Development, Energy Security and Climate Security: India's Converging Goals

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INTRODUCTION:

This paper investigates two aspects of the energy-climate challenge faced by India. It first examines the country's energy security in the light of the anticipated growth in power generation to maintain 8 - 10% annual growth in GDP. Second, it examines possible realistic options for mitigation and adaptation that India can propose for the ongoing climate negotiations. We posit a scenario in which India increases its annual electricity production fourfold between 2010-2032 while decreasing carbon intensity to meet its development goals.

Assuming an annual rate of growth of 8-10% is achieved, India's CO_2 emissions would initially grow up to a cap of 5 giga-tonnes / year and then start reducing after 2032. This paper argues that, by themselves, hard resource constraints place limits on the size of the fossil fuel powered economy that India can build both in terms of the fossil fuels it can import or produce and its consequent CO_2 emissions. A 5 GT/year cap thus becomes a matter of inescapable necessity. Viewed in this light, India should best use this cap as timely forewarning to plan strategically for the future, rather than in terms of a forced curtailment, to eventually create a sustainable energy economy that moves beyond fossil fuels post 2032.

Access to cheap, clean and copious supplies of energy is essential for building modern technological societies. Over the last century fossil fuels have been the source of these supplies that has lead to unprecedented development. The criteria for "clean" and "sustainable" energy production have evolved subsequently with greater understanding of the impact on human health and the environment. Nations have developed policy and regulation to mitigate and deal with pollutants such as lead, SOx, NOx, and particulate matter. This paper does not address these emissions but concentrates on the challenge of global warming and climate change caused by anthropogenic emissions of Green House Gases (GHG) in the Indian context.

This paper first examines India's precarious fuel resources and growing lack of energy security, and then provides planning and policy options for India as it tries to reconcile its needs for development and poverty alleviation with the environmental and health consequences of energy production and use, especially emissions of GHGs.

The magnitude and complexity of the challenge necessitates efficient planning and implementation in order to sustain 8-10% annual growth in GDP. Needless to say such planning cannot be done behind closed doors; it requires open and transparent information sharing in order to develop feasible options for economic growth that becomes increasingly more energy efficient and carbon-neutral. To facilitate such open information sharing the Appendix to this paper also introduces a web-based open and collaborative tool for spatial and temporal analysis of energy systems called the Global Energy Observatory. The goal of this tool is a transparent framework for real-time analysis that integrates data on power generation, fuels and resources, transmission and distribution with demand, demographics, policy and economics.

The three overarching issues --- energy security, development, and reduction in emissions of pollutants and GHG --- are analyzed using a two-phase timeline. The long-term goal (post 2050) is a sustainable energy economy based on carbon-neutral systems. The intermediate point 2032 which marks the end of India's 15th Five Year Plan, is taken as the plausible year when India's CO_2 emissions peak assuming the country can sustain a steady growth of 8-10%. This timeline is shown schematically in Figure 1. In our analysis, the key factor that drives the transition to carbon-neutral systems is India's need, by the year 2032, to import most of the fossil fuels needed to power its industrial and transportation sectors.

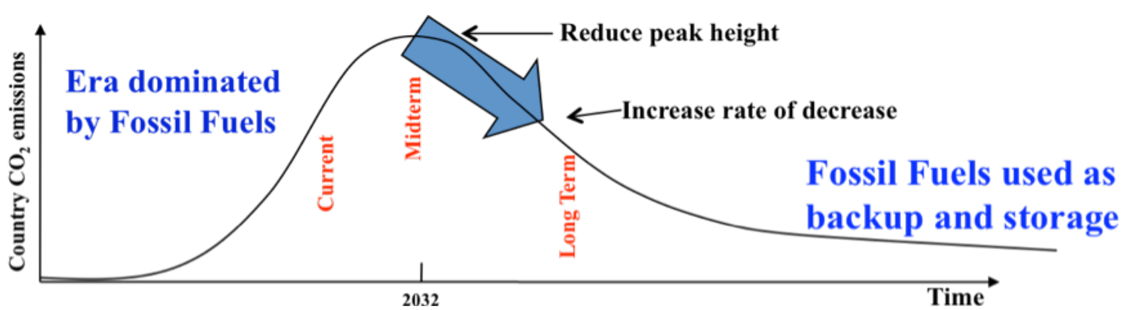

Figure 1: A schematic of CO_2 emissions and strategy to address development and climate change. All countries will exhibit a peak in their CO_2 emissions at some point in time. For concreteness, we posit this time to be 2032 for India. The lifetime of CO_2 in the atmosphere being hundreds of years, the area under the curve gives the total contribution of a country's emissions to climate change.

