter. Explicit forms of this equation can be quite complicated, and where engineering is concerned the thickness of the pipe and length of pipe between compressors has to be taken into consideration. Personally, my favorite pipeline is the 1,222 kilometers *Nord Stream* gas pipeline, which is operated by a consortium led by Russia's Gazprom, and pumps 55 billion cubic meters of natural gas a year under the Baltic to Greifswald, Germany. If it were not available to fuel German generators, the electricity I consume would cost more, because Germany would increase its imports of electricity from many countries (to include Sweden).

Issues of the above sort are important for many reasons. For instance, in my work I reject the belief that globally there cannot be an oil or gas peak , although it will not arrive next month or next year. But as the brilliant researcher Gail Tverberg has noted (2014), some politicians in the U.S. insist on an expansion of oil and natural gas because of the unexpected appearance of technology that made possible the exploitation of *very large* amounts of shale resources. As noted earlier however, the fact that the U. S. is a significant *importer* of natural gas (and oil) suggests that in the very long run the U.S. may not be as energy rich as some people believe, and given the expected future population of the country, and domestic energy requirements, energy exports should not be excessive.

SOME ASPECTS OF THE PRODUCTION OF NATURAL GAS

Now we can return to the discussion at the beginning of this contribution. In what follows, it will be suggested that if the reserve-production ratio for natural gas is 100 for virtually any part of the world, then perhaps the best *estimate* of the time to the peaking of output is about 50 years. This assumes that future production profiles of natural gas (or oil) continue to be related to conventional economic and geological practices or influences, and the statistical 'distributions' underpinning these profiles are mostly 'logistic' (as compared to e.g. normal or bell-shaped). Professor Goodstein arrived at the same conclusion, and he also insinuated that 50 years might be too high.

I see no reason for excessive harping on this matter in the present contribution, but the news presented by Mr Obama about gas included the belief that every effort should

be made to turn this assumed 100 year gas bounty into the energy basis of a new American industrial renaissance. As an American citizen I am definitely in favor of a project of this nature, but the mathematical characteristics and relevance of the logistic distribution function make it clear to both Professor Goodstein and myself that American voters and politicians should not launch an industrial renaissance believing that they have 100 years before they begin thinking about when or how they are going to replace a crucial industrial input like natural gas when – or if – that becomes necessary.

Two observers have greatly influenced my view of natural gas economics. The first was the former U.S. Central Bank director Alan Greenspan, who some years ago stated that the U.S. faced a severe shortage of natural gas that had to be dealt with immediately. Strangely enough, something *was* done in the form of a brilliant improvement in the technology for obtaining shale natural gas.

My reaction here was and is that shale natural gas, as well as shale oil, are very important resources, though perhaps not so important as is sometimes believed. The researcher to consult about this issue is J. David Hughes, and his opinions – in the light of the inability to exploit shale deposits in parts of the world more richly endowed with that asset than the U.S. – cannot be dismissed. It is also useful to remember the major (and very expensive) shale failure suffered by a firm that is not in the habit of experiencing failure, by whom I mean Exxon Mobil, and if you have a taste for applied energy economics research, you can join persons like myself in exploring the overall economic and financial significance of the unusually large (natural) depreciation rates for shale deposits, where some estimates of this depreciation are so atypical that I prefer not to mention them.

Note the term "financial"! If indexes for oil or natural gas share/stock prices in the U.S. were 100 in the middle of 2013, they are between 40 and 50 now, and the financial capital typically available to energy firms from banks and bond markets has also been reduced. This should remembered when you reach the section below on futures markets, because apparently it is too late for oil and gas producers to apply the (short) hedging operations mentioned in that section, and which might have been very helpful had they been resorted to earlier. As things stand now (October 2015), the estimated revenues that can be 'locked-in' with futures (or options) are much lower, while the risk that is involved is much higher.

I leave clarification of these matters for another occasion, because at this point I prefer to help readers who are seriously interested in oil and natural gas to know what the logistic distribution function is all about, since fortunately mastering its details

requires only a small amount of concentration and/or patience. The logistic function was mentioned on several occasions by Professor Goodstein, and in my classrooms I have found that a slight extension is valuable.

As you might have been informed somewhere in the middle of your Economics 101 course, producers of various items have a great deal of authority over what and how much they can produce, but geology enters the picture in a decisive manner where the production of fossil fuels (oil, gas and coal) is concerned, and this can complicate matters for students of economics, as well as analysts operating in corporate space. Of course, when managers have to decide how much to produce, then it is routine for them to think dynamically, which in the present context means that they will consider the future as well as the present.

Something to be clear about is that geology functions as what is known in economic theory as a constraint: no matter what the manager would like to achieve, he or she must work with the resources (the deposit or deposits) and the technologies that are available. As far as I can tell, the managers and engineers of energy companies know a great deal about things like geology as well as present or future technology, and if they don't, they know whom they should contact in order to find out what they need. By way of contrast, voters (and politicians) as a group often know very little, and many of them are not interested in improving their knowledge where this subject is concerned. The upshot of this condition is that as a result of their lack of interest, voters and their families run the risk of ending up as members of the loser's club, though perhaps later rather than sooner.

That brings us to Figure 3 and, for example, the claim that the U.S. can expect to enjoy 100 years of natural gas *AT THE PRESENT LEVEL OF CONSUMPTION*. Let me begin by noting that if you look at analogous diagrams for a few hundred oil or gas wells/deposits, most of them will look like 1-c and not 1-b. In fact it is absolutely amazing that when discussions about oil and natural gas production in various regions begins at a few energy conferences, and many academic seminars, attention is not directed at production records and realistic sketches like 1-c for some of the largest oil and gas deposits, but instead focusses on trivial and occasionally incorrect mathematics.

Going to the diagrams just below, a problem is that it is easy to mathematically approximate a Bell curve or Bell-like curve of the type we have in 1-b, but not logistic outcomes such as we have in 1-c, and so we cannot carry out the analytical manipulations that sometimes pass for valid proofs in the faculties of economics. At the same time it can be shown that we need no complicated math to deal with this subject: all we need is Figure 1, and if there are doubts as to its suitability or finesse, I

recommend a brief perusal of the best mathematics book for dealing with this topic, which is CALCULUS FOR THE LIFE SCIENCES, by Rodolfo de Sapio (1976).

