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India's Choice of an Energy Policy and its Impact on Future Economic Growth – Discussed with Special Reference to Fossil Fuels[1]

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ABSTRACT

India's oil consumption seems to have reached a plateau[2] – this is basically due to modernization of the goods transport system in the Indian Railways and the consequent reduction in volumes of goods transported by road. This is partly also due to the extensive electrification of the Railways and consequent reduction in diesel consumption by the railway sector itself. Indian oil consumption could actually decline from current levels of 100 million tonnes/year and "flatten out" at about 90 MM t/yr.

Indian GDP growth is no doubt linked to total energy consumption. But, from 1999-2000, it appears that GDP growth is delinked at least from oil products consumption. As Indian dependency on imported oil would be not critical any more, India can then be considered to have become even actually independent of future oil "shocks".

More than 55% of the refined products from crude oil is used almost entirely in the transportation sector (motor spirit, diesel, ATF). Kerosene and LPG, forming another 23% of refined products, are used basically for cooking. Naphtha forms another 8% of refinery output. All this put together, come to more than 85% of products from crude oil and none can be really replaced by any other item in the "energy pie".

Finding 'new' oil is no more a critical item for India and pressure would be off from the national oil companies to invest scarce capital in very high-risk exploration projects. If, instead, much lesser risk investments are made to improve the efficiency of management of Indian oilfields and recovery factors are improved substantially it is even possible for India to once again attain a 70% to 80% crude self-sufficiency level – with no new oil discoveries. From the angle of applied geophysics we can note that the emphasis would shift from exploration seismology to geophysical techniques for reservoir monitoring and management.

From the standpoint of reserves India's ability to use coal for generation of thermal power is almost unlimited. However, the Kyoto protocol comes in the way. Hydro and nuclear generation possibilities seem to have peaked.

Natural gas seems to be the only available alternative fuel for energy infrastructure growth. However, domestic reserves would seem to be inadequate to base ANY MORE thermal plants on gas. Unless India imports very large volumes of piped gas or LNG this route is also not easily available. Regional arrangements outside the purview of global trading systems would be the only safe way for India to go for increased use of energy by the natural gas route.

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[1] Figures for reserves, production and consumption are ALL from Government of India publications. Annual reserves additions are easy to work out when the annual position regarding reserves and production in that year are known. The term "reserves" has been used by MOPNG to mean recoverable oil (and for the last twenty years or more are exactly matching Exxon and BP figures for India).

[2] There are several who question the Government figures regarding decline in demand for oil (in crude equivalent units) with the largest number saying that volumes of kerosene used to adulterate diesel are being ignored in the Government figures. What is missed by those who believe in such 'conspiratorial theories' is the simple fact that the biggest decline is in sales, not of diesel, but of kerosene made in Indian refineries! That, until a week back when Government put a stop to this, the private sector continued to import kerosene during the period when the PSUs were finding it difficult to offload all the kerosene they were producing is the bigger paradox.

INTRODUCTION

Per capita energy consumption in India is quite low in comparison with that characteristic of the developed countries. On a per capita basis Indian consumption of total primary energy is 325 kg oil equivalent per year compared to Japan's 1700 kg oil equivalent a year, or 5160 kg oil equivalent per year of France or the 9969 kg oil equivalent for the United States. Even in the Third World ,India's neighbour to the north, China, consumes 832 kg oil equivalent per capita per year.

Future economic growth in the developing world, and in India too, will clearly be related to bridging this energy gap between the First and the Third worlds. The path for energy infrastructure development that any one country chooses depends on several factors but, it could be stated at the outset that there are only a very few scenarios for the path India will choose in order to develop her economy. To a large extent, it is the way a country attempts to bridge this gap that is specific for that country or a group of countries. Therefore, instead of looking at India alone or on India as part of a very large number of Third World countries, it might be more useful to look at India and just one other country say, for example, China, both having comparable patterns of energy infrastructure development over the last few decades. The reason for this will become obvious as we look more deeply at the problem facing India.

One path that could be followed is for minimal government involvement in the entire process of infrastructure development and leaving the energy sector entirely in the hands of the entrepreneurship of the local or foreign investors. This is what would be expected to happen when a state follows the standard "trickle-down" concept of economic growth where a growing middle class is supposed to "lift up" the population on the bottom rung of the economic ladder. This concept has failed to do what it is meant to do in almost all of the sub-Saharan countries but is the preferred path of those who subscribe to the Washington Consensus. In India the best estimate is that the "middle class", at a generous estimate, now numbers about 300 – 350 million. If the richest tranche forms only a small number it is not difficult to accept that those living at the subsistence level must be around 700 million with at least half of this number living below the poverty line. Leaving the general philosophy of a preferred economic theory out for the moment we still have the problem that the linkage with infrastructure development, particularly the energy infrastructure, and the "trickle down theory" is extremely tenuous. The so-called linkage of per capita energy consumption with growth in GDP is entirely empirical and does not take into account how a given industrialized country reached its current level – a captive source of raw material or a captive market for exports would have been far more critical for the given country's growth rather than mere increased usage of commercial energy – the classical chicken and egg conundrum. In any case the Industrial Revolutions of Europe and North America which necessitated the enormous growth in the consumption of energy took far too long a time and happened in a totally different environment than what prevailed in the second half of the 20th century. One should also note that the quantum leaps in energy consumption in Western Europe and Japan took place in the background of the Marshall Plan for Europe and during MacArthur's pro-consulship in Japan. One is, therefore, not really sure that individual entrepreneurship (including the much touted FDI) will make Indian energy consumption grow from today's low figure of 325[3] kg oil equivalent per head per year to something like 1500 kg oil equivalent per head per year.

If circumstances permit the South Korean model, where, of course, the state played a significant part, is yet another one we could follow. In South Korea oil, natural gas and nuclear power form 75% of the energy pie (see Table 1 below). The most important reason why we may be unable to follow the South Korean example is the simple fact that our industrial exports are nowhere near enough to permit us to import LNG and crude oil in enough quantities (another 75 million tonnes of crude oil on annual basis and more than 20 million standard cubic metres a day of natural gas as LNG). Note that currently crude, natural gas and nuclear power forms precisely 39% of our energy pie with coal alone forming more than 55% of the energy pie as a whole and being practically responsible for over 80% of power generation. The South Korean model is, most probably, inapplicable for India.

In France, where coal forms just around 5% of the energy pie and the largest contribution comes from the nuclear sector (38%), the energy infrastructure sector is (or was until very recently) very rigidly controlled by the state. France had the good fortune also to be in a "buyer's market" for gas – the Algerians

[3] This figure is an apporximation. With the country consumption (Table 1) being 325 million tonnes/year (325.000 million kg/year), if the population is taken to be 1000 million, then the figure of 325 kg/head/year is very nearly correct.

across the Mediterranean have really no other customers for their enormous LNG trade other than France, Spain, Turkey and Italy. France also imports very large volumes of piped natural gas from Norway and Russia. Neither the development of nuclear power generation capability of this size nor the import of natural gas in such enormous volumes – again in "near buyer's market" conditions - are feasible for India. We need to look at another example to follow.

This leaves us with one more model, the "Chinese model", for a closer look. Even though there are differences as regards the initial endowments of crude oil, currently, China having increased oil consumption to match and then exceed her own production is now a net importer of crude. Although China's consumption of total energy is two and half times that of India this is the only country of comparable size to India which is still not too far ahead of India in terms of industrial production. This is the reason for comparing the energy consumption growth pattern of India and China over the last few decades. China was able to base her growth in thermal power generation primarily on coal – and that too rather poor quality coal at that. Despite having double of India's natural gas reserves current annual consumption of China is only equal to that of India. We should, therefore, note that India will never be able to reach China's current level of per capita commercial energy consumption without either using much larger volumes of coal in thermal electricity generation plants or by importing natural gas (most probably in the form of LNG) in enormous quantities for power generation purposes.

Table 1: Primary Energy Consumption in 2002 - by Fuels (MM tonnes oil equivalent[4]).