The goal of any climate-change mitigation strategy is threefold:

(i) To progressively reduce carbon intensity;

(ii) To reduce the magnitude of the CO_2 emissions peak;

(iii) To reach the transition point (peak) as early as possible.

The paper contends that the major instruments for reducing emissions in India in the period 2010-2032 will be increases in efficiency in the production, transmission and use of energy, structural changes that facilitate the implementation of win-win options, and active participation in the global R&D effort to develop carbon-neutral systems. In the period post 2032 a closed nuclear power cycle with other cost-effective, sustainable (along with some anticipated but yet to mature/develop) carbon-neutral systems will drive the transition to a carbon-neutral end-state.

What are the possible alternative scenarios if India does not meet these aggressive targets? The most likely result would then be that it would not be able to maintain the desired growth rate of 8-10% and the postulated time of the transition (2032) will slip by with half of India's population (estimated to be about 1.5 billion people by then) poor and lacking access to 21st century opportunities. Constraints on fossil fuel based growth will rise in tandem with international will to mitigate climate change, which will itself depend on how fast and dramatically scientific evidence of global warming accumulates. The point is that India's position vis-à-vis development and climate change mitigation is predicated on its ability to access and buy fossil fuels in the world market, which could be very uncertain due to the size of India's needs and competition from China and other rapidly developing countries, US, Europe and the Asian Tigers. It will also depend on the cost-effectiveness and the timescale within which the world adopts alternate technologies.

I. ALLEVIATING ENERGY POVERTY

Current estimates of population growth suggest that India's population will peak at 1.7 billion people around 2050 and be about 1.5 billion in 2032.[i] (The current population is 1.17 billion and has been growing at about 18 million people per year for the last decade.) To provide its population with a reasonable level of 21st century opportunities India would need to generate 0.5 kW per person of electric power. This number, which is roughly half of the European average and a quarter of the US average, translates to approximately 6500 TW (Tera Watts) hours per year of electric energy in 2032. The total generation in 2008 was a factor of eight less, approximately 800 TW hours representing a mere 0.07 kW per person. More modest goals for poverty alleviation would still require 0.25 kW per person or 3250 TW hours per year, i.e. four times the present generation. The question is: what kind of fuel mix would enable India to reach this very necessary goal of reducing its energy (and concomitantly human) poverty by 2032?

India's large and growing population will continue to stress the system. If the size of the population were to stabilize, the transportation sector could demonstrate large gains through energy efficiency and per vehicle reduction in fossil-fuel consumption. Even incremental developments in small cars, hybrid and electric vehicles will have a significant impact in the future. However, because of the continued growth in the number of people owning automobiles, gains in efficiency and fuel-substitution will, under business-as-usual (BAU) scenarios, not result in decreasing oil consumption or alleviate traffic congestion. It is therefore safe to assume a continued linear growth of 3% in India's demand for crude oil resulting in a doubling of India's oil consumption by 2032 to 6 million barrels per day.