In any case, along with the diagrams in Figure 1, it is useful to know to know that the mathematical representation of the logistic 'plot' shown in Figure 1a is $Q = Q'/(1+be^{-at})$, and it equally useful to know that if you differentiate this expression with respect to 't' (i.e. dQ/dt), you obtain the *slope* of Q', which is the same as production (q). The differentiation is easy, but the key thing is the simple 'result' and its interpretation, which is that – *ceteris paribus* – the change in the amount of reserves is equal to the production (q) of the resource.

Perhaps the basic problem now is accepting that Q′ is the total amount of natural gas (or for that matter oil if the discussion is about crude oil) that, to use the expression of David Goodstein, was "initially was made available by nature". Numerical estimates of Q' for oil have been made by the United States Geological Service, and often promptly disputed, because this is a very important variable.

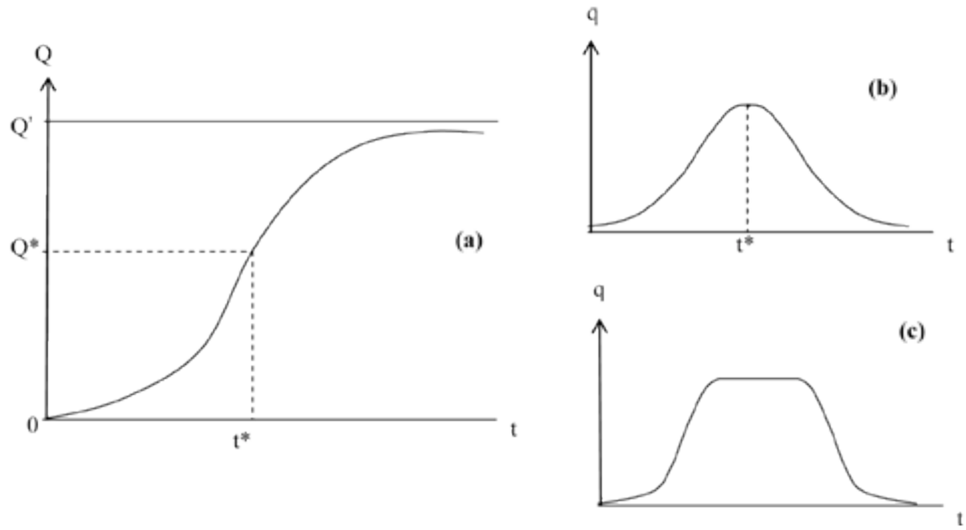


Figure 3

Like Professor Goodstein, I deal with the global rather than a local situation, although since the analysis was valid for oil in the U.S., it should work for natural gas in that country or any other large region. What happens in Figure 3 is that if the total amount of the resource that has been discovered is Q', the correct assumption for the present time (2015) is that globally we are *probably* lower than Q*, and as production (q) takes place we move up the vertical axis past Q* and toward Q' (and the exhaustion of the resource). As is the situation with the logistic curves in your favorite statistics textbook, for mathematical convenience we never discuss reaching Q', but that is unimportant. What is important is that the slope of this curve (which is output per time

period, or q) is shown in the curve in Figure 3-c, *and if the portion of the curve on both sides of (t*, Q*) in 3-a was not 'flat', and the slope along that portion not equal, the output of the resource would peak at (t*,Q*) as in Figure 1-b.* As it is, the flat section in 3-a defines the flat section in 3-c.

This peaking of both natural gas and crude oil is discussed in detail in my textbook ENERGY AND ECONOMIC THEORY (2015), and the peaking of both has taken place in many of producing regions, both for large and small deposits and for individual natural gas (or crude oil) wells. (And you should remember that a natural gas (or crude oil) *field* or *deposit* is defined as one or more subsurface 'reservoirs' or localities where significant amounts of hydrocarbons are found.

If Figure 3-a is applicable for the entire world, with Q' the estimated largest amount of natural gas (or oil) reserves that ever existed, then as noted it is possible that at the present time we are still somewhere below Q*, and to the left of t*. If we limit our consideration to natural gas in the U.S., and calculate the reserve-production ratio, that might well be 100 years, but that does not mean that gas will be available at the present or a higher output for 100 years – although some observers are prepared to argue that this could happen because additional reserves might be located, although the amount is uncertain.

There has been a great deal of talk in every part of the industrial world about the peaking or non-peaking of items like natural gas and crude oil, and I turn again to the opinion of Professor Goodstein, which is that buyers might be subject to some bad news about these resources before many more decades have passed. Not just because the mathematics of logistic curves leave that impression, but because we are dealing with a setting characterized by geological, economic, demographic *and* political uncertainties whose aggregate logic is difficult to grasp, although perhaps no more difficult than the illogic of some voters and politicians.

It also is likely that if q (annual output) is increasing, which is usually the case, then the approximate time to peaking in the example above could be considerably less than 50 years. Of course, predictions might be that Q' (proved reserves) will increase at a *rate* faster than q is increasing for several reasons, one of which is that technological breakthroughs will or have taken place (as was the case with shale gas), but as far as I am concerned the present evidence indicates that it is unwise to be overoptimistic when estimating the natural gas *or* oil futures.

Two more considerations can be noted. Unlike crude oil which can be transported in pipelines, trains or tankers, moving natural gas might be a serious problem. Domestically, pipelines are the only way to move large amounts, and since these are

expensive investments that optimally should be fully utilized throughout their 'lifetime', investors tend to be especially careful. For instance, just now there appears to be a pipeline shortage in the U.S., and as a result, and unexpectedly, there has been some 'flaring' of gas in North Dakota due to a lack of space in pipelines. Apparently billions of dollars of new pipeline capacity has being proposed or planned, but much of this new capacity will never appear.

