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Trends in carbon and hydrocarbon resources

Abstract: While the conventional and non-conventional oil reserves are growing as growing is the oil production, the growing reserves of natural gas and the huge coal reserves make attractive the production of synthetic transportation fuels having properties similar to gasoline, diesel or jet fuels from the coal or gas feed stock. The paper discusses production and reserves of oil, gas and coal and their potentials as a source of power, heat and fuels for at least a century from now. In addition to the Fischer-Tropsch suite of chemical reactions, methanol synthesis and other paths are worth consideration to produce fuels from coal and natural gas. The integration of the fuel production with power generation and waste heat recovery and the valorization of by-products are key factors for better economic, environmental and energy costs.

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1 Introduction

According to the main-stream “fossil fuels” theory, oil and natural gas are both produced anaerobic decay of organic matter deep under the Earth’s surface. As a consequence, oil and natural gas are often found together. It is believed that organic sediments buried in depths of 1,000 m to 6,000 m at temperatures of 60°C to 150°C generate oil, while sediments buried deeper and at higher temperatures generate natural gas. The deeper the source, the smaller is the proportion of condensates. Oil and natural gas are lighter than water and they tend to rise from their sources until they either leak to the surface or are trapped by non-permeable layers of rock.

The “global peak oil” idea is intrinsically linked to the “fossil fuels” theory. Global peak oil is the point in time when the maximum rate of petroleum extraction is reached after which the rate of production is expected to enter terminal decline. This point in time has been predicted many times over the last six decades, and every time these predictions have proved to be wrong.

2 Past global peak oil predictions

Hubbert’s 1956 speech about Peak Oil [10] asserted that global oil production would follow a bell-shaped curve with a peak followed by an irrevocable decline. He predicted that production of oil would peak in the continental US around 1965 to 1970 and a worldwide peak would occur at about 50 years from publication of his memo around the year 2000.

The idea of “global peak oil” has been around for 60 years, with academics arguing about whether this peak has already passed or has been reached at a continuously moving present time, but never doubting the concept was wrong ([2, 5, 7, 11, 24, 25, 37] just to name a very few of the many) and politicians building on the theory their campaigns. On April 18, 1977 President Jimmy Carter announced to the Americans that peak oil was “*the greatest challenge our country will face during our lifetimes*”. “*We simply must balance our demand for energy with our rapidly shrinking resources*” because “*The oil and natural gas we rely on for 75 per cent of our energy are running out*”. Presently, Murray and King [25] still say “*The economic pain of a flattening supply will trump the environment as a reason to curb the use of fossil fuels*”, “*There is less fossil-fuel production available to us than many people believe*”, “*From 2005 onwards, conventional crude-oil production has not risen to match increasing demand*”.

All these statements are about as wrong as they could be, because at the present time oil and natural gas reserves are still very far from running out as it is demonstrated by the actual oil and gas fields discovery and exploitation announced in the press. And the coal reserves are huge.

3 More reasonable peak oil estimations

Oil and natural gas reserves presently appear if not inexhaustible then inconceivably large [20–22] and coal reserves have never been doubted to be larger than oil and natural gas reserves. In addition to abundant oilfields in Russia, North America, Saudi Arabia and other producers in the Middle East, there are massive reserves of hydrocarbons in South America, Africa, Australia, North America and the Arctic estimated trillions of barrels.

A recent field-by-field analysis of most of the major oil exploration and development projects in the world predicts a 20% increase in global oil production by 2020 [23]. Oil supply capacity is growing worldwide at such an unprecedented level that it might outpace consumption and this could lead to overproduction and a steep dip in oil prices. Maugeri [23] suggests that an unrestricted, additional production of more than 49 million barrels per day (mbd) of crude oil and natural gas liquids is targeted for 2020, totalling more than half the current world production capacity of 93 mbd. Considering the risk factors affecting the actual accomplishment of the projects, and factoring in depletion rates of currently producing oil fields and their reserve growth through extension, revision, improved recovery Maugeri [23] suggests a net additional production capacity by 2020 of 17.6 mbd, yielding a world oil production capacity of 110.6 mbd by that date. This estimation excludes coal products.