With most of this oil being imported, the growth will be subject to international markets and India's own financial health. The economy's growing needs therefore are constrained by the availability of global energy reserves, production capacities, markets and geo-politics. It becomes important to consider what countries possess significant known reserves of fungible carbon that can be traded and transformed into fuel for production of electric power or for transportation. While smaller reserves in many countries do and will play a significant role, the **following fourteen countries will dominate fossil fuels market post 2032**:[ii]

Country	Oil	Natural Gas	Coal	Other
USA			Yes	Shale Oil & Gas, CBM, Clathrates
Canada	Tar Sands			
Venezuela	Heavy Oil	Yes		
Russia		Yes	Yes	
Australia		Yes	Yes	Yes
South Africa			Yes	
Saudi Arabia	Yes	Yes		
Iran	Yes	Yes		
Iraq	Yes			
Kuwait	Yes			
Qatar		Yes		
UAE	Yes	Yes		
Algeria		Yes		
Nigeria	Yes	Yes		

Given this concentration of fossil-fuel resources in a few regions it is important to assess what investments each of these 14 countries will be willing to make and the production levels they will sustain in the light of

(i) Climate treaties
(ii) Demand pressures and international competition in the face of progressively depleting reserves in other countries,
(iii) Increasing consumption in other developing countries as well as in the producing countries themselves.

Any strategy must account for the possibility that changes occur quickly and unexpectedly in the international arena and add to uncertainty in supply and trade.

Climate change and environmental concerns can change the playing field dramatically for both conventional and unconventional sources. For example, the Obama administration may not promote large-scale conversion of coal and shale to either oil or natural gas until either clean conversion technology or carbon capture and sequestration technologies, or both, mature. As will be discussed later, the US is the most likely country that could supply India with the required volume of coal imports post 2032 when India's domestic reserves are exhausted and US converts its coal-fired generation to other fuels and renewables. The question is – will it find coal exports defensible if climate change mitigation becomes a global imperative!

Far smaller reserve to production ratios (which at present range between 50-200 years) in the major producing countries listed above could, by 2032, force substantially different market conditions in the absence of major new finds. Fossil-fuel poor countries/regions with high energy demand such as India, China, Europe and the Asian Tigers thus face the challenge of not only what their response to climate change treaties to curb emissions today should be, but whether they will be able to procure adequate supplies of fossil fuels at all. These are the imperatives that really make energy security and climate change mitigation convergent goals.

I.1 India's Electric Power Sector

This section examines a credible scenario in which India can meet 0.25 kW per person capacity by 2032 as a necessary poverty alleviation goal. This is far from being a limiting scenario because the difference between the poverty removal (0.25 kW per person) and the development (0.5 kW) goals will continue to drive additional growth in capacity. The points being made here are (i) meeting even this modest poverty removal goal is by itself a daunting challenge; and (ii) the goal of 0.25 kW per person is so basic that it, and its timeline, is assumed to depend only on the total rate of growth in GDP and not on the detailed scenarios of relative ratios of growth in the service, manufacturing and agricultural sectors.

The paper limits itself to examining possibilities for the growth of coal, gas, hydro and nuclear power generation while acknowledging impediments like access to fuels and capital expenditure. It does not address the extremely important structural, policy and regulatory challenges that will impact and control this growth, optimistically assuming that India will address these. Readers should refer to the Government of India plans contained in the August 2006 Integrated Energy Policy report for a discussion on these topics.[iii]

The paper also makes the assumption that, given the current status of technology, costs and available storage options, while solar and wind farms will continue to be installed, their contribution to energy generated will remain a small percentage. The reason for this being that utility scale solar PV and thermal plants, will still not be the most cost-effective options for India by 2032. In addition, the integration of intermittent resources such as solar and wind via smart grid technology (including judicious deployment of hydro, pumped storage hydro, geothermal and gas turbines for backup) will still be in its infancy. Generation from renewable sources is therefore considered as an additional resource in the near-term (until 2032), and will not significantly impact nor displace the growth of traditional resources – coal, gas, hydro and nuclear.

I.2 Coal-fired Power Generation:

Coal-fired plants provided about 65% of electric energy generated in 2009 and will continue to dominate until 2032.[iv] Most of the 80 GW of installed coal-fired capacity [v,vi] is government owned, with central government corporations (NTPC, DVC, Neyveli and BTPS) accounting for approximately 30 GW, state utility companies 43 GW and private sector 6 GW. In addition there is about 10 GW capacity in Captive Power Plants that are connected to the grid. The total annual energy generated by the utilities in 2008 was about 500 TW hours corresponding to an average Plant Load Factor (PLF) of 72%. Using an average coal consumption of 0.70 kg per kWh for domestic coal, 355 million tonnes were consumed for grid connected power generation (the total coal mined in 2008 was about 500 million tonnes and the average heat rate of Indian coal is between 3500-4000 kcal per kg[vii]).