On the other hand, the greater the amount of gas used in order to supply electricity, the more attractive solar and wind could become, because (fast-start) natural gas equipment can rapidly enter into the electric generation picture on those occasions when the wind is not blowing or the sun is not shining.

NATURAL GAS STORAGE, HUBS AND MARKET CENTERS

The natural gas production-consumption process begins with lifting gas from a 'field' or 'deposit', and as shown in Figure 1 proceeds to a large diameter transmission or 'merchant' pipeline, with perhaps a small amount gas siphoned off to 'run' compressors. After that there might be some sort of processing and often a portion of the gas diverted into storage and/or sales to very large consumers such as manufacturing industries and power plants (i.e. generators of electricity). Eventually the gas goes into distribution systems where pipes are smaller, and via these pipes to 'final consumers' (e.g. households and small businesses). In Germany, there might still be many local distribution companies (LDCs), but since that country has no domestic gas production, they rely on major natural gas producers such as Holland, Norway and Russia.

Storage is another of those subjects which submits to an interesting theoretical treatment. On this occasion the exposition will be non-technical, although readers who want to impress others are advised to pay close attention to the terminology. Strangely enough, storage is almost completely ignored in microeconomics textbooks, despite its importance, because when storage is absent or insufficient, *prices often tend to be extremely volatile*. This is one reason why more storage facilities are being constructed in some countries.

The amount of natural gas in storage is a carefully observed statistic, particularly in the run-up to winter. Low storage levels mean to buyers and governments that palpable shortages of gas that may appear during the coming months could impact heavily on gas prices, as well as the availability (and price) of other fuels, such as heating oil, which is one of the fuels that substitutes for gas in various uses. Often the strategy here reduces to buying natural gas when it is cheap and storing it. A short, easily read and valuable article on this subject is Lee Van Atta (2007), published on the site

EnergyPulse **(www.energypulse.net). He mentions that the majority of present storage development in the U.S. have to do with salt caverns, while much of the rest is in depleted reservoirs.**

Just as transport involves moving a commodity through space, storage performs a similar function with respect to time – 'similar' but not identical, because time runs in only one direction. By putting goods into inventory, we move from the present to the future at finite cost, but the option exists for returning all or a part of these goods to the present if it is deemed profitable.

This suggests that we have a *consistency* problem, in that at time 't' we make a plan for t+1, t+2,…, t+x,…,t+N, where N is the terminal date, but it might happen that at e.g. t + x, we perceive that the decision taken at 't – y' was sub-optimal. While conceivably we would have been happier if we had gotten things right in the first place, holding inventories might be judged an element in a strategy which takes into consideration the possibility of making and – if lucky – correcting expensive mistakes. This strategy not only features storing more or less of the commodity, but relying more heavily on such things as futures and forward markets. Naturally, obtaining increased flexibility generally involves a cost.

An important and accessible article on storage is that of Benoit Esnault (2003), although it contains one implication that I have some difficulty accepting. Namely, in a natural gas market deregulation is a logical precursor to a decrease in prices and improvement in service. Such was the theory when electric deregulation was adopted, but if it was true that the ultimate object of deregulation was to obtain lower prices, then I take enormous pleasure in noting that electric deregulation has failed, is failing, or will fail just about everywhere.

What we also have here – at least in some countries – is a nice example of an aspect of the consistency problem mentioned above. By that I mean the absence of a strategy for automatically reversing a sub-optimal venture (e.g. deregulation), and thereby mitigating the bad news that might unexpectedly appear.

A concept that is unique for storage is the *convenience* yield. This is explained in some detail in my first energy economics textbook (2000), but roughly it is the yield (i.e. gain) associated with greater flexibility that might devolve on the owners of inventories. For example, the availability of inventories permits output to be increased without incurring the expenses that are often unavoidable when it is necessary to resort to spot purchases in order to fulfil contract stipulations, or for that matter to purchase futures or options contracts at prices that are regarded as unfavourable.

The theory here is straightforward: an additional unit put into inventory can provide a sizable marginal convenience yield if inventories are small, while with very large inventories, the *marginal* convenience yield (associated with adding another unit) might be zero (although the convenience yield would still be positive and could be very large). Another way of viewing this is to say that having access to storage encourages the transfer of consumption from periods in which the value of a commodity is low to those periods when it is higher (e.g. *peak periods*).

In examining this issue, it can be argued that gas storage can not only moderate upward price movement, but also function as an excellent *hedge* against price and volume uncertainty. With natural gas – as with electricity – one of the key issues is *peak demand.* If a storage option is available, the exposition above indicates that gas is stored during off-peak periods and, if peak demand (or a 'glitch' of some sort in transmission or distribution) jeopardizes the ability to deliver desired quantities to end users, then gas is removed from storage. (Electricity cannot be stored, and so this procedure cannot be employed, but peak demand is satisfied by holding some equipment idle during off-peak hours.) An expression that might appear here is '*peak shaving'*, which sometimes brings a frown to the faces of energy economics students, but it means no more than releasing gas from storage into a pipeline during periods of maximum demand (i.e. peak periods). Possessing this option might make investment in additional producing or transmission capacity unnecessary.

Quality can also be brought into the storage picture. Depleted reservoirs are often used, but withdrawal is relatively slow from these structures. Salt caverns are better and allow rapid injections and withdrawal, which as Van Atta (2007) points out makes them attractive for traders who want to "capture value from price volatility". What this means is that when they have an opportunity to make some serious money, they do not want to be hindered by an inability to obtain the commodity that they are holding in storage and can be sold at premium prices.

***Hubs* are physical transfer points that are sometimes called 'pipeline interchanges'. They make it possible to redirect gas from one pipeline into another. However, at the present time, I prefer not to accept a recent report which claimed that spot prices at Henry Hub, which is one of the largest and best know gas market hubs in the world (and is close to the Lake Charles (Louisiana) LNG terminal) have assumed the role of international reference prices. This kind of claim is sometimes tied to the belief that a large expansion in the trade of liquefied natural gas (LNG) will eventually lead to an international market that is capable of replacing regional markets of one type or**

another. In the very long run, this hypothetical international gas market would comprise – via uniform net prices – both pipeline gas and LNG.