4 Reasons for peak oil delay

One reason for the oil boom is mostly hydraulic fracturing, a technological revolution transforming the way to find and extract oil, a way of releasing oil or gas that is tightly bound up in shale rock using pressurised water. Technology has found a way to get “*tar sand*”, in addition to helping producers release the “*tight oil*”.

The oil boom is also fuelled by new methods of drilling, the invention of horizontal drilling and finally by drilling much deeper than ever before. Exxon Neftegaz has completed drilling the world’s deepest well in the Chayvo oil field on the Sakhalin shelf in the Russian Far East, where the shaft of well Z-44 is 12,376 m deep [6, 30]. Chayvo is one of the three Sakhalin-1 fields and is located off the northeast coast of Sakhalin Island in eastern Russia. The Chayvo, Odoptu and Arkutun-Dagi fields are estimated to yield 2.3 billion barrels of oil and 17.1 trillion cubic feet of natural gas [30].

At the moment, basic geometry prevents anybody going much deeper than that with the present drilling technology. The only way to sink the individual steel casings of well bores is for each one to be marginally smaller than the one before, and this is the present limiting factor to drilling deeper and deeper where the “*fossil fuels*” theory has suggested that oil and natural gas could not be.

5 Trends in carbon and hydrocarbon production and reserves

The amounts of coal, oil and gas that may be present in a deposit or field constitute the coal, oil and gas reserves. The reserves do not take into account the feasibility of mining economically the coal, oil and gas. Furthermore, not all the reserves are exploitable using current technologies. Reserves are divided as proved and probable reserves. Estimations of probable reserves are obviously much less reliable. Proved reserves are economically recoverable taking into account current mining technology and economics. Proved reserves therefore change in between the others according to the price of oil, coal and gas. The U.S. Energy Information Administration [35] data of coal, oil and gas production and proven reserves is analysed here after.

5.1 Oil production and reserves

Figure 1 presents the oil production and proved reserves according to EIA. It is not the scope of this work to discuss the reliability of the EIA statistics, but clearly the carbon and hydrocarbon resources are a very sensitive matter where the circulation of information is everything but free, with the cost component also playing a significant role. From Figure 1, the Total Oil Supply is increasing with a rate of 1014.7 Thousand Barrels Per Day more every year, but the Crude Oil Proved Reserves are also increasing of 25.62 Billion Barrels every year.

Russia holds the world’s largest natural gas reserves, the second-largest coal reserves, and the ninth-largest crude oil reserves. The Russian oil production is presently increasing, with a 2012 production estimated at 10397 mbd (millions barrel per day), as increasing are the estimated reserves augmented more than 30% over the last year from 60 to 80 billion barrels.

Saudi Arabia has almost one-fifth of the world’s proven oil reserves, is the largest producer and exporter of total petroleum liquids in the world, and maintains the world’s largest oil production capacity. Saudi Arabia has the world’s fifth largest natural gas reserves, but natural gas production remains limited. The total oil production of Saudi Arabia is also slightly increasing, 11546 mbd in 2012, as slightly increasing are the reserves presently estimated at 268 billion barrels. The Saudi Arabia reserves rose sharply about the 1990s, but since then have not ex-

Fig. 1. (a) Oil production according to the U.S. Energy Information Administration [35]. www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1&cid=regions&syid=1980&eyid=2012&unit=TBD
 (b) Oil proved reserves according to the U.S. Energy Information Administration [35]. www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=57&aid=6&cid=regions&syid=1980&eyid=2013&unit=BB

perience any rise due to technological break troughs as in the case of Russia.

The third largest producer, the United States, has a 2012 production of 11127 mbd, about same of the previous peak of 11193 in 1985, and sharply increasing from the 2005 minimum of 8317 mbd. The United States reserves are presently estimated at 23 billion barrels, up to a minim 19 billion barrels of 2009 but much less than the almost 30 billion barrels of the 1980s.