An average growth of 10 GW per year over the next 22 years would result in 300 GW of coal-fired capacity by 2032. Past trends in demand and capacity addition suggest that such growth is feasible because

- It is only twice the average rate achieved during 2007-2009.
- To sustain this growth will require about $15 billion (2009 dollars) capital investment per year assuming an average cost of $1.5 per kW over the next

22 years in the absence of CO_2 tax. Even with taxes below \$20/tonne of CO_2 coal plants will continue to provide cost-effective base load capacity.

- Enough public and private sector companies have demonstrated they can develop and operate plants at high (over 80%) PLF and are aggressively pursuing new opportunities.
- There is an adequate industrial base to provide the required engineering, procurement and construction (EPC) services.

On the other hand this growth rate, while modest compared to even the 11th Five Year Plan (2007-2012),[v] will not be easy to achieve because

- Coal linkages are already falling short. It is estimated that India is losing about 10% generation capacity due to inadequate coal supplies (both domestic and imported). This problem will become more acute as participation by the private sector grows – in a competitive environment neither private entities nor the government will invest unless there are long-term guarantees of coal linkages. Significant growth in coal mining and transport infrastructure will be needed to maintain high PLF nationally.[viii]
- India plans to install most of this new capacity using supercritical technology. Because of the poor quality of Indian coal,[xiv] this technology will require far better coal beneficiation to increase the heat rate, more expensive boiler technology, imported coal or a combination of all the three.
- Electricity is a concurrent subject under both the Federal and State Governments as per the Indian constitution, and performance varies significantly between states. Plants operated by the central government agencies have high PLF and are profitable. The financial health of most State Electricity Boards (SEBs) is very poor and plants operated by them have low PLF, high operating costs and high distribution losses. Significant restructuring of SEBs, beyond what has already been done, and larger private participation is therefore essential, both for improved efficiency and for attracting adequate capital.
- Nationwide, the transmission and distribution grid (especially from pit head and coastal power plants) will need to be enlarged by almost a factor of ten. Estimates of cost range around \$1 trillion.[xxxvii] Current transmission grids are mostly controlled by the SEBs which need very significant restructuring and manpower training to deal with increasing automation of the grid in response to increases in system size and complexity.

The question is: is this capacity addition and generation feasible? This needs further elaboration. If the full 300 GW capacity were to operate at 85% PLF by 2032 and consume 0.65 kg of domestic coal per kWh, then about 1450 million tonnes of coal would be required to generate 2234 TWh. This estimate is also consistent with the values given in Table 2 of the 2006 Integrated Energy Policy.[iii] To meet this demand, however, the coal mining industry would need massive restructuring, with significant infusion of private capital[ix] and [re]development of underground mining. Public opposition[x] to land acquisition for mining is expected to grow as GDP and literacy increase. Assuming the societal dimensions of the challenge are addressed, the average annual incremental growth required in coal production is 43 million tonnes per year against the recent rate of increase of 18 million tonnes.[xi,xii,xiii] Even if this growth in coal mining and transport is achieved, the dilemma is that the current estimate of extractable coal reserves (40-58 billion tonnes[xiv]) would have been reduced by about half by 2032 and would last only until 2050-60![xv] With coal-fired power plants having lifetimes of 35-50 years, dwindling coal reserves will therefore limit any capacity addition based on domestic coal well before 2032.

Significant improvements in efficiency of power plants can, however, bring the required coal tonnage for achieving equivalent generation to about 1200 million tonnes per year. These much-needed efficiency gains can provide another decade of coal supply without fundamentally changing the conclusion that India's coal reserves will limit the growth of coal-fired capacity post 2032 if only domestic coal is used.