Even a survey of this length is not the place to speculate on a scheme of this nature, although if the demand for gas in the U.S. reaches the levels predicted by the U.S. Department of Energy, then it will mean that the movement of LNG toward the U.S. could increase to a point where there will be upward pressures on gas prices in every market. Moreover, this is only the beginning. According to one prediction, China and India are expected to double their use of coal by 2030, and their combined oil imports are expected to surge from 5.4 million barrels per day (= 5.4 mb/d) in 2006 to perhaps l9 mb/d in 2030. To at least partially offset (or avoid) the environmental deterioration this is liable to bring about, they will almost certainly be in the market for huge amounts of natural gas.

In theory it might be desirable to combine hubs with market centers, where either of these might provide facilities that permit the buying and selling of services such as storage, brokering, insurance and *wheeling* – where wheeling means the provision of pure transportation services between external transactors. For pedagogical reasons, hubs are often portrayed as displaying a radial system of spokes (i.e. pipelines) and conceivably these spokes could be joined by adding short links.

Market centers are supposed to be able to operate independently of facilities for producing, transporting or storing the physical product, but even so, it might be optimal if they provide a locale where shippers, traders, etc, can buy and sell transportation, gas, etc. To a certain extent the layout of these establishments could take on the structure of trading facilities in the financial markets. If there are imbalances anywhere, then in an 'ideal' market center there will be a mechanism where they can be located in a very short time and rectified, which might include providing access to tradable pipeline space and also storage capacity.

In the U.S. for example, market centers have direct access to almost 50% of *working gas* storage capacity and, in general, enjoy a special relationship with many of the high profile storage establishments. (Working gas is the amount of gas in a storage facility in excess of the 'cushion' or 'base' gas that is needed to maintain facility pressure and deliverability rates.) Regardless of the actual configuration, it is hard to avoid the conclusion that market centers will tend to form at, or in the vicinity of hubs, and that the number of arbitrage paths that can be utilized for obtaining uniform prices in a system are expanded if there is a proliferation of hubs, market centers and storage facilities.

There was a mention of LNG that can be expanded before moving to the next section. Qatar produces 77 million tons of LNG every year, which makes that country the largest producer of LNG in the world. There are sales to other Gulf states, and Qatar has more than 40 vessels that are used for the export of LNG. Almost 70 percent of Qatar's export of natural gas goes to Asia, especially to Japan and China, while about 20 percent is sold to Europe.

NATURAL GAS AND FUTURES MARKETS

Now that you know a few things about storage, it should be easier to get an insight into futures markets, and so I will start with a recent announcement about the natural gas futures market.

> **On the New York Mercantile Exchange, natural gas for delivery in November hit an intraday low of $2.410 per million British thermal units (Btu), before ending the day at $2.430, down 2.3 cents, or 0.94%.**

That statement is what I call special! I have published and lectured in many countries on oil 'futures' (= oil futures markets), where the amounts being bought (*going long*) and sold (*going short*) were barrels. My first lectures on this subject though were on copper, where the buying and selling was also in physical units. But here the trading is in HEATING UNITS (or millions of Btu of natural gas). If that is too rich for your blood, as it once was for me, let me suggest that you examine the appendix to this contribution, or better, a short and non-technical discussion in my book ENERGY AND ECONOMIC THEORY involving two young finance geniuses called Millicent and Condi, who are going long in oil futures after unexpectedly receiving some very special private information – the kind of information that enables people to become rich.

In any event, futures trading is centuries old. John Cary has described the "disposal" of brandy on the Amsterdam market in 1695 via a scheme that did not require the commodity to be delivered, while it is said that during the Middle Ages techniques were developed in Japan designed to guarantee the forward delivery of silk at previously agreed on prices. Although such conveniences as clearing houses for the settlement of contracts do not seem to have been a part of the Japanese experience, it is very possible that the mechanics of these transactions were akin to those employed on modern futures exchanges.

(OBSERVE: A clearinghouse is a 'non-profit' entity affiliated with a futures or options exchange. It monitors/supervises clerical activities associated with buying and selling, paying particular attention to transactions that have to do with the offsetting (i.e. reversing) of 'open' futures positions, since these 'close out' those positions. If

necessary, the clearinghouse makes sure that the commodity in question is delivered to or shipped from the official delivery point, and if contracts are settled by cash instead of delivery, it might do some of the necessary accounting.)

Futures markets operate as follows. Against a background of speculators 'betting' on the direction and size of commodity price movements by buying and selling futures contracts, an impersonal agency can be created which permits producers, consumers, inventory holders and various traders in physical products to reduce (i.e. hedge) undesired price risk. This process will be described below.

The success of a futures market is dependent on the satisfaction of a number of well-defined criteria. Among the most important are that the commodity in question can be traded in bulk, is susceptible to grading, is relatively imperishable, attracts a lot of attention from market actors, and almost as important as the last item, the physical commodity is bought and sold in circumstances that cause its price to fluctuate in a random or non-systematic manner. Without this latter provision, speculators are unlikely to be attracted to the commodity, and without considerable speculation (i.e. the provision of liquidity), futures markets will not function properly. This observation deserves repeating: without considerable speculation (i.e. the provision of liquidity), futures markets will not function properly. Put another way, transactors in a physical commodity (e.g. buyers and sellers of physical crude oil and natural gas) can employ futures markets to reduce price risk only if other traders and/or speculators are willing to accept this risk.

The social gain from futures trading derives from the voluntary redistribution of risk between speculators and risk-averse dealers in physical products. The belief here is that in the oil market this gain is considerable, and everyone is made better off by the presence of e.g. oil derivatives markets, and as far as I can tell, this applies to the futures market for natural gas. (OBSERVE: A *derivatives* market – where price is *derived* from what takes place in another market – can be based on organized exchanges, or over-the-counter arrangements. The price of *derivatives* – e.g. futures and options – is ultimately derived from the price of the *underlying* – e.g. of natural gas or oil. The underlying is also called '*actuals'*.) Exchange traded derivatives are standardized assets whose trading is characterized by margin requirements (which ensure payments to and from buyers and sellers) while over-the-counter derivatives – which are often encountered for options and swaps – are privately negotiated bilateral agreements that are independent of organized exchanges and their 'transparent' prices.)