The United States have proved reserves as known by EIA much less than countries like Saudi Arabia, Venezuela, Canada, Iran, Iraq, Kuwait, United Arab Emirates, Russia, Libya, Nigeria, Kazakhstan, Qatar.

The proved reserves of Saudi Arabia, Venezuela, Canada, Iran, Iraq, Kuwait, United Arab Emirates, Russia, Libya, Nigeria, Kazakhstan, Qatar are not presently reducing but actually mostly increasing, as an example almost tripled in Venezuela over the last two years.

5.2 Gas and coal production and reserves

Similarly to oil, Figures 2 and 3 present production and proven reserves of natural gas and coal to complete the assessment of the carbon & hydrocarbon resources. As a matter of fact, globally, both production and reserves are statistically increasing in 2013, with some uncertainty mostly in the estimation of the coal reserves.

The Total Recoverable Coal information on the EIA web site is less reliable and complete than the oil and gas proven reserves information. EIA only provides the 2008 data from a 2009 survey. The 2005 data from a 2006 survey that was previously shown on the EIA web site and it is now mirrored in large.stanford.edu/publications/coal/references/coalreserve/ may be used for a first guess of the trend in the total recoverable coal to compare with the oil and gas proven reserves trends.

Fig. 2. (a) Natural gas production according to the U.S. Energy Information Administration [35]. www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=3&pid=26&aid=1&cid=regions&syid=1980&eyid=2012&unit=BCF
 (b) Natural gas proved reserves according to the U.S. Energy Information Administration [35]. www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=3&pid=3&aid=6&cid=regions&syid=1980&eyid=2013&unit=TCF

Although relatively stable, historically the total recoverable coal estimations were declining gradually from the 1,145 billion tons in 1991 to 1,083 billion tons in 2000 to the 929 billion tons in 2006, mostly because of downward adjustments apparently attributable to better data or the use of more restrictive criteria for geologic reliability, but also for a more restrictive use of the economically viable concept that limit the total recoverable to be considered versus the amount theoretically available.

From Figure 2, the Dry Natural Gas Production is increasing with a rate of 1878.5 Billion Cubic Feet per year, but the Proved Reserves of Natural Gas are also increasing 128.6 Trillion Cubic Feet every year. From Figure 3, the Total Primary Coal Production is increasing 10350 Thousand Short Tons per year. If we only consider the latest data of the surveys 2006 and 2009, the Total Recoverable Coal is also possibly increasing of 8788.38 Million Short Tons per

year, but this trend is obviously much less reliable than the trend in oil and gas proven reserves.

6 Abiotic oil theory

The “*abiotic oil*” hypothesis was first proposed by Agricola in the 16th century and various abiogenic hypotheses were proposed in the 19th century, most notably by Humboldt, Mendeleev and Berthelot. “*Abiotic oil*” hypotheses were revived in the last half of the 20th century by Soviet scientists who had little influence outside the Soviet Union because most of their research was published in Russian. This hypothesis fell out of favour at the end of the 20th century, but cannot be dismissed yet because the mainstream “*fossil fuels*” theory clearly has some major downfalls.

(a)

	Total Recoverable Coal (Million Short Tons)	
Reference Year	2008	2005
North America	269343	
Central & South America	13788	
Europe	84202	
Eurasia	251364	
Middle East	1326	
Africa	34934	
Asia & Oceania	293042	
World	948000	930423

(b)

Fig. 3. (a) Coal production according to the U.S. Energy Information Administration [35]. www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=1&pid=7&aid=1&cid=regions&syid=1980&eyid=2012&unit=TST
 (b) Coal proved reserves according to the U.S. Energy Information Administration [35]. The 2008 data are from www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=1&pid=7&aid=6 The 2005 data are from large.stanford.edu/publications/coal/references/coalreserve/mirroringwww.eia.doe.gov/pub/international/iea2006/table82.xls.