Assuming that 100 GW of capacity addition will utilize supercritical technology and operate on imported coal, 320 million tonnes coal imports will be required annually to generate about 800 TWh in 2032 at a coal burn rate of 0.4 kg per kWh. The question posed above, therefore has a corollary – will it be possible to import such large volumes of coal and at what price? Indian planners should regularly evaluate the pace of implementation of new coal mining infrastructure in exporting countries midst mounting global pressures to meet climate change mitigation goals. Simultaneously, transport and port handling capacities in both India and the exporting countries could emerge as another major bottleneck.

The global export and reserves situation of major coal producers is summarized in Table 1. Only four countries have sufficient reserves to meet India's projected need. These are the USA, Russia, Australia, and South Africa whose combined exports (thermal plus metallurgical coal) today are about 440 million tonnes out of a global traded amount of about 800 million tonnes. At this point in time only the US has adequate mining capacity to export the requisite amount, more so if its own coal-fired generation transitions to other technologies. Thus, the question Indian planners have to address is whether these countries will expand their coal exports in response to India's needs and what economic and political cost India will have to bear! It is also worth noting that China become a coal importer in 2006 and will be competing with India for the same global reserves.

To summarize, even if the desired coal-fired generation capacity additions are possible, the required coal linkages remain an Achilles heel. The Indian government has developed a plan[iii,vii,ix] to increase domestic production, but the magnitude of the challenge and lack of significant underground mining capacity calls for caution.

Country	Export Million Tonnes/year (% of total mined)	Reserves Million Tonnes (2009 BP statistical review)
Australia	**260 (65%)**	**76200**
Indonesia (x)	150 (65%)	4328
China (x)	5 (0%)	114500
South Africa	**70 (28%)**	**30408**
Russia	**60 (18%)**	**157010**
USA	**50 (5%)**	**238308**
Canada (x)	30 (45%)	6578
Poland (x)	15 (10%)	7502
Vietnam (x)	15 (36%)	150
INDIA	**2008 Use = 512 MT**	**40000 - 58600**

Table 1: Estimates of annual coal exports in million tonnes and as a fraction of the mined tonnage. The data for reserves are from the 2009 BP Statistical Data Tables.[ii] *Countries marked with an (X) will not contribute significant amounts to world exports by 2032.*

I.3 India's Nuclear Program

India has developed a very ambitious nuclear program to meet its energy needs. The 3-stage plan[xvi] – first formulated by Homi Bhabha in 1958[xvii] – is finally being pursued with vigor on multiple fronts with the lifting of the international ban on civil nuclear trade in 2008. A summary of current, under construction and planned capacity is as follows: [xviii, xix]

Installed operating capacity of 3.8 GWe

- Pressurized Heavy Water Reactors (PHWR): There are 15 PHWR reactors operating at the 6 facilities – Kaiga, Kakrapar, Kalpakkam, Narora, Rajasthan and Tarapur. The capacity of the first two in Rajasthan is 90 and 187 MWe, the 2 at Tarapur are of 490 MWe and the remaining 11 are of 202 MWe each.
- Light Water Reactors (LWR): There are two Boiling Water Reactors (BWR) operating at Tarapur, each with 150 MWe capacity.

Capacity close to completion (2.9 GWe)

- Kaiga (PHWR): Unit 4 (2010) of 202 MWe capacity.
- Rajasthan (PHWR): Unit 5 (2009) and 6 (2010) each of 202 MWe capacity.
- Kudankulam (VVER-1000 LWR): Units 1 and 2 (2011) of 917 MWe capacity imported from Russia.
- Kalpakkam Prototype Fast Breeder Reactor (PFBR): First unit of 470 MWe is under construction with expected commercial operation in 2012.

India's future nuclear plans and our estimate of capacity addition by 2032:

Below is a short summary of the different technologies that are being pursued, along with India's stated plans and the capacity likely to be realized by 2032. This paper follows India's stated plans to assess what will be built, but does differ in its estimated schedule for reaching the set goals. The conclusion reached is that India's stated completion date of 2022 for reaching 40 GWe capacity[xviii] will be delayed by at least 10 years to 2032.