	Oil	Natural Gas	Coal+ Lignite	Hydro	Nuclear	Total
United States	894.3	600.7	553.8	58.2	185.8	2293.0
China	245.7	27	663.4	55.8	5.9	997.8
Japan	242.6	69.7	105.3	20.5	71.3	509.4
India	97.7	25.4	180.8	16.9	4.4	325.1
France	92.8	38.5	12.7	15	98.9	258.0
South Korea	105	23.6	49.1	1.2	27	205.8

Coal, some lignite, crude oil and natural gas are the four main types of fossil "fuels" used in India. The share of each in the energy "pie" is fairly similar for India and China (see Table 1) the two that are the large developing countries of the world. The large-scale use of products of refining crude oil being largely restricted to the transportation sector (with a large volume of kerosene still used for home needs – cooking and illumination) is another common characteristic of India and China. Thermal power generation is the sector in which both countries are consuming very large quantities of coal and lignite.

More than annual increases in the use of any given type of commercial energy it is the pattern of the "energy pie" that tells us which group we belong to. The difference between South Korea and Japan lies, as can be seen in Table 1 above in how the former country, on a per capita basis, has invested much more in nuclear power generation than Japan. If you look at a larger data base you will see that South Korea modeled itself, at least in developing the energy infrastructure, more on France than neighbouring Japan.

It is accepted by all that energy consumption will have to be growing at some given rate linked to growth in GDP but what forms the core part of this study is the way different types of "fuels" are used by different countries to reach the same goal – growth of GDP. The composition of the "energy pie" is (as seen in Table 1 itself) not the same for different countries at the same levels of development. The present analysis is constructed in such a way that we would first look at specific "fuels" and then only go and look, in the final parts of the note, at total commercial energy used. To sum up this introductory part, the main conclusion of this note is that India will have to actually develop her own unique path to solve this question of energy infrastructure development.

DOMESTIC SUPPLY OF CRUDE OIL – THE CURRENT SCENE

The term "reserves" is used here in the conventional way it is used in the industry :- "reserves" mean the volumes of oil that are recoverable from "initial-oil-in-place" by using currently available techniques and with oil selling at current price levels. Depending on the technology in use in a field, "reserves" can be anywhere between 10% to 80% of "initial-oil-in-place". In India, the Ankleswar oilfield has already produced over 55% of initial-oil-in-place and the S_{3+4} reservoir (which has the bulk of Ankleswar's oil) in that field

[4] 1.6 tonnes of hard coal or 3 tonnes of lignite are the calorific equivalents of one tonne of oil. 1 tonne of LNG is equivalent to 1.23 tonnes of oil. 1100 cubic metres of natural gas is equivalent to 1 tonne of oil. 12 mega-watt hours of electricity is the equivalent of 1 tonne of oil.

has produced a little over 74% of IOIP of the reservoir. The Zaloni block of Nahorkatiya has produced a little over 50% of IOIP. If you leave Ankleswar and the Zaloni block out then the average recovery factor for the rest of the fields together is between 24% and 26% of IOIP. The Ankleswar oilfield of ONGC is undoubtedly the best-managed field in India.

The term Reserves to Production Ratio (R/P) indicates "the Reserves remaining at the end of any year divided by the production in that year .. the result is the length of time that these remaining reserves would last if the production would be continued at that level" (Exxon-Mobil's definition). Although this term is freely used by all of us in the industry it should be made clear here that such a production scenario, of producing at a constant annual rate all the way to the day the field is abandoned, is actually impossible for any oilfield. It is against all the laws of the physics of oil production from a reservoir. After a certain period of production at a constant annual rate – termed the plateau production rate – the production rate would annually decline (hyperbolic, exponential or harmonic declines are the normal decline patterns). R/P ratio is, if wisely used, a useful method of giving a general idea of the value of the remaining reserves and the efficiency of the management of the assets. R/P ratio is never to be used for engineering calculations. In a very general sense, R/P ratio is, as mentioned earlier, an index of operating efficiency – all other things being equal, the lower the R/P ratio the better would be the style of management of the concerned pool or group of pools. However, it should be noted that not even an experienced professional would care to judge managerial efficiency merely from the R/P figures.

"Ultimate reserves" consist of three parts:

Volumes of oil that have been already produced to the given date.

Volumes of oil proven "reserves" remaining to be produced from currently known fields (this is generally estimated with a high degree of accuracy by the companies operating the fields and is double-checked by the country's regulatory body).

Volumes of oil "reserves" in fields that are yet to be discovered (this figure is actually unknown and an educated guess is all that characterizes the amount of these "reserves").

For the world as a whole, the currently generally accepted figure (for 1.1.2002) is 891 MMM barrels of oil already produced, 1050 billion (MMM) barrels of crude oil as proven reserves PLUS a certain volume (720± billion barrels) oil that is yet to be found. But, as the "third ingredient" noted above is merely an estimate which includes (i) considerable personal bias, (ii) improved knowledge regarding the geology and oil prospectivity of basins, (iii) improved techniques for enhancing the recovery of discovered volumes of "oil-in-place", etc. it is obvious that this number would have kept on "increasing" over the last several decades. But, in the last 10 or 15 years there is a general consensus that world Ultimate Reserves should be of the order of 2661 billion barrels (a realistic "looking" figure – and not a rounded figure – is arising because it is the product obtained after several thousand Monte Carlo simulations of a generally acceptable data base of basic parameters). For all practical purposes we could say that world Ultimate Reserves are around 2660 billion (MMM) barrels[5] of which:

891.29 MMM bbl have been produced as of 1.1.2001.

1050 MMM bbl proven reserves remain to be produced as of 1.1.2001.

Around 720 MMM bbl reserves are expected to be discovered.

The "proven reserves" as estimated for 1.1.2001 have been estimated using the very much higher recovery factors of initial-oil-in-place that would be possible in the next couple of decades. As economic recovery of as high as 80% of IOIP has already been found realistic in carbonate reservoirs in Canada and as economic recovery of more than 70% of IOIP has been accepted to be possible from harsh environments like the North Sea one should assume that currently available technology is adequate for such high expectations from the rest of the world. This means that all possible future revisions of reserves in the already discovered oilfields of the world are already "included" in the current estimate of proven reserves. In this context all of the listed under "oil yet to be found" would be only "new" oil (see later sections for a definition of this term).

Before we go on to see what has been the history of oil in India and estimate what the future is going to look like, we should look at the historical data of

[5] As I was finalizing this paper, on 28.11.03 a friend sent me a copy of Holditch's paper on "Increasing role of unconventional oil…". My figure of 2660 MMM bbl (which I worked out from Campbell's classic 1997 paper) as the world's Ultimate Reserves is being considered as the most optimistic estimate by Holditch. Holditch's "median case" would mean that UR is only around 2200 MMM bbl with only 259 MMM bbl remain to be discovered. In one of the "keynote talks" for Petrotech 99 I did say that UR could even be as high as 3200 MMM bbl with around 400 MMM bbl to be found in the Rub al Khali of Saudi Arabia – I suppose this is too optimistic.

Table 2. Annual additions of "new oil"** to reserves and annual production of oil (after Longwell, 2002).- billions barrels crude oil. Cumulative oil data is summarized from several other sources.

Year	Additions of "new oil" in the year	Annual Production	Cumulative Production
1865			0.005
1875			0.0181
1885			0.0550
1895			0.1581
1900	0.7	0.7	
1905	0.5	0.5	0.3737
1910	0.7	0.7	
1915	0.7	0.7	0.8058
1920	0.7	0.7	
1925	4	0.7	1.8749
1928	20.05	0.7	
1930	3	0.8	
1935	20	0.8	3.5298
1938	31	0.9	
1940	23	0.9	
1943	8	1.2	
1945	6	1.5	6.1246
1947	40	1.9	
1950	45	2.2	
1952	21	3	
1955	35	4.5	11.5996 (estimated)
1960	48	6	
1962	58	9	
1964	43	10	
1965	47	11.61	23.2077
1970	29	17.54	97.60
1972	32	17.59	135.75
1975	38	20.38	198.85
1978	38	23.11	266.91
1980	22	22.97	313.97
1985	18	20.96	419.23
1990	11	23.86	533.66
1995	6	25.53	654.80
1997	7	26.75	784
2000	14	27.19	864.1
2001	n.d	n.d	891.29
2002	10	27.38	918.66

Table 3. Additions to Crude Oil Reserves (revisions to old oil plus discoveries of new oil), Annual Oil Production and Cumulative Oil Production (data source from 1980, MOPNG, Government of India – earlier data is estimated by author and are largely correct)