In a recent survey of abiogenic oil theories by Sephton and Hazen (Sephton and Hazen, 2013) the authors say “*despite their intensive study and exploitation for more than a century, details of the origins of some deep hydrocarbons remain a matter of vocal debate in some scientific circles*” and “*This long and continuing history of controversy may surprise some readers, for the biogenic origins of “fossil fuels” - a principle buttressed by a vast primary scientific literature and established as textbook orthodoxy in North America and many other parts of the world - might appear to be settled fact. Nevertheless, conventional wisdom continues to be challenged by some scientists.*”

Kutcherov, Bendeliani, Alekseev and Kenney [12], Kolesnikov, Kutcherov and Goncharov [13], Kutcherov and Krayushkin [14], Kutcherov, Kolesnikov, Dyuzheva and Brazhkin [15], Kutcherov, Kolesnikov, Dyuzheva, Kulikova, Nikolaev, Sazanov and Braghkin [16] are only few of the references supporting the existence of abiogenic oil.

It has been shown recently [3] that hydrocarbons are certainly naturally formed in space abiogenically (huge hydrocarbon fields have been discovered in Titan and the Horsehead Nebula in the Orion constellation) and it is not to be ruled out the possibility that hydrocarbons are also formed abiogenically on earth at high pressures and temperatures [33, 34]. Hydrocarbons may be formed from methane in deep Earth at extreme pressures and temperatures. Numerical experiments demonstrate the polymerization of methane to form high hydrocarbons and earlier methane forming reactions under pressure.

Many oil and gas fields have been developed by applying the perspective that oil originates from the crystalline basement rock, which forms below sedimentary rock, and that oil may be been found deeper than the deepest fossils. The opportunity hydrocarbons may also be naturally produced from abiogenic precursor molecules under high pressure and temperature conditions or could be produced

by other undescribed mechanisms is not to be ruled out because the “*fossil fuels*” theory has been successful in many circumstances. Contrary, the downfalls of the “*fossil fuels*” theory evident in the recent oil boom and the oil and gas field certainly present even deeper than the 12,376 m Chayvo oil field well Z-44 support the abiotic oil theory more than ever before.

The open question is what produces abiogenic hydrocarbons. One possibility (Manuel [18]) is that our planet has a core more closely related to that of a mature or neutron star and carries out processes related to neutron repulsion reactions which produce mainly carbon and hydrogen with these light elements percolating upward to form light hydrocarbons, the natural gases, and then heavier oils thereafter. This theory may certainly be wrong, but certainly not more than the “*fossil fuels*” or the “*global peak oil*” theories.

Considering proven coal reserves are even much larger than the proven oil and gas reserves that are presently still growing, there is for sure enough coal, oil and gas to last us much more than a century from now at current rates of production, and even longer if the opportunity of further discoveries and new technologies is taken into account, or more efficient ways to use carbon and hydrocarbon resources to produce power, heat and transportation fuels.

7 Power, heat and fuel production from coal, oil and gas feed stocks

Being “*fossil fuels*” reserves very far from depletion, effort should be made for a more efficient use of these reserves to produce power, heat and fuels. Combined cycles and waste heat recovery are key factors to increase the fuel energy usage from much less than one third to almost one half and above. Another key factor that should be exploited is the opportunity to produce power, heat and fuels by combining the feed-stock streams and the processes. For what concerns the transportation fuels, the most precious fossil fuel product, efforts should be made to produce same property transportation fuels of today Diesel, gasoline and jet fuels not only from oil, but also from natural gas and coal. This would improve dramatically the energy supply perspectives and sustainability and near future costs and security.

Gas-to-liquid (GTL) and coal-to-liquid (CTL) are everything but new, but integration of fuel production with power generation and waste heat recovery, and valorisation of by-products as synthetic oil, may dramatically improve the economical, energy efficiency and environ-

mental perspectives. Transportation fuels are liquid for optimal distribution, storage and consumption, even if gaseous fuels are also receiving attention. Apart from the traditional production from oil, liquid fuels may also be produced from methane or coal as well as from biomass.