PHWR: India is developing an Indian Standard PHWR of 700 MWe capacity based on its past experience with 200 and 500 MW units. The 2005 plan calls for 7 units by 2022. Considering that construction of even the first unit is yet to be started, it is reasonable to presume that this schedule will slip to 2032 assuming a construction period of 5-7 years and 2 plants under construction at any given time. Seven operating units would provide about 5 GWe additional capacity by 2032.

FBR: India's second stage of the 3-stage long-term plan includes 200 GW of FBR capacity based on metal and oxide fuels (MFBR and OFBR) supported by plutonium reprocessed from 10 GWe of PHWR. Based on the anticipated success of the PFBR due to start operation at Kalpakkam in 2012, the plan is to build in units of two, *i.e.* 2 x 470 MWe units, at a given site. It is estimated that the start of construction of the second reactor at Kalpakkam will take place post 2012 and an additional 6 units will be built by 2032 assuming an optimistic 5 year build cycle with, on average, 3 reactors under construction at any given time. Thus FBRs will contribute about 6.5 GWe of new generation capacity by 2032.

LWR (Russia): India signed a deal with Atomenergoeksport of Russia in 1998 for up to eight VVER-1000 and VVER-1200 reactors.[xx] The completion of the first two VVER-1000 units at Kudankulam has been delayed by two years to 2011. It is estimated that the remaining 6 units of VVER-1200 technology will be built by 2032 and contribute about 6.6 GWe of new capacity.

LWR (France): India recently signed a nuclear deal with France and is in negotiations with Areva for up to 6 Evolutionary Power Reactors (EPR) of 1.4-1.65 GWe capacity. The price for the first two reactors is variously quoted between $11-14 billion. Assuming a seven years build time of at least the first set based on delays experienced at Olkiluoto 3 in Finland and of the VVER-1000 at Kudankulam it is estimated that 6 such reactors will be built by 2032. Six EPR units would add about 9 GWe capacity.[xxi]

Additional LWR: Other reactor manufacturers and NSSS suppliers are poised to enter the Indian market. However, the current price tag of over $5 billion per GWe will prevent any significant capacity addition beyond the 15 GWe of new LWR from Russia and Areva. In total 20-25 GWe LWR can be expected from all vendors. A big hurdle will be the capacity of Indian companies to provide most of the major non-reactor components (for example heat exchangers, turbines, generators, etc.) and keep costs down. Indian companies such as BHEL, based on technologies licensed from various international manufacturers, are just beginning to develop capacity for manufacturing thermal units bigger than 500 MWe [xxii] and other Indian companies are just starting to create partnerships with large international vendors for production of key components in India.

AHWR: India has announced plans to start construction of the first AHWR (Advanced Heavy Water Reactor) based on U-233 fuel produced by irradiation of thorium.[xxiii] India has tested the U-233 fuel concept in the KAMINI reactor (30KWe) at Kalpakkam, nevertheless, the AHWR will be the first of its kind and we estimate it will take up to 2032 to make this technology a large scale deployable option. We, therefore, estimate only 4 AHWR reactors operating by 2032 with a total capacity of about 1.2 GWe.

The Indian government is committed to rapid development of nuclear power. This will, however, not be easy and we summarize our many concerns regarding large-scale deployment of nuclear power in the near term. These include:

i) The above growth scenario requires 8-10 reactors of four different technologies under construction at any given time. While India has developed indigenous capability for most of the components, the scale of manufacturing infrastructure needed for combined growth in nuclear, coal, gas and hydro power plants in an uncertain domestic and global financial market will be a non-trivial challenge. In this context it is useful to note that the completion schedules of many of the coal and gas-fired power plants under construction have slipped by 1-3 years due to delays in the supply chain and for financial reasons. [xxviii, xxvii]

ii) The fuel processing capacity to extract Pu and U-233 required to support the growth of Fast Breeder Reactors (both MFBR and OFBR) and the thorium based AHWR needs to be increased by a factor of about five.[xxiv] A 1000 tonnes/year reprocessed fuel capacity to support FBR using spent fuel from 10 GWe of PHWR is non-trivial to develop and the experiences of France and Japan in developing such systems show that it can easily take 10-20 years.