Year	Reserves additions in the year: billion (MMM) tonnes – MMM bbl within brackets	Production Rate (MM) tonnes/yr	Cumulative Production from 1889 million (MM) tonnes	Fractional Depletion of Proven reserves 1518 MM tonnes##
1953	0.082 (0.6)	0.249	n.d.	
1961	0.055 (0.4)	3.0	n.d.	
1974	0.109 (0.8)	9.822	76.769	0.051
1975	0.477 (3.5)	7.684	84.453	0.056
1976	0.068 (0.5)	8.448	92.901	0.061
1977	0.068 (0.5)	8.898	101.799	0.067
1978	0.068 (0.5)	10.763	112.562	0.074
1979	0.041 (0.3)	11.633	124.195	0.082
1980	0	11.766	135.961	0.09
1981	0	10.507	146.468	0.097
1982	0.081 (0.59)	14.194	160.662	0.11
1983	0	21.063	181.725	0.12
1984	0	26.02	207.745	0.14
1985	0.00098 (0.0072)	28.99	236.735	0.16
1986	0.0307 (0.2251)	30.168	266.903	0.176
1987	0	30.48	297.383	0.196
1988	0.2531 (1.855)	30.357	327.74	0.216
1989	0.122 (0.8945)	32.04	359.78	0.237
1990	0.029 (0.2137)	34.087	393.867	0.26
1991	0	33.021	426.888	0.28
1992	0	30.346	457.234	0.301
1993	0	26.95***	484.184	0.319
1994	0	30.86	515.044	0.34
1995	0	35.27	550.314	0.363
1996	0	35.17	585.484	0.386
1997	0	32.9	618.384	0.407
1998	0	33.86	652.244	0.43
1999	0.078 (0.5722)	32.72	684.964	0.451
2000	0	31.98	716.944	0.472
2001	0	32.43	749.374	0.494
2002	0.032 (0.2376)	32.03	781.404	0.515

** Longwell explicitly states that all reserve additions other than "new oil" have been backdated to date of discovery of the field.

*** Rising water cut and lack of gas lift facilities in the Bombay High field are the reasons for drop in production in 1993 and 1994. Otherwise, peak production should have been in 1994 ?

Proven reserves of 737 MM tonnes crude oil in 2002 plus 781.404 MM tonnes crude already produced at end of 2002 giving a total of 1518 MM tonnes. Oil yet to be found is NOT is not taken into account for calculations in this column.

oil in the world as a whole. In World Energy Vol.5, No.3, 2002, Longwell (Vice-President and Director of Exxon-Mobil) has given a very interesting chart. Following the accepted definitions for "new oil" Longwell has backdated all revisions to reserves in any field to the date of discovery of the field. He has shown the additions to reserves ("new oil" only) made from 1900 to 1.1.2002 and has also shown annual crude production for the same period (Table 2). Cumulative production of crude oil for the world is from a variety of sources (including Yergin's classic book on the history of oil).

The main points made in Longwell's analysis are that (i) the "peak year" for crude discovery was 1962 and (ii) that, after 1980, the world's Reserves Replenishment Ratio has been less than 1.0.

It will be interesting to compare the world scenario with that of India (Table 3)[6] even if we are unable to distinguish, in our annual reported additions to reserves, between additions by way of "new oil" (as defined here) and those by way of revision of reserves in fields already discovered. In our case the revisions have been more due to the highly conservative nature of the initial assessments than any other reason. Stepout wells and/or improved seismic coverage have generally tended to make subsequently estimated volumes of reserves to be much larger than the initial estimates.

The last column in Table 3 below will plot as a proper King Hubbert Bell curve ONLY if we add the reserves that we expect to discover in the future to the reserves which have been already produced (and used) as well as the reserves which are now considered to have been proven and which is sure to be produced in the future. Only the sum of all three of the types of reserves can be called "Ultimate Reserves" and only by calculating depletion index using Ultimate Reserves can we say whether Indian oil production has peaked once and for all or not. The last column of Table 3 does not use Ultimate Reserves as defined here and, therefore, the numbers are merely only indicative of where we are heading.

Really significant oil discoveries were made in India only after Burmah found Nahorkatiya in 1953. Before that we had only the Digboi field in NE India and the fields of the Attock basin in the northwest, in what today is Pakistan. Ankleswar was found by the newly formed Oil and Natural Gas Commission in 1960. Thereafter a string of medium sized discoveries were made in the Cambay basin of Gujarat and the Brahmaputra valley in Upper Assam. The next big find, made by ONGC early in 1974, was the near super-giant[7] oilfield, Bombay High as it was then called, offshore of Maharashtra. This was followed by several medium sized discoveries in the same general area as Mumbai High (the current name of the Bombay High field) – Bassein, Heera, Panna, Muktha, Rathna etc. (the last two are small sized yet to be developed). Meanwhile the size of the discoveries in the Cambay Basin had been getting smaller and smaller until the Gandhar field was found – this is termed a "bump on the tail"[8] and very large volumes of new oil are not expected to be found any more in the Cambay Basin. The latest discovery of West Vasai (Bassein) – a big gas field with a thin oil column – can also be termed the "bump on the tail" for the offshore part of the Cambay rift. Another important series of discoveries were in the Oil India licence area of upper Assam – the discovery of oil in Eocene sandstone reservoirs. A series of such pools have been found by OIL which has permitted the company to continue producing around 3 million tonnes per year even though production from the Oligocene Barail and the Miocene Tipam pools had declined to less than a quarter of a million tonnes a year by the middle of the 'nineties from the original rates of around 3 million tonnes/year. The two oil fields found on the shelf area of the Bay of Bengal – Ravva and PY-3 – are unique in the sense that nothing more has been found in the offshore areas of either the Godavari Basin or the Kaveri Basin.

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[6] Note that world figures are in billions (MMM) barrels while Indian figures use billions (MMM) or millions (MM) tonnes. Govt. of India conversion factor is 7.33 bb/tonne and this is what is used in this note.

[7] Fields with reserves exceeding 500 million barrels are termed as "giant" fields. Fields with reserves in excess of 5000 million barrels are termed "super-giant" fields. There are close to 375 giant fields in the world but there are only 51 super-giants. Bombay High would be termed a super-giant, and would be the fifty second largest field in the world, if the recovery exceeds 40% of initial-oil-in-lace.

[8] When one plots discovery sizes against time (on the x-axis) one would note that the size of each subsequent discovery is, in a general sense, smaller than the previous one. This is not to be taken literally – as said earlier, in a very general way such a plot would show how the Law of Diminishing Returns works in the sector of exploration for oil. Often enough though, one would make an anomalous find of a large field at the tail end of the exploration history in a region – such a find is called a "bump on the tail".

DOMESTIC SUPPLY OF CRUDE OIL – FUTURE SCENARIOS

According to several studies, including those by Government agencies (the NOCs in the main) as well as by private ones (such as TERI), Indian demand for products obtained by refining crude oil will exceed 250 million tonnes a year by year 2020. The "accepted version" in the Vision 2020 document shows these high "expectations" (the "optimistic" figures in Table 4 below are quite close to the Vision document expectations). The difference between the Vision 2020 estimate and what is shown as the author considers as realistic (but is listed as "pessimistic" in Table 4 is big and a mistake in prognosis will have a big impact on how the investment requirements are planned and, indirectly, will also have an impact on how our economy would develop in the next couple of decades. We need to have multiple working hypotheses in order to select that scenario that has the highest probability of coming correct.

If the hope of major crude oil discoveries in the immediate future is the basis for assuming a doubling of oil consumption in the period 2002 – 2020 then one should be very careful before accepting assumptions of dramatic increases in domestic crude oil production in the immediate future. While discussing the volumes of oil discovered or hoped to be discovered, one important point should always be kept in mind: One should not, while planning for the future, club together crude oil and natural gas. And one should also distinguish between non-associated gas, associated gas as gas cap gas and associated gas as "solution gas". As of now natural gas does not replace products obtained after refining crude oil – with the sole exception of CNG in Delhi buses.