The Fischer-Tropsch (F-T) reaction converts a mixture of hydrogen and carbon monoxide to liquid fuels. The F-T process was first developed by Franz Fischer and Hans Tropsch in 1925. Iron-based and cobalt-based catalysts have been popular so far. SASOL in South Africa and other oil companies as Shell, Chevron, and ExxonMobil have been conducting research and built pilot and small plants to produce synthetic fuels. Raw liquid F-T fuels are further refined to create highly-isomerized jet and diesel fuels with branched and straight chain alkanes and alkenes but no aromatics or oxygenates.

There is interest in synthetic fuels because for many countries they will lessen dependence on foreign oil, and in general they reduce the number of different fuels required, and reduce environmental impacts because they burn cleaner liquid fuels. GTL is a well proven technology (Saxol [31], Wood [37]) however with some energetic and environmental downfalls. A recent work has shown the opportunity to produce liquid alkane fuels from natural gas and carbon dioxide with minimal energy costs (Boretti and Dorrington [4]). These energy costs are subjects to further reductions by a better integration of the power plant producing electricity and the carbon dioxide of the feed stock and the fuel production plant.

In terms of chemistry, limiting our interest to natural gas, usually the first step is to produce Syngas with dry or steam reforming. The dry reforming of natural gas produces Syngas:

The steam reforming natural gas also produces Syngas:

While (1) and (2) are the reforming paths more interesting, other possible reforming paths are partial oxidation:

and auto-thermal reforming:

Syngas is the intermediate product of different technologies, from Fischer-Tropsch (FT) synthesis to methanol synthesis. While the FT suites of reactions are very well

established [17], the methanol synthesis has received significant attention only in the recent past but mostly for the opportunity to generate methanol from the splitting of the water molecule and the recycle of carbon dioxide (the methanol society, Olah [26, 27], Prakash [28, 29]). The methanol synthesis may also be used without the impractical splitting of the water molecule by solar energy starting from methane feed stock [1].

Oxy-coal combustion [8, 9] has been proved effective in small pilot plants to produce electricity with minimal extra energy costs (the upstream nitrogen separation to produce oxygen is partially balanced by the better combustion having higher power density).

The FT process is a catalytic chemical reaction in which carbon monoxide (CO) and hydrogen (H₂) in Syngas are converted at high pressure into hydrocarbons of various molecular weights according to the following equation:

with n a integer. The FT process conditions are usually chosen to maximize the formation of higher molecular weight hydrocarbon liquid fuels which are higher value products. There are other side-reactions taking place in the process such as the water-gas-shift reaction:

Depending on the catalyst, temperature, and type of process employed, hydrocarbons ranging from methane to higher molecular paraffins and olefins can be obtained. Small amounts of low molecular weight oxygenates may also be formed.

Methanol (CH₃OH) can also be produced from Syngas. CH₃OH can then be converted to gasoline via the “methanol-to-gasoline” (MTG) process or be converted to dimethyl ether (DME). Catalytic conversion of hydrogen (H₂) and carbon monoxide (CO) from Syngas into CH₃OH can be done with conventional gas-phase processor with a liquid phase methanol process. The reactions of interest are:

Novel methanol synthesis may offer a better route than the traditional FT or MTG approaches for the production of higher hydrocarbon fuels.

8 Conclusions and policy implications

The peak oil threat proposed by many, from Hubbert, 1956 to President Jimmy Carter, 1977, has been demonstrated to be wrong many times, without any proper comment of the issue. This paper discusses the peak oil hypothesis on the basis of the latest oil findings.

Proven oil reserves are presently increasing, and the increasing production and discovery of new oil fields is expected to continue at least up to 2020. Proven gas reserves are also presently increasing, while the total recoverable coal is certainly very large. The opportunity to produce transportation fuels from oil, conventional and non-conventional, and natural gas and coal make certainty their availability over this century.

Renewable energies are everything but extensive, inexpensive and efficient, and we must still rely on carbon & hydrocarbons for many years to come to cover the energy, heat and fuels needs. Therefore, as a R&D priority we should pay more attention to better use these carbon & hydrocarbons resources to produce power, heat and fuels much more efficiently than what is done now, by refining individual technologies, as well as by integrating technologies to deliver multiple outputs from multiple feed stocks.

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