iii) The time required to gain enough experience and quality control along the entire supply chain to move from first-of-kind reactors developed by the research organizations to commercial versions can easily be 5-10 years especially when even the respective roles and opportunities of the private sector vis-à-vis the dominant central government owned operators NPCIL[xix] and NTPC[xxv] have yet to be clarified. Private participation and joint opportunities will take time to mature.

iv) The Indian government is investing significant resources to open new uranium mines and processing mills. The current production of processed uranium (magnesium di-uranate) from the mills at Jaduguda (operational since 1967) and Turamdih (2007) is about one tonne per day from each plant.[xxvi] The goal is to double this 750 tonnes per year capacity to meet the needs of the 10 GWe PHWR. Even if this mining and processing capacity were accomplished and assuming that the estimated reserves of 56000 tonnes are all recoverable, India will still be dependent on imported fuel for the 20-25 GWe of LWR capacity. Fuel supply arrangements are part of the LWR contracts, nevertheless, they will constrain India's nuclear independence and become a vulnerability if national security scenarios change and the Nuclear Suppliers Group modifies its stance regarding sales to India.

v) So far the Indian government has assumed all financial risks for the installation of nuclear units and provided all the funding for R&D. Estimating construction costs at \$2 per Watt for Indian PHWR units, \$3 per Watt for FBR and \$5 for imported LWR, we find the projected capacity growth requires capital outlay of about \$150 billion at today's prices. To this add another \$25 billion for developing fuel reprocessing facilities for the FBR program. The cost of transmuting thorium to U-233 at an industrial scale is still unknown. It is doubtful that the Indian government would either have the capacity or the will to continue making this magnitude of investments in nuclear energy in the future. A clear roadmap for generating sufficient resources from India's private as well as huge public sector becomes imperative under these circumstances.

vi) Expanding nuclear power on this scale by 2032 requires a national effort in human resource development. Nuclear engineering programs to train the manpower required to support the development of nuclear power have just been initiated by some of the leading academic institutions and the first batch of master's students at IIT Kanpur and IIT Madras will graduate in 2011-12. Most likely, there will also be a growth in demand for these engineers from the private sector, which would initially hire them to work in their coal or gas-fired power plants while awaiting clarification on the nuclear policy regarding joint ventures. We believe migration of this talent, which so far has been restricted due to security concerns, will also increase if there is growth of nuclear power in Europe and the USA.

For the reasons outlined above it is unlikely that India will have more than 40 GW of nuclear power capacity by 2032. This number, while lower than India's plans of 48-63 GWe by 2030 (See Table 3.4 in Ref.[iii]), is not to be frowned at – it represents a 6 fold increase in 22 years accompanied by very significant development and maturation of breeder reactor technology. Achieving this puts India in an excellent position to transition to carbon-neutral systems after 2032 through rapid build up of nuclear power, especially if the cost of renewable (wind and solar PV) generation remains high, their integration into the grid is slow, and other anticipated clean-technologies such as hydrogen fuel cells do not become cost-effective. Even opponents of nuclear power should recognize this option as India's long-term insurance policy.

To summarize, in the short term i.e. up to 2032, India has only two options to achieve the power generation capacity needed to sustain a GDP growth of over 8%: (i) continued buildup of the most energy efficient coal and gas-fired power plants and (ii) improvements in efficiency in generation, transmission, distribution and use of energy along with policy and structural changes at all levels to mandate this efficiency.

I.4 Gas-fired Power Generation:

India has added gas-fired capacity since 1988 at a steady rate of about 0.7 GWe per year as shown in Figure 2. The correlated increase in gas consumption is shown in Figure 3.[xxvii] Historically, gas turbines have been running at low PLF (national average of 50-55%) due to shortages of gas supply. Starting in April 2009, new supplies from the KG Basin (Reliance Industries D-6 field) have improved the PLF to 67% and the total production for the year 2009-10 is anticipated to be about 90 TW hours, almost 40% higher than the 2008-09 figures.[xxviii]