Now we can look at some aspects of hedging. As already noted, if a speculator believes that the price of a commodity is going to rise, she buys futures contracts – *goes*

***long*. These contracts are referred to a certain delivery month, and often the first day of that month, in which case we can speak of the expiry month or expiry date. In a very liquid market, before the contract matures, this 'long' position can be easily offset – i.e. reversed – by the sale of futures for the same delivery date or month. When this is done, the position of Ms Speculator is registered as *closed*. If the sale price of the contracts is higher than that at which they were bought, then she has made a profit.**

One measure of liquidity is *Open Interest*! This is the total number of *open* contracts, long or short – but not both – in a given market. A transaction involving a buyer and seller that is not a reversing trade will increase the open interest by one contract – *note, one and not two contracts!* Open interest can be regarded as a measure of liquidity, and the greater the open interest, the easier it should be to open or close a position. This is because there are a large number of (open) contracts – both long and short – that are candidates for a reversing transaction.

Similarly, if she had begun by selling contracts – going short – and (taking into consideration brokerage costs) the price at which she made an offsetting transaction (a buy or going long) was lower than the original sale price, she has also made a profit. This is also what the hedging of oil and gas prices that was mentioned earlier is all about. The trick, however, is to hedge *before* the fall in price takes place, and not after.

Something that is often forgotten or ignored is that the maturity of these contracts is for the most part less than six months. The talk about futures contracts for oil or oil products with a maturity of three or four years does not deserve much credibility, because there is inadequate liquidity for contracts of that maturity. (OBSERVE: A semi-formal definition of liquidity might be the ability of individuals to obtain cash with minimal delay by selling an asset. *Market liquidity* means that large sales and purchases can take place without unduly moving market prices. In a 'thin' market dramatic price movements can .)

If this is clear, the mechanics of hedging can be considered. Hedgers also buy and sell futures contracts, depending upon whether they want to guard against price rises or price falls. Consider, for example, someone who has contracted for a given quantity of natural gas or crude oil, but does not know the price at which this oil will be delivered because the seller insists that buyers will be charged the price prevailing on the spot market at the time of delivery. The buyer thus faces considerable price risk in that the price of the commodity might rise sharply; however a risk-averting buyer can 'lock in' a price in this situation by *buying* futures contracts at or around the same time they contract for the underlying (e.g. physical oil). These futures (i.e. paper) contracts should have a maturity (expiry) date at or close to the date on which the oil will be delivered.

Then, around the time that the oil is delivered, they make an offsetting (i.e. reversing) sale of futures. If the spot (i.e. market) price of the oil rises, this transactor takes a loss on the physical transaction, however compensation will be gained on the sale of the futures.

Note also that even if no contract is signed between a specific buyer and seller, for someone who is going to buy a commodity in the future, a resort to futures might be judged wise. If both physical and paper prices for a commodity rise at roughly the same average rate, which generally tends to happen, the loss on the physical purchase will be (partially or totally) compensated for by the gain on the futures transaction. What about sellers of natural gas? If they are afraid of a price fall they sell futures (i.e. go short). If the price of physical gas falls the price of paper gas should also fall, with the loss on the physical transaction being compensated for by the gain on the futures contracts. (This is worth understanding, because there is considerable talk at the present time about the price of oil and gas in the near future!)

One thing remains to be done in this section, which is to provide a brief discussion of the convergence of physical and futures prices. This topic is discussed at considerable length in my textbooks, however readers should make an effort to comprehend the following.

Formally, the proposition that is being put forward is that in the delivery month or date specified on a futures contract, the futures price and the physical market price of the commodity (e.g. oil) must be very close. If this is not the case, arbitrage comes into the picture! If there was a discrepancy between the two prices, either buyers or sellers of the contract would become involved with delivering or taking delivery of the commodity, as well as buying or selling on the physical market. (OBSERVE: ***Arbitrage can be explicitly tied to the law of one price:*** **there cannot be different prices in the same market for identical goods! Stockholm and Uppsala are essentially in the same market for certain goods. If the price of a designer shirt is higher in Uppsala than in Stockholm, then I might travel to Stockholm and buy the shirt, which I sell in Uppsala.)**

Suppose, for example, that the price of oil on a futures contract was posted as $75/b, while the price of oil in the physical (spot) market was $80/b. Someone who has bought a futures contract perceives this difference, and does not make an offsetting (i.e. reversing) sale. Instead they accept delivery on the contract, and immediately sell it on the spot market. This yields a profit of $5/b. Arbitrage of this nature – i.e. taking delivery and selling the commodity will tend drive down its spot price. There will also be an increased demand for futures (in order to take advantage of this arbitrage

situation) which should raise their price. In a very short time the futures and spot prices should be very close.

Deliveries are not common in the oil futures market, and cash-settlement of course reduces deliveries even more. The detailed mechanics of cash settlement will not be taken up in this exposition because this is really a simple matter. If cash settlement prevails in a market, and a 'player' decides not to or forgets to close out his or her (open) long or short position, then at what was defined as the expiry date of the contract, the player's broker would receive whatever he or she had gained on that transaction – assuming that it was a gain. The price employed to calculate gains or losses was either the market price or a price close to the market price and specified (or authorized) by the clearing house. Moreover, cash-settlement reduces transaction costs because it is unnecessary to be concerned with moving and storing a physical commodity such as natural gas or oil.