We would only be deluding ourselves by talking about "reserves of oil plus oil-equivalent-gas" instead of separately reporting "crude oil reserves", "reserves of associated gas" and "reserves of non-associated gas" and "dissolved gas". This further distinction for natural gas is extremely important because, in most cases, associated gas will never be produced until all the associated oil reserves have been produced and gas dissolved in oil can never be produced unless oil is getting produced. One should also distinguish between additions to the reserves portfolio by better management of the reservoirs and the fields and additions to reserves by finding "new" oil. As the normal practice in the world is to backdate all revisions to reserves in a field to the date of discovery of the field only oil found by "new pool wildcats" can be really called "new oil". The entire discussion below is strictly within the framework of the above-mentioned definitions of terms.

The drafts of the Vision 2020 document are the only ones where future reserves and production figures are discussed. What I am not too certain about is whether future crude oil production at the levels mentioned for that document is actually possible or not. My own estimates are quite pessimistic and are much lesser (see Table 4).

Table 4: Anticipated crude production profiles–millions tonnes/year

	2002-03	2010-11	2016-17
Optimistic Version	30	55	65-70
Pessimistic Version (KN)	31	30	25

**Condensate production is not included here.

As there are two contrasted expectations regarding the outcome it becomes all the more necessary to analyze more closely which viewpoint has the better chances of proving right.

The current production rate of around 227 million bbl/year (31 MM t/yr) is from a reserve base of 5.4 billion bbl (737 million tonnes) at R/P ratio of around 24. For the currently producing fields the physical effort and financial investment to improve recovery factors will take several years to "bear fruit". The reserves in hand now (the old reserves) will, therefore, be getting produced at an annually declining rate and this situation is not easily changed.

Before we look at what is realistically possible in the next 15 years it is necessary to have a look at the Indian "crude oil reserves pie" (note that the word "reserves", following standard practice in the industry, means only volumes of crude oil that can be produced economically using currently known technologies. The initial-oil-in-place is NOT being shown here).

Oil produced and consumed to 1.1.2002 are 781.4 MM (million) tonnes.

Proven crude oil reserves as of 1.1.2002 are 737 MM tonnes.

Reserves of "new" crude oil expected to be discovered are.350 MM tonnes (author's estimate).

India's "Ultimate Reserves" of crude oil would then total to 1868 MM tonnes.

There is considerable difference of opinion in regard to the volumes of oil that are "yet to be found". Several highly optimistic estimates of the oil reserves remaining to be discovered in India have been published (most of them were made in the early 'eighties by ONGC on behalf of the Ministry of Petroleum and Natural Gas). Some of these estimates were reviewed by some of us[9] as long back as 1984 and we were not convinced about the precision of these estimations. For the purposes of this note, one would prefer the figure of 350 MM tonnes (requiring discovery of new fields with IOIP in excess of around 900 MM tonnes (recovery expected being around 40% of IOIP) as the reserves of "new" oil that are yet to be discovered in India. The record of all the oil companies working in India over the last decade and a half would even suggest that the figure of 350 MM t is itself rather over-optimistic. If, however, efforts for enhancing recovery factor to around 70% of IOIP in the old fields now being operated and in the fields yet to be discovered are successful, then it is not unrealistic to expect Ultimate Reserves of India to be closer to 2200 MM tonnes than the 1868 MM tonnes shown above in the data for the "Reserves Pie". But, it is then important to note that the increase in reserves by another 332 MM tonnes comes entirely from fields that have already been discovered and this additional volume would have to be "backdated to the years of discovery of the fields".

Production at a declining rate (see Table 5) from 31 MM t/yr (in 2003) to 18 MM t/yr (in 2010) from the 'old reserves' would deplete the current reserves of 737 MM tonnes by 150 MM tonnes – bringing the figure of remaining 'old' reserves down to 567 MM tonnes by 2010. With further production, again at a declining rate from 18 MM t/yr in 2010 to 12 MM t/yr in 2016 there is a further depletion of a further 88 MM tonnes bringing the 'old reserves; down to 507 MM tonnes by 2016. These numbers can change and a higher rate from the 'old reserves' will be possible if considerable efforts are made and considerable investments are also made to improve the recovery factor from the 'old reserves'. The present writer does not believe that the fields currently under production can be rehabilitated and redeveloped in time for the benefits to be seen by 2010. A large volume of 'new' oil will then have to be found to maintain a rate of 30 MM t/yr till 2010 but even this will not be enough to produce at a rate more than 25 mm t/yr in 2016. Without a great deal of luck and more serendipity than should be normally expected with all this resulting in the discovery of a huge oil field in the next couple of years the optimistic production rates of Table 4 are just not possible

As will be discussed below the writer is not very optimistic that such large volumes of 'new' oil as are required will be found and developed for production by 2010.

It should be noted that other than the thin oil column in West Bassein (Vassai) no "new" oil pools have been found last year (2002-2003) and unless significant discoveries (with IOIP in excess of 600 million tonnes – "reserves" of 240 million tonnes at 40% of IOIP as recovery factor) are made in 2004 itself there would be little chance of maintaining a production rate of 30 MM t/yr in 2010-2011 (see Table 5). Table 5 also goes on to show the other essential conditions such as (i) finding another set of fields between 2010 and 2016 with IOIP in excess of 250 MM tonnes ("reserves" of at least 100 MM tonnes), (ii) developing all future discoveries for a much higher UER than the current expectation of 28% of IOIP and (iii) having the ability to produce from all new discoveries with R/P ratio of at least not more than 10 years.

The production rates optimistically hoped for in 2010-11 and 2016-17 (see Tables 4 and 5) can be achieved only if another 340 (240+100) million tonnes of crude reserves – equivalent to another 850 million tonnes of oil-in-place with a minimum 40% recovery for estimation of reserves - are found (see Table 5 for details). The currently available reserves of 737 million tonnes cannot even sustain current production rates of 30-31 MM tonnes/year – the annual rate will be steadily declining unless the impact of future inputs to improve recovery bear fruit.

During the formulation of the 9th Plan the question of how much contribution, the arrival of new technology had made to discovery of oil in India, was raised by Ministry and the Energy Division of the Planning Commission. A study made by the author, while formulating the 9th Plan (see E&D Sub-Group's Report of July 1996), had shown that all of the crude reserves discovered in India prior to 1982 have been found by use of rather primitive technology (single fold surveys with analog data recording). As seen from Table 3 above, of the 1518 million tonnes of oil found in India, the bulk of it in the period after 1952, only about 33% (516 MM tonnes) have been found with digitally acquired multifold data[10]. There are, of course, no discoveries on account of 3D done for exploration. If one takes current crude production

[9] When two of us from the Norwegian Petroleum Directorate were invited to Dehra Dun to have a look at Basu's first estimate of Ultimate Reserves of Oil.

[10] Digital recording became standard from around 1963 but was used in India only from the mid-seventies. Multiple subsurface coverage became standard operating procedure in the world even earlier (earlier than 1963). In fact 3-fold and 6-fold subsurface coverage was used in Jaisalmer as far back as in 1964 even though it became standard in other parts of India only in late seventies.

Table 5. A possible scenario for the period till 2016-2017. Crude oil reserves** and annual production rates are both in millions of tonnes (MM t).

	2003	2010	2016
Balance reserves "old" oil (known in year 2003)	737	587	507
Production Rate from "old" oil in year 2010 (R/P ratio 30)	31	18	12
Production required from "new" oil found between 2003 and 2010 to keep production rate at 30 MM t/yr in 2010 and at 25 MM t/yr in 2016	0	12	8
Volume of "new" oil reserves to be found before 2010 to assure a production rate of 12 MM t/yr from "new" oil reserves (R/P ratio 10 for 'new' oil)		240	
Balance of reserves of "new" oil found before 2010		240	180
Volume of "new" oil needed to be found between 2010 and 2016 to assure a production rate of 29 MM t/yr in 2011			50
Production rate from oil found between 2010 and 2016 (R/P ratio 10)	0	0	5
Volume of more "new" oil reserves to be found before 2016 to assure a production rate of 25 MM t/yr in 2017			100
Annual Crude Production Rates MM tonnes/year	31	30	25

**The term "Reserves" is as defined above: volumes of oil recoverable at current prices and with currently available technology.

figures instead, one notes the significant fact that actually about 80% of crude production comes from reserves discovered with 'primitive' technology. What is even more important is the fact that all the post 1982 discovery of crude reserves have been made only in the already established producing basins and NOT in a new basin. Eight years later, the main conclusions of that report remain valid. These are that:

Merely using the latest technology is not enough to find "new" oil. 3D has been in use for several years now and no newer techniques have in fact been used in India. There have been lots of discussions of 4D and 5D but other than some experimental work done a decade back in a heavy oil field (Balol) in North Gujarat where a fire-flood was being tried, a time series survey has not been done in India.