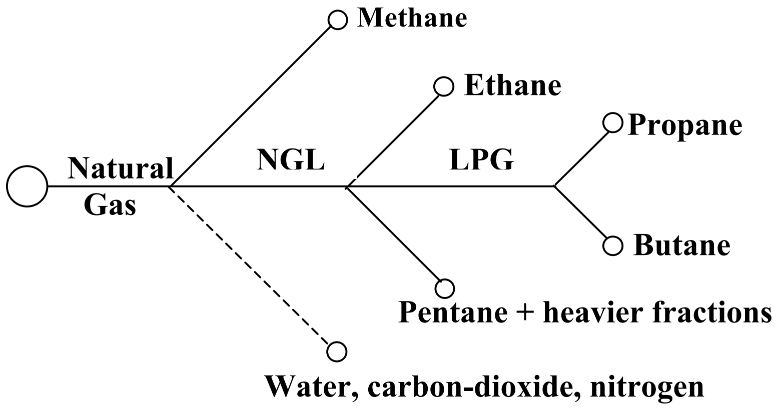
A LONG CONCLUSION

Initially the gas industry was based on town gas (or manufactured gas) which is not natural gas but a gas manufactured by carbonizing coal. This fuel was first introduced to the large cities of the world in 1812 (in England), and may still be used in the German Ruhr. The U.S. first used town gas in 1816, and five years later the first use of what we now call natural gas was recorded at Fredonia, New York. The first long distance all-welded pipeline (or 14 to 18 inches and 217 miles long) was put into operation between Louisiana and Texas in 1925, and this can probably be taken as the beginning of the modern gas industry. However Robert Carr (1978) has argued that the age of natural gas was born about 1935, when thin walled pipe could be successfully welded to yield long pipelines of sufficient strength to carry gas under extremely high pressures. It should also be mentioned that the 'natural' of moving natural gas is via pipelines, which probably applies to distances of well over 5000 kilometers.

There is plenty of literature on shale natural gas these days, and it has constantly been referred to as a game changer, and the same is true of shale oil. Two things should be mentioned here, with the first being that this is not a new technology, but the refinement of an old technology. My book THE POLITICAL ECONOMY OF OIL was published in l980, but I had plenty to say about shale oil in that work. But if you are accustomed to going into the informative sites such as *321 Energy*, *Energy Pulse*, *Talk Markets* and *The Energy Tribune* for up-to-date information you will find plenty of criticism of shale oil and natural gas, by which I mean the manner in which they have

been promoted so as to lead to the conclusion that they can provide U.S. energy independence.

When shale gas was resuscitated in a spectacular manner a few years ago, it became necessary to emphasize that a natural gas deposit consists of more than methane, but also contained liquids. If you look at Figure 4 you can get an inkling of that situation. What is lacking however is a specific reference to the fact that many environmentalists consider methane is more dangerous than carbon dioxide.



	Liquified at	Definitions
Butane (normal)	- 0.5°C	NGL: Natural gas liquids
Butane (Iso)	-12.0°C	LPG: Liquified petroleum
Propane	- 42.0°C	LNG: Liquified natural gas
Ethane	- 88.0°C	SNG: Synthetic (substitute) natura
Methane	- 161.0°C	

Note: Natural gas = methane + NGL + (water, nitrogen, CO2).

NGL = ethane + LPG + (pentane and heavier fractions).

LPG = propane + butane + mixtures of propane and butane

Figure 4

Natural gas from a well consists of methane (on the average 85%, and sometimes thought of as ‘pure’ natural gas), heavier hydrocarbons collectively known as natural gas liquids (and composed of ethane, propane, butane, pentane, and some heavier fractions), water, carbon dioxide (CO_2), nitrogen, and some other hydrocarbons. (And, note here, that gas is *not* free of carbon dioxide. It merely has less than oil and coal.) Before dry natural gas can be distributed to consumers, some undesirable components must be removed and, by decreasing the share of heavier hydrocarbons, a uniform quality attained. That is what processing is all about in Figure 1.

The last-mentioned operation takes place either at or near the gas well itself or in special installations farther away. It is at this point that the natural

gas liquids (NGL) can be separated out. (NGL should not be confused with liquified natural gas (LNG), which mostly consists of methane and ethane.) The most important constituents of NGL are butane and propane, which I have heard called 'wet gases', and in liquid form these are called liquefied petroleum gas (LPG). In many countries, LPG is sold under the name gasol or bottled gas, and when I taught in Australia I remember hearing that the government wanted a greatly increased use of LPG, although I never heard anyone say how this could be brought about in that energy-rich land, with its huge reserves of inexpensive coal.

The option mentioned above (LNG) involves cooling gas to about –100 degrees Celsius by a cryogenic cooling process, which reduces the volume of the gas, and after transferring the gas to a cryogenic carrier/vessel transporting it to a consuming country where this liquefied natural gas (LNG) is regasified. It has occasionally been claimed that LNG trade is more flexible than the selling and buying of piped natural gas, because LNG carriers can be rerouted, while pipelines are fixed. In considering the long-term contracts under which a large fraction of gas is sold, and the efficient pipeline networks that can be found in North America and Europe, I doubt whether this claim is valid.

Before turning to less provocative aspects of this topic, something should be made clear. According to Robert Bryce, an editor of the *Energy Tribune Magazine*, coal dominated the energy picture in the 19th century, oil the 20th, and – in his opinion – natural gas will be the dominant "fuel" of the 21st century. Whether he was thinking of the U.S. or the world is unclear. In the U.S. natural gas accounts for 23% of domestic electric power, while coal generates more than 40%, wind and solar only about 3%, and nuclear about 19%. With power demand scheduled to increase by a large amount in the not too distant future, and the belief expressed by the managing director of Exxon (often the most profitable company in the U.S.) and others that the U.S. possesses an exceptionally very large supply of natural gas, it might be easy to believe that – in the U.S. at least – natural gas is capable of outshining coal and nuclear as, e.g., a source of (base load) electricity throughout the entire 21st century. I have very strong doubts about this contention however.

One reason for these doubts is because the U.S. may not have the 100 year supply (at the present consumption level) that I constantly hear about, and definitely not if consumption escalates and the cost of production increases. What it has is a reserve-production ratio of about 100, which suggests that (at

the present consummation level), in about 50 years or so years, a 'peaking' of the natural gas output may take place. Moreover, in China and India natural gas consumption has increased by 376 percent and 131 percent respectively over the past decade, and there is no indication that it will decrease, since the rate of macroeconomic growth in these two countries is expected to remain in the 7-8 percent range during the next decade.