Not much new oil is expected to be found easily in the 'old' basins. Hardly 253 million tonnes crude oil reserves have been added in the last 15 years with much of it on account of revision of reserves in old fields.

New basins with crude reserves are not going to be found by exploration in the "Category 2, 3 or 4" types of basins already identified in India or at least the probability of making such finds are extremely low. In any case, no new oil-producing basin has been found in the last three decades.

It is possible that decisions for investments to increase reserves by improving the recovery factor in the old fields will not be made fast enough to get results before the field rates decline to much lower levels – this naturally means that the level of investments required for higher recovery will become too high and the technology required for improving recovery would steadily become more and more complex. Average recovery factor continues to be the same (26% or so of IOIP) as at the start of the 9th Plan.

The main new effort during the 10th Plan has been in the deep-water areas. The deep-water prospects are discussed in some detail in a later paragraph.

Returning to the subject of exploration success in the last decade and a half we noted in Table 3 that, in 1988, additions to crude reserves of the order of 0.253 billion tonnes (1.855 billion barrels) were made and these include the reserves of new fields such as Bechchrajji (Cambay basin), Neelam (Maharashtra offshore), both in the ONGC licence areas, and the Eocene pools (Dikhom, Kataloni etc.) in the Oil India licence area of Upper Assam. In the last 12 years, after 1991, only very small volumes – 110 million tonnes - of oil reserves ("new" as defined above PLUS upward revisions of "old" oilfields) have been found in the country:

The 1999 additions to crude reserves of 0.078 billion tonnes (0.572 billion barrels) have mostly come from revisions to reserves of Ravva, Panna, the Eocene pools of Upper Assam etc. very little has come by way of discovery of "new" oil (as defined in this note).

The 2002 announcements of additions to crude reserves 0.032 MMM tonnes (0.2376 MMM bbls) have been partly about the small oil find by Shell/Cairn in Barmer Distrtict of Rajasthan and mostly about the thin oil column of the West Bassein gas discovery. The thin oil column of the main Bassein field has been abandoned without production and there is not much reason to believe that the thin oil column of West Bassein would get produced.

The annualized additions to reserves in the last 12 years then would be would be just about 16.9 MM tonnes/year (including 9.2 million tonnes a year of new oil). The RRR from 1991 to now is then around 0.5 which means we are finding only half of what we should be finding annually - just to keep ourselves in the same place as we were an year before. There is considerable risk in all future oil exploration ventures in India (as well as anywhere else in the world). Unless a very new type of productive basin is found in India there is little chance of domestic oil production growing much higher than the current 30 $\pm$ MM t/yr.

Other than speculations for possible oil pools beneath the outer foothills of the Patkai Bum (or in more difficult situations of complex folding and thrusting in the Cachar Hills, the hills of eastern Tripura and of Mizoram), the only areas where one could find really new oil should be in the deep-water areas of the Bay of Bengal or the Arabian Sea. The deep water areas of the Bay of Bengal is underlain by oceanic crust with hardly any prospect for finding crude oil accumulations in overlying sediments. Closer inshore oil prospects are expected to be limited to the early Cretaceous rifts associated with the break-up of Gondwanaland. Also interesting would be the earlier rifts where Permian synrift sediments could have acted as source rocks. By and large all the oil that is easy to find has been found in the land and marine parts of the Godavari rift and delta. The "passive margin prism" should be expected to be low in organic content and whatever is there should develop the so-called Type 3 kerogen leading to finds of dry sweet gas and hardly any oil.

The "deep water" expectations in the Vision 2020 document are not based on any serious geological analyses and the only area where I would say there are good prospects is the rift basins area in southern Arabian Sea identified almost a quarter of a century back by the Oil and Natural Gas Commission (as the organization was termed in the days when those remarkable studies discussed below were carried out by the late Dr. Prasada Rao).

The late Dr. R Prasada Rao made an extra-ordinarily imaginative interpretation of the very first deep water seismic done in the Arabian Sea (see Rao and Srivastava, Bull.ONGC, vol.21, no. 1, June, 1984). Dr. Rao was unfortunately not wanted back in ONGC when he came back from Belize to India and most unfortunately he also passed away soon after he settled down in Hyderabad. He has mapped several rifts, which, from what I remember of the discussions with him on the phone (when he was in Belmopan and I was in Stavanger), he felt were NOT of lower Tertiary age like the Cambay Rift. I cannot be sure but, if I remember right, both of us were inclined to think that they could be Permian rifts much like the Morondova basin on Madagascar or the Mandawa rift in Tanzania. In India the geographically closest analogy is the Mandapeta rift in Andhra. Both of us rated the prospects in the Arabian Sea rifts (in the rifts mapped by Dr. Rao) to be high on account of the huge tar deposits in the Permian sands of the Bemolanga area in the Morondova rift basin on Malagasy. Even in mid-Cretaceous times Prasada Rao's rifts were closer to the Bemolanga area than the Mandapeta rift of India.

There has never been a major crude oil discovery, whether it be in Iran or in Saudi Arabia, without a certain element of luck and ONGC has had its share of luck in the past. It will be very wrong to state that ONGC will not find any oil at all in the deep-water areas[11]. The major part – over 80% - of oil reserves in India has been found by ONGC and the company is bound to find lots more oil. In fact if one excludes the small oil find by Shell in the Barmer district only Oil India and ONGC have found any oil in India. A *part* of the Sagar Samvriddhi programme should, therefore, be certainly executed. But whether the first wells will give enough positive indications to go ahead with the whole programme or not is what cannot be decided right now. Almost all the exploration eggs appear to be in just one basket and this creates a feeling of uncertainty in regard to fulfillment of very big expectations.

The only way to hedge the bets is by equally heavy investment in (i) foreign exploration and (ii) efforts to double, in the first instance, and then, later, try to treble our recovery factor – from the current 26% of IOIP to around 80% of IOIP. There is a lot less risk

[11] The Oil and Natural Gas Commission of India made three new basin discoveries – the Cambay Basin (including its offshore extension), the Kaveri Basin and the Godavari Basin. No other company in the world has made more than two new basin discoveries in the last 53 years.

in working to improve recovery factors in old fields than in pure exploration for 'new' oil reserves.

HAS INDIAN CRUDE CONSUMPTION REACHED A PLATEAU ?

This is what using the old cliché we would term the "million-dollar question" and we must try to answer it here. As early as in 1996, when we were all busy with the formulation of the 9th Plan, we used to have very long and contentious discussions on this subject. Some of us were very sure that crude discovery had clearly peaked in 1975. We were also suspecting that domestic oil production had also peaked in 1994-95. The 9th Plan document showed that consumption in 2000-01 was being estimated at 112 MM tonnes. However, during the 9th Plan discussions itself there was partial consensus that domestic CONSUMPTION of oil (as crude oil or as refined products) will also not go above 100 million tonnes a year by the last year of the 9th Plan. Has demand for crude oil also peaked ? On the answer to the clichéd question above hangs the choice of India's future energy policy.

A reliable forecast of the future scenario of Indian consumption of oil (as crude oil or as refined products) is essential to plan investment[12] in energy sector infrastructure development. If the state has any part at all to play in planning for growth of GDP there is little doubt that certain basic strategies would need to be developed on a national basis. If, for example, Indian oil consumption has reached (or is about to reach) a plateau then it should be recognized that a very intensive analysis of why this has happened is extremely important. It is only then that the state can introduce corrective measures for a re-definition of the commercial energy "pie".

Table 6 shows the growth in Indian consumption of oil products (in crude equivalent terms) from 1950 to 2002.

Over the last fifty-three years there have been only very brief periods with poor growth in oil consumption but the last five years have been years when consumption is more or less steady at 102 $\pm$ 2 MM tonnes/year. From 2001-02 there appears to be declining trend – suggesting that Indian demand for oil has peaked in 2001-02. Without going into too many details the product-wise data shows that while diesel consumption is actually remaining 'flat' with even an indication that there is fall in demand in several areas that were characterized by fast growth in earlier years. Demand for kerosene and naphtha is actually seen to be falling off sharply.