In addition, as pointed out by Len Gould and Malcolm Rawlinson in the forum *EnergyPulse* (www.energypulse.net), it is now possible to construct (in China) a 1000 Megawatt (= 1000 MW) nuclear facility in slightly less than 5 years – from 'ground break' to grid power – and this reactor should have a 'life' of at least 60 years. Assuming that there are no problems with the supply of nuclear fuel (uranium + thorium), the residents of some countries may conclude that natural gas is an inferior resource, particularly since a commercial breeder reactor should be ready in about a decade, or sooner.

What this will mean economically or otherwise cannot be gone into in this contribution, however I see no reason to hurry those breeders. Federal regulators have approved an operating license for TVA's Watts Bar Unit 2, allowing the first new American (conventional) nuclear plant to begin operation in nearly two decades. The first but not the last, because as the young lady said, nuclear is the future.

Anne Lauvergeon, the former director of Areva (the French nuclear manufacturer), was also aware of the progress of the Chinese nuclear sector, and regarded it as "worrying" – by which she meant worrying for the management and shareholders of her firm. Given that nuclear reactors do not release any carbon, and considering the estimated supply of uranium and thorium, it is difficult to believe that electric power generating sector in the U.S. will be dominated by a fossil fuel (e.g. natural gas) whose global availability was once questioned by knowledgeable people like Alan Greenspan, the long serving director of the U.S. Central Bank (i.e. the Federal Reserve System). On considering shale gas, Professor David Victor of the University of California ostensibly stated that "We don't know if it will be truly awesome or only theoretical in its impact".

As it happens, some of us know enough about energy issues to become unreservedly sceptical. Not only shale gas, but coal deserves some scrutiny. Coal is considered a near-toxic resource by a number of politicians and environmentalists, and so daily we hear about the strenuous efforts that will be

made to replace it with renewables and or natural gas (since natural gas has about 50% of the carbon dioxide (CO_2) emissions of coal). I have been informed about some of these goals for decades, and it is clear that in every part of the world there are politicians and civil servants who are serious about putting some sort of 'cap' on carbon emissions. Even so, I am afraid however that a large fraction of these intentions have no future. There is too much energy in coal for it to be ignored.

Decision makers in China and India have not provided any proof that they will augment their high-minded rhetoric with tangible efforts to reduce their huge dependency on coal, nor are the scientific elite in Europe and North America are not making the efforts that they should make to provide us with the information we need. However since the message is more important than the messengers, the following message from the *International Energy Agency* should be on the tip of all tongues: less than 1% of global energy comes from solar and wind, and even in 2040 it will only be about 2%. Those two numbers are tough to take, aren't they, and the reason is simple. *Wind and solar have little to offer heavy energy users like transport and industry, where reliability is a crucial factor!*

APPENDIX: ENERGY UNITS AND HEAT EQUIVALENTS

One of the problems with academic economics is that too much emphasis is placed on elegant trivialities, while really important themes are sometimes given a superficial treatment. Accordingly, some – and perhaps many – readers will choose to skip this section. Needless to say, any of my students who favour that option will not find it easy to pass my next course in energy economics, because there is nothing in this section that requires more concentration than that associated with secondary school lesson in physics.

In the most elementary, yet most comprehensive sense, energy can be defined as anything that makes it possible to do work – i.e. directly or indirectly bring about movement against resistance. Energy takes many forms, and one of its most interesting characteristics is that all aspects of motion, all physical processes, involve to one degree or another the conversion of energy from one state to another. For example, the chemical energy that is found in natural gas can be converted to active heat, which in combination with water will generate steam in a boiler. This steam can then be used to drive a turbine which, in turn, rotates the shaft of an electric generator, and thus produces electricity. Note that the rotating shaft implies the ability to do physical work

All this is perfectly straightforward, but unfortunately heat cannot be converted into work without loss, and the loss takes the form of heat transposing (or descending) to a temperature closer to that of the surroundings, and away from that of the heat source that made the work possible. Once heat has descended to the *ambient* (i.e. surrounding) temperature, it is no longer available to do useful work. What we are dealing with here is a highly abstract concept from thermodynamics known as *entropy*, sometimes called "time's arrow", which signifies energy going down the thermal hill and being diffused into space. Lost forever in the sense of doing work we might say, which implies that the universe itself is in danger of 'running down' (in e.g. a few million or so years).

John von Neumann was sometimes been called 'the best brain of the 20th century', and one of his advantages was to have virtually every physical constant known to mankind stored in his brain, and available for instant recall. That sort of achievement is not normally required to convince friends and neighbours of your acumen, but it is always useful to have a few numbers at hand when studying the present topic. First of all I suggest knowing that one metric ton (= 1 *tonne* = 1t) equals 2,205 pounds, and that 2.2 pounds = 1 kilogram (= 1000 grams), Similarly, 1 inch = 2.54 centimetres, 12 inches = 1 foot, 100 centimetres = 1 meter and thus 1 meter is approximately equal to 3.28 feet = 39.37 inches. One cubic meter (= 1 m^3) is therefore equal to 3.28^3 = 35.3 ft^3. In everyday life the usual ton is the *short ton*, or simply *ton*, which equals 2,000 pounds. Thus 1t = 1.103 tons.

When dealing with energy we are often interested in heat equivalents, and when the topic is gas the most favoured unit is the British thermal unit, or Btu, which is the amount of heat required to increase the temperature of one pound of water by 1 degree Fahrenheit. (1 pound of water is approximately equal to one *pint*.) Here it might also be useful to remind readers that with F Fahrenheit, and C Centigrade (or Celsius), we go from C to F with the equation F = (9/5)C +32. In scientific work, and in certain countries, *joules* might be preferred to the Btu as a unit of heat energy, however since the price of natural gas is commonly given in dollars per million Btu (= $/MBtu), there is no reason in energy economics to spend a great deal of time pondering the utility of the joule or for that matter the calorie or kilocalorie (= 1000 calories = 3.968 Btu), which are other heat units.

That brings us to a key observation, which is that 1000 cubic feet (= 1000 cf = 1000 ft^3) of natural gas has an approximate energy content of 1,000,000 Btu.

(To be exact, 1 ft^3 of natural gas has an average heating value of 1035 Btu, but 1000 Btu is almost always used.) A not especially useful observation is that the *average* energy content of natural gas varies from a low of 845 British Thermal Units per cubic foot (845 Btu/cf = 845 Btu/ft^3) in Holland to 1300 Btu/ft^3 in Ecuador.)

Now let us make a calculation involving gas and crude oil, where one barrel (= 1 b) of oil has an average energy content of 5,686,470 Btu (≈ 5.686 MBtu). If we assume the price of oil to be $100/b, and the price of natural gas about $5 per million Btu (= $5/MBtu ≡ $5/mBtu ≡ $5/MMBtu), then it is easy to compare Btu prices of these two energy resources. The cost of a *million* Btu of oil is thus 100/5.686 = $17.587/MBtu (as compared to $5/MBtu for natural gas). There is a large difference between these two prices, and it has occasionally been suggested that this difference will result in the (dollar) price of oil falling by a great deal. I do not share this belief.

Persons who find this approach interesting or important can turn to articles in the academic literature where authors are of the strange opinion that the *burner tip parity rules'*, which have to do with an inevitable convergence of oil and gas prices (in Btu terms), and possess virtually the same authority as Albert Einstein's 'equivalence theorem/principle. (In case you forgot, the theorem says that if two phenomena produce equivalent effects, they must be manifestations of the same fundamental law.) Thermodynamically the equivalence theorem holds everywhere, but when a substantial decline in the oil price takes place as has happened during the last year or two, it is because it fits OPEC'S agenda.

It is possible that the economics of natural gas markets will eventually be altered by the kind of subtle technological advances that made the exploitation of large amounts of shale gas possible, although shale gas is far from being a new resource. In the U.S. the availability of large amounts of shale gas has sometimes depressed the gas price to an unexpectedly low level (≈ 2.4 dollars per million BTU), while at the same time the price of natural gas might be well above 10 dollars in much of Asia.

The technological advances that are necessary to liquidate these differences (or as we sometimes say to '*arbitrage'* away these differences) have to do with the processing of natural gas so that it can be transported between continents. (In other words, to buy inexpensive gas in North America and sell it at the elevated prices in Asia, which by the usual supply-demand mechanisms should bring about something close to a price equality). Here it might be useful to

mention that oil is generally rated a more 'efficient' resource than gas, because on a Btu basis it is more economical to transport in its 'raw' form, or as oil products (e.g. motor fuel) and petrochemicals (e.g. fertilizers).

In reality, the efficiency with which fossil fuels can be converted to electrical energy is well under 100 percent. An efficiency of about 33 percent seems typical for much of the industrial world, and so on average it would require 3412/0.33, or 10,339 Btu to obtain a kWh of electrical energy. A number of this type is conventionally referred to as a *heat rate*. and is sometimes referred to as the utilizable energy content of a fuel! Using the above numbers, this can be put another way: 1 kWh(e) = 3.12 kWh (fossil fuel). Some time ago the UN and OECD calculated that 1 kWh(e) = 2.6 kWh (oil). Naturally, we are dealing in averages.

As simple as all this seems, many readers may feel that something is missing. While electrical power is defined as a 'rate', it is not always explicitly associated with a time dimension: for instance, the 'rating' of a power station is likely to be in megawatts. However in the example above with the bulbs, we saw that a large bulb exhausted the energy potential of a tonne of coal more rapidly than a small bulb, which trenchantly suggests that the dimension for power is energy per unit of time. Furthermore, a watt is one joule per second (which is immediately recognized as a rate) or 3,600 joules per hour, and since 1,055 joules is one Btu, one watt is 3.412 Btu/hour (which is more easily recognized as a (time) 'rate' by those of us accustomed to working with the Btu). Observe that 1 kW = 1,000 J/second, where J signifies joules.

Finally, there is the very small unit called a calorie, and here we have 1000 calories equal one kilocalorie (kcal), and 1 kcal = 3.968 Btu. Where equivalencies of this nature are concerned, we are of talking about the outcome of perfect experiments in a perfect laboratory. This kind of perfection is not easy to achieve in the real world however, which is why the term 'heat rate' had to be introduced.

Let's conclude this discussion two simple examples. For the first, the fuel in the tank of a vehicle may be depleted of 10 million Btu (= 10 MBtu) during an hour of driving. A portion of this energy – for example 3.5 MBtu – might be transformed into work in the form of rotating a shaft that turns the wheels of a vehicle. The rest of the energy is discharged as heat into the air (or perhaps into cooling water). Fuel efficiency in this case is only 35%, which is the percentage of the fuel that is actually transformed into useful work. Just as unfortunate, as the

temperature of the 'non-useful' work falls, we are losing forever its availability to do work: its unavailability is increasing. As alluded to earlier, this is what *entropy* is all about: the permanent degradation of energy.

Once we have the heat rate, obtaining an estimate of the fuel cost is elementary. if we have a natural gas turbine with a heat rate of e.g. 10,000 Btu per kilowatt hour (= 10,000 Btu/kWh), and in addition a fuel (i.e. natural gas) cost that at the present time is about $3/MBtu, the *fuel* cost of the electric output is clearly:

$$\left(\frac{\$3.00}{1{,}000{,}000Btu}\right)\left(\frac{10{,}000Btu}{1kWh}\right) = \frac{\$0.03}{kWh} = \mathbf{\$0.03/kWh}$$

In the U.S. this would be called three cents per kilowatt hour. This is an unsophisticated estimate of the fuel cost of electricity generated with a natural gas turbine, but it is satisfactory for this exposition. In my new energy economics textbook (2015), an important calculation will be presented dealing with the capital cost that also easy, but which requires slightly more patience.

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