Indian roads are not currently tailored to have trucks carrying large containers from ports to cities in the interior and, seeing this opportunity, the Indian Railways have gone in for container transportation in a very big way (including provision of 30 to 40 tonne cranes in most railway stations). It was, then, natural to expect a major shift away from trucks as far as

Table 6. Growth in consumption of oil products (millions of tonnes

Year	Millions tonnes/year	Annualized Growth %
1950-51	2.46	
1970-71	16.00	
1975-76	26.00	
1979-80	28+	
1980-81*	30.896	5
1981-82	32.5	5
1982-83	32.5	5
1983-84	34.1	5
1984-85	35.8	6
1985-86	38	6
1986-87	40.3	7
1987-88	43.1	8
1988-89	46.6	8
1989-90	50.3	9
1990-91*	55.035	8
1991-92	60+	9
1992-93	65.38	9
1993-94	70.36	7.6
1994-95	72+	2.3
1995-96*	74.637	3.67
1996-97*	79.188	6.1
1997-98*	84.29	6.4
1998-99**	90.562	7.4
1999-00**	97.09	7.2
2000-01**	100.07	3
2001-02**	98.55	-1.5
2002-03***	103.422	3
2003-04	Est. 99.5 + 2	

*Data from MOPNG pamphlet ed. Ravi Saxena JS&FA
**Data from MOPNG website (Feb. 2003)
***Date from MOPNG website (Feb. 2004)

[12] Look at how we now have a situation in India when domestic refining capacity will soon (in the next two or three years) be more than 145 MM tonnes/year while domestic demand for refined products may not even be 110 MM t/yr. Investment on building up an excess capacity of 35 million tonnes a year would have been of the order of Rs 40,000 crores or more.

goods transportation is concerned. Growth in diesel consumption would then naturally taper off and even start to decline.

Without being too melodramatic about it, a recent picture in the daily papers showing the Konkan Railway running flat-bed bogies (on to which one can roll-on and from which one can roll-off fully loaded 20 tonne trucks) with fully loaded trucks on board says it all and shows where things are headed for. On the west coast it looks it is cheaper for trucks to load normal goods and then use the Ro-Ro technique to get on to trains of the Konkan Railway to go from, say, Panvel to Khed or Chiplun and then cross the Ghats to Satara and towns beyond on the Deccan Plateau (or, do the same from Goa to Karwar using the railway and then cross the Ghats to Hubli and towns beyond) than drive fully loaded on NH 17 along the coast. Konkan Railways are actually not even running special Ro-Ro rakes but are attaching the flat-beds to normally scheduled trains. Having taken the trouble to merely construct roll-on/roll-off facilities at several stations on the route it is the customers who now come to the Railways. There seems to be no need to tempt them with special offers It is not surprising then that a diesel plateau has been reached and even a decline in kerosene consumption is also foreseen. The Public Sector Refineries, having cottoned on to this situation, are quickly re-tooling to "crack" large volumes of the excess kerosene, diesel and naphtha to LPG (propane in the main). There is a high probability of LPG sales being boosted to reduce the dependence on kerosene and this is all to the good. The existing excess capacity for kerosene production in Indian refineries would then be cancelled out when these white products are also cracked to make, with the addition of appropriate quantities of hydrogen, smaller chain-paraffin molecules like propane and butane.

In the "old days" (hardly five years back) our refineries were producing only around 6-7 barrels of gasoline from each 100 barrels of crude oil. This number too is not a "fixed number" and is entirely dependent on technology. Currently it is perfectly feasible for refinery engineers to increase the percentage of gasoline produced from a given barrel of crude - without too much investment. The current throughput of around 100 million tonnes crude through existing refineries should then be adequate to meet the demand for the type of products needed in the country for the next several decades even if the number of compact cars and two-wheelers (or three-wheelers) treble or even quadruple in the next 15 years.

In other words, GDP growth and growth in oil consumption are now either already delinked or are about to be delinked. If this argument is valid then we need not worry about the almost insoluble problem of supplying, by 2015 or 2020, 250 to 300 million or more tonnes of crude oil to Indian refineries and we need not invest in increasing our refining capacity from current levels (in fact we already have – or will soon have - excess refining capacity to the tune of around 45 MM t/yr). From the standpoint of exploration for "new" oil reserves the pressure on the oil companies would naturally get reduced. What would then become more important is the matter of efficient management of existing oilfields to increase the recovery factor. And this effort on improving oil recovery from known fields is all that is perhaps needed for India to be nearly self-sufficient as far oil is concerned. The question of natural gas (as piped gas or as LNG) will be discussed separately.

COMPARISON OF COAL AND CRUDE OIL SECTORS OF INDIA AND CHINA

Several other parameters that are generally used for macro-economic analyses seem to suggest that future development of India may not strictly be like that of the newly industrialized countries of East Asia or of China or Brazil. There seems to be no chance for India to "take off" from current levels and suddenly become another Germany or Japan. From the oil products consumption point of view one should note that China's industrial growth and energy infra-structure development were more or less directly linked to find of major oilfields in the sixties, seventies and the eighties. If the immense growth in crude consumption had not been made possible by dramatic increases in domestic crude production China might have found it difficult to find the funds for industrialization or development of coal mines and setting up huge thermal power generating stations. One needs to have a closer look at these aspects of the problem before affirming that Indian consumption of oil products would climb north in the same way as China's did. India's future scenario for energy infrastructure growth may in fact be a path unique to India alone.

Chinese consumption of crude oil increased at a much faster rate than India's and this appears basically because China was better endowed with reserves of crude oil. The country became a net importer of crude only by 1995. On the other hand, India had always had to import crude. In 1965 India and China were both consuming around 11 million tonnes a year of crude oil but within three decades, by 2002, Chinese consumption of oil was already more than double that of India.

It is the development of the energy infrastructure on an immense scale in the 1965 – 1995 period that set the stage for the opening up of the economy on the eastern seaboard of China. It is doubtful whether there would have been any foreign direct investment in industry if the energy infrastructure were not already available. Part of energy availability has been on account of natural endowment (as regards crude oil) in which China was luckier but the rest of it is a matter of utilizing quickly the coal resources (where the natural endowment is greater for India) in which India has lagged behind.

A detailed analysis will be made in a later section of the historical record of India of the demand for crude oil products, crude oil refining capacity and domestic production of crude oil. But, before that, it is necessary to have an overview of the oil, natural gas and coal sectors of India and China. Such an overview is important for formulation of appropriate strategies for the Indian energy sector.

The table below shows the Indian demand and domestic supply situation for crude oil. Worth noting is the differences between India and China in regard to crude self-sufficiency in the crucial period 1965 to 1995.

The total energy consumption of India and China, over the last thirty five and more years, is shown in

Table 7. China: Oil production and demand (millions tonnes/year)

	Production	Demand	Volume Exported/Imported	
1965	11.3	11.0	0	No import
1970	30.7	28.2	2.5	Exports mall volumes
1975	77.1	68.3	8.8	Starts exporting significant volumes
1980	106	88	18	Crude exporter
1985	124.9	90.3	34.6	Crude exporter
1990	138.3	110.3	28	Crude exporter
1995	149	160.7	11.7	Starts importing crude
2000	162.6	230.1	67.5	Imports same volumes as India ***
2002	168.9	245.7	76.8	Imports nearly same volumes as India ***

*** But, China produces five times more crude than India does.

Table 8. India: Oil production and demand (millions tonnes/year)

	Production	Demand	% self sufficiency for crude	Volume of crude imports
1965	4	11	36%	7
1970	6.82	16	43%	9.18
1975	8.45	26	33%	17.55
1980	10.51	34.66	30.32%	23.15
1985	30.168	46.96	65.64%	16.79
1990	33.02	61.4	53.8%	28.38
1995	35.17	82.81	42.5%	47.65
2000	32.43	102.88	31.6%	70.45
2002	32.03	104.7	30.5%	72.67
2003	32	100.1	32%	68

China never imported any oil at all from 1950 to 1995 – the period when that country got industrialized. In contrast India's industrialization has been largely in a period when she had to import almost 70% or more of her crude oil needs.

Table 9: Total Energy use (millions tonnes oil equivalent*)

	1965	1970	1975	1980	1985	1990	1995	2000	2002
India	52.9	64.9	82.1	102.9	136.9	193.4	252.3	312	325.1
China	182.4	233.4	337.7	426.9	559.9	685.8	893.6	765.7	997.8

*In calorific terms 1 tonne of oil is equivalent to 1.5 tonnes of hard coal and 3 tonnes of lignite.

Table 10: Demand and Supply of Coal (millions tonnes oil equivalent*)

	India Prodn	China Prodn.	India Demand	China Demand	Remarks
1965	No data	No data	35.7	165.6	
1970	No data	No data	37.8	196.5	
1975	No data	No data	48.5	250.9	
1980	No data	No data	57.1	314.4	
1985	74.2	439.8	77.4	436.5	
1990	104.9	542.3	107.8	537.6	
1995	135.2	**650.9**	142.8	**671.9**	**India imports coal**
2000	157	501.8**	169.3	**454.7**	**India imports coal**
2002	168.4	**703**	180.8	**663.4**	**India imports coal**

*In calorific terms 1 tonne of oil is equivalent to 1.5 tonnes of hard coal and 3 tonnes of lignite.
**Chinese production falls temporarily BUT no imports were made.

Table 9. It is interesting to compare the share of crude oil in the total energy spectrum of both these countries. In India's case the share of crude oil is roughly 1/3rd of the total energy consumption (and oil products are substantially used only in the transportation sector) – this number is constant from 1970 to 2002. For China, crude oil today forms less than a quarter of total energy consumed. Both countries have attempted and, to a large extent, have succeeded in avoiding getting caught in the oil trap.

Both countries have very large reserves of coal and both are high consumers of coal with China consuming annually a little over three times Indian annual consumption This is what has permitted both India as well as China to keep crude consumption under strict control. It is difficult to say with any certainty whether this "control" has been managed intentionally or it was achieved due to mere serendipity but this is not as important as the fact that crude oil consumption did not grow wildly in either country even if the estimates of reserves discoverable in the future, as estimated in the beginning of the 'eighties, were extravagantly optimistic in both the countries. Fortunately neither country had to pay a price for misjudging the quantum of future discoveries. However, one may not be lucky a second time around and this is the reason for the present analysis.

We see the anomaly of India starting to import coal despite having very large reserves – larger than China's at least for the better quality coals (Table 11 below). One of the reasons is that some Indian reserves are too deep for mining with relatively old-fashioned techniques. The Chinese modernized mining technology ahead of India but were ahead of India in terms of R/P ratio even by the early 'sixties when mining technology was nearly the same in both the countries. There is, however, little doubt that China's coal industry was and is better managed than India's.

Chinese coal production dropped sharply in 1997 and de-bottlenecking of the production line was not completed till end of 2001. China made no attempt to import coal during this four-year period and all efforts and major investments were apparently made to refurbish the mining industry. India, on the other hand, has preferred to import coal from other countries (Indonesia and/or Australia that actually have reserves of bituminous coal far less than what India has) when the domestic coal mining industry is having technical or managerial problems. However,

Table 11: Coal reserves at end of 2002 (millions tonnes oil equivalent)

	Anthracite and bituminous	Sub-bituminous and lignite	Total	R/P ratio**
India	82396	2000	84396	235 years
China	62200	52300	114500	82 years
Australia	42550	39540	82090	243 years
Indonesia	790	4580	5370	52 years

**Reserves to Production Ratio = years left for production at current annual rates of production. Where there is a good demand for the item a low R/P ratio is generally a sign of efficiency. There are important exceptions to this 'rule' – Australia uses very little coal and finds it hard to find another country to buy her production. Australia's high R/P ratio is not a sign of inefficiency.

India cannot now follow the Chinese strategy on account of the Kyoto Protocol (see below).

Most of the OECD countries as well as Russia are now reducing coal consumption. Many are signatories of the Kyoto Convention (to prevent further increase in the rate of global warming) and are bound to do so. The US, even if yet to sign the Protocol, and continuing to be the second largest consumer of coal (after China) in the world, is yet to start reducing coal consumption. Certain countries such as Australia are major supporters of the movement to reduce CO_2 emission into the atmosphere but strangely do not seem to mind exporting large quantities of coal to the Third World countries – the actual country burning the coal being the party to pay the carbon tax.

NATURAL GAS AND LNG SECTORS OF INDIA AND CHINA

When we look at the figures for natural gas production and consumption of China and India we see that currently there is a great similarity between the two countries (Table 12).

Table 12. Natural Gas Reserves, Production and Consumption: India and China (2002)

	India	China
Reserves BCM (Billions standard cubic metres)	760	1510
Production BCM/year	28.4	32.6
Consumption BCM/year	28.2	30.1
R/P ratio (years)	26.8	50.17

But, when it comes to the percentage share of primary energy by fuels (see Table 13 below), we note that the share of gas in India is more than twice that of in China.

South Korea does not have any gas reserves at all and all the gas consumed, 23.6 MM tonne oil equivalent (around 26.2 BCM natural gas a year) is imported as LNG. This is very close to current Indian production (for sales). If India will have to generate all additional electricity by using gas then the Indian gas consumption will increase by another 18 – 20 BCM per year.

The Bassein, South Bassein and Tapti gas fields are the big ones currently contributing to production from reserves of non-associated gas. There are practical reasons why production rates cannot be increased very much from current levels in these three fields even if West Bassein is brought on production by ignoring the thin oil column beneath the huge gas cap. As a result, in the immediate future, it may not be possible to bring down the Indian R/P ratio for natural gas from the current level of 27 years (see Table 14).

India is already having two liquefied natural gas (LNG) re-gasification points: Dhabol and Dahej. Dhabol came up as a 'captive' unit for the old Enron power plant there. Dahej came up due to Gujarat's ingenuity to find the State's most important raw material for the local industry. Additional LNG import points such as Cochin, Goa, Chennai, Vishakhapatnam etc. are under active consideration but it is doubtful if any of these can up without some form of investment by the states concerned.

Growth of the LNG sector is not expected to be very rapid. Use of piped gas from Iran and/or Malaysia/Thailand could happen earlier. Huge projects of this type will not come up in the region without major investments by the countries or their national oil companies (Petronas in the case of Malaysia and Iran National Oil company in the case of Iran).

Table 13. Percentage Share of Primary Energy by Fuel – Comparison of India, China and South Korea (for year 2002).

	Oil	Natural Gas	Coal	Nuclear Power	Hydro
India	30.04	7.81	55.6	1.35	5.20
China	24.6	2.7	66.5	0.60	5.6
S Korea	51	11	24	13	1

Table 14. INDIA: Natural Gas Reserves and Additions to Reserves (revisions to old gas plus discoveries of new gas), Annual Production and Cumulative Production (data source from 1980, MOPNG, Government of India)

Year	Reserves BCM	Production (sales) BCM	R/P years	Net Addition for year BCM	Cumulative Gas (sales) BCM
1981	350	1.9	114	No data	13.2
1982	410	2.6	158	62.6	15.8
1983	420	3.1	135	13.1	18.9
1984	420	3.8	111	3.8	22.7
1985	480	4.5	107	64.5	27.2
1986	500	6.3	79	26.3	33.5
1987	500	7.5	67	7.5	41.0
1988	650	8.6	76	158.6	49.6
1989	650	10.3	63	10.3	59.9
1990	710	12.0	59	72.0	71.9
1991	730	13.6	54	33.6	85.5
1992	730	15.3	48	15.3	100.8
1993	720	15.9	45	5.9	116.7
1994	710	16.6	43	6.6	133.3
1995	710	19.6	36	19.6	152.9
1996	692	20.7	33	2.7	173.6
1997	490	23	21	-177	196.6
1998	540	24.7	22	74.7	221.3
1999	650	25.9	25	135.9	247.2
2000	650	26.9	24	26.9	274.1
2001	650	27.3	24	27.3	301.4
2002	760	28.4	27	138.4	329.8

CONCLUSIONS

In the short and intermediate term:

Shift emphasis from exploration for oil to more efficient exploitation of oil

Even if no company is immortal, no oil company should allow itself to live within a strictly "limited lifespan". A great Indian petroleum geologist (MK Ranga Raju) once said that oil companies, like men, grow old – and he went on to suggest that Peter's Principle is also applicable to oil companies. I disagree and would insist that oil companies, like the mythological phoenix, can rejuvenate themselves even when burnt to ashes. This is what I am sure will happen to the two national oil companies of India which are involved in exploration.

ONGC and Oil India would, therefore, continue with a carefully planned and efficiently executed exploration programme. This is primarily because they should continue to have a production profile that is marked by a steadily increasing annual crude production rate so that when they evolve to become vertically integrated oil companies both should always have a crude reserves portfolio adequate for their refining capacities. A steady stream of new discoveries coming on line is extremely important to meet this particular objective. What this paper discusses is that with oil demand in the country touching a plateau there is no need for Government to force the national oil companies to cut in the 'afterburner' and make enormous expenditures on extremely high-risk projects – taking risks they would normally not have accepted. With demand for oil staying on a plateau or even falling, ONGC and Oil India should be able to resist such pressures and need not forsake their traditional methods of risk analyses before investing in costly drilling activities.

The currently stated "reserves", for end 2001, of 737 million tonnes, imply that balance oil-in-place in the discovered fields should be of the order of about 2800 million tonnes. If, taking into consideration that not more than 300 million tonnes would have been withdrawn from the oil-in-place in these fields, it should be possible to design and implement redevelopment plans to improve recovery of initial-oil-place to 40% to 50% instead of the current expectation of an average 28%. Additional oil from these fields would then be of the order of 383 million tonnes[13] and with improved field management should result in reduction of R/P ratio from 24 to somewhere in the region of 15 years – thus giving an improved annual rate from the same fields that are getting produced now.

Table 3 shows that additions to reserves in the last 15 years (from 1988 to date) totaled only to 514 million tonnes (and this includes not only 'new oil' but also reserves additions on account of mere revision of parameters). If you take only the last 12 years (from 1991 to date), Table 3 shows that additions to reserves came only to 110 million tonnes. Obviously risks in exploration are steadily increasing and, unless there is immense pressure from the national security angle, there is no doubt that the option of reserves accretion by improving recovery efficiency is a clearly low risk one. What this paper is trying to prove is that India's energy problems are far higher in the sector of power generation and not in the sectors of transportation, cooking and rural illumination.

Shift in emphasis from exploration geophysics to reservoir geophysics

For the last 70 or 80 years the only tool that has found new oilfields is the seismograph. Perhaps it is the same old technique – no doubt with a whole new generation of instrumentation – that will now help in more effective reservoir monitoring and management. But there would be one major difference in approach:

In the typical EXPLORATION MODE on land one would first do an aeromagnetic survey over a huge area (a bird's eye view).

Then home in on interesting areas and carry out gavity surveys.

Choosing from the short-list provided after the gravity surveys one goes in for reconnaissance seismic surveys.

For the marine areas reconnaissance seismic surveys would be the first step.

The next and final step in both types of areas would be detailed close-grid or 3D seismic surveys over drillable prospects (the worm's eye view).

In the EXPLORATION MODE one goes from the general to the particular. In the case of the RESERVOIR MONITORING/MANAGEMENT MODE one goes the opposite way (go from the "worm's eye view" to get the "bird's eye view").

One starts with detailed analyses of wells and or small parts of the field with existing data.

A larger quantity of much more sophisticated data is collected (local area time series 3D, time series micro gravity surveys, cross well tomography or even part field tomography etc.).

Design and implementation of innovative re-development plans with inbuilt facilities for continuous monitoring – trying out two or more styles in different parts of the field.

Lastly, choose the right model and implement a full-field plan.

The most important element of all this is the inbuilt facility to re-do the whole sequence of operations once in a few years – of course, with more recent technology being used each time.

The most important thing to bear in mind is what I would call "the geologists conondrum" – how to remain a pure optimist whilst exploring for the first oilfield and how to turn a full 180° once you have found the first barrel of oil. From the day of discovery one should become a total pessimist – or else he would be only deluding himself. Men have lived with this problem over the last 100 or more years and the next exploration geophysicist to become a reservoir geophysicist will have to learn, like many of us did, to live with this dichotomy.

Almost a decade back a former Petroleum Secretary (Vijay Kelkar) wrote a serious note on the great need for the use of techniques like cross-well seismic tomography, time series 3D seismic surveys, the very latest types of well surveys (production logging tools, water flow analysis tools, current saturation logging tools) etc., in order to improve the efficiency of exploitation of the reserves that had been found till

[13] At 40% recovery the balance-oil-in-place in the discovered fields would let us recover 1120 million tonnes more from the same fields. This number, less the expectation at 28% average recovery (737 million tonnes), is what is stated above as "additional oil" of 383 million tonnes.

then by immense physical effort and enormous investment of funds. I cannot think of anything more that could be done

Keep looking for non-associated gas

DHIs (including evidences for gas chimneys) have always been more prominent when gas was involved. There are several techniques but only the less time-consuming ones have been generally used. A search of old data and selective reprocessing should be expected to end up with at least a few gas discoveries. In the early days, when there was no market for gas in the country (see Table 14 – there were hardly any gas sales prior to 1980), many such indications could have been ignored.

Onshore shallow gas fields would also have been ignored in the past. These are easier, far easier, to exploit than methane from coal seams. Again a search of old data should be mandatory.

In the long term: Become a major consumer of natural gas

Crude oil and refined products obtained from it will play no part in any other sector but road transportation (with kerosene and LPG used for cooking). Use of oil would seem to have peaked and future increases in consumption of petrol and LPG could be met by changing the product pattern of the refinery output stream by reducing production of diesel and kerosene. The ultimate aim for India would be to double commercial energy consumption from the current levels of 325 MM tonnes oil equivalent by 2020. Practically the whole of this increase will have to be in the form of electricity. Hydro has peaked and nuclear power generation is not going to be safe or easy. Thermal power from coal is not possible any more and this leaves natural gas as the only fuel for power generation.

If there is no dramatic change in technology[14] in the next 15 to 20 years then India would need to import natural gas to the tune of around 250 million tonnes oil equivalent – 277 BCM natural gas – each year. This is because we may be unable to increase our coal consumption to more than 250 MM tonnes/year, from the current levels of 180 million tonnes a year, on account of carbon emission restrictions. Currently LNG prices vary between 3.5 to 4 USD per million Btu (roughly per thousand cubit feet). Piped gas (piped long distances such as for Algerian or Russian gas in Western Europe, for example) also is priced in the same range. IF gas prices do not go up, the annual Indian gas import cost, to import 277 BCM gas, would then be, at 4$/1000 scf (at 112$/1000 scm), around 31 billion USD in year 2020. If, however, gas prices go up to become comparable to the "calorific equivalent" of oil, then the gas import bill could be as high as 45 billion USD (with oil price remaining at a low of 25$/bbl). There is no point in predicting the level of the problem if oil and gas prices rise even further.

Sweat shop[15] work alone will not make us rich enough to afford LNG imports of the volumes shown above. Growth in commercial energy consumption is impossible without gas as burning more coal is not a valid option. The old truism, known to all economists from, Adam Smith, Bagehot and Keynes, is that "all countries cannot grow richer at the same time" – some will have to import if others are to export.

Long term forecasting is risky business and I would like to hedge my bets by merely suggesting, and not discussing in detail, what may actually let us off the hook. As the oil and natural gas trade is being carried out entirely outside the ambit of the World Trade Organisation there is nothing to prevent Iran, Pakistan, India, Bangladesh, Burma and Malaysia one day forming a shared gas grid. Qatar gas is already tied up for LNG exports whereas the Iran gas will be piped gas. Iran (with over 812TCF or 23000 billion standard cubic metres) has the largest reserves of natural gas after Russia (which has 1680 TCF or 47600 MMM scm) and Pakistan and India are the only markets for the country. Malaysia, on the other hand, is interested in developing a new market. Myanmar can sell only to Bangladesh or India and the former could one day in the not too distant future become a net importer of gas.

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[14] Such as superconductivity at ambient temperatures etc.

[15] In the "IT" sector, for some time it was Y2K, then came medical transcription work and now we have Business Process Outsourcing (a nice name for "call centres"). "Software Solutions" is something at which others can become as good as us – China for example. Manufacturing spare parts for European or Japanese or Korean automobiles is also not far from the Dickensian picture of sweat- shops – "value addition is elsewhere" as it once was for the tailors of the "garment export" days.