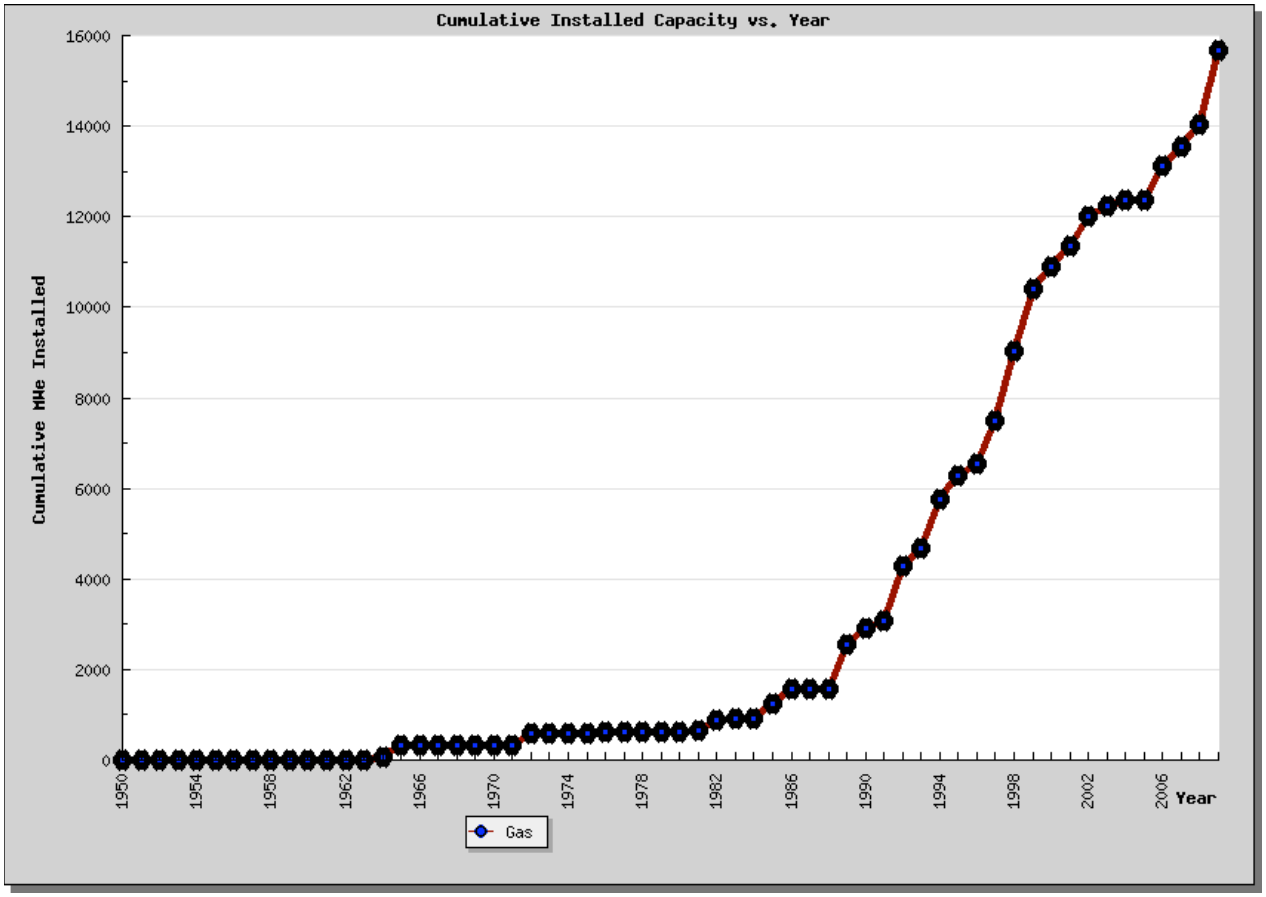

Figure 2: Data on cumulative installed gas-fired generation capacity from CEA.[xxviii,xxx] Data for 2008, 2009 are incomplete. The total value in Oct 2009 was 16.5 GW.

The private sector (Independent Power Producers) has been most active in installing combined cycle gas turbine (CCGT) power plants in the last decade, however, generation and growth continues to be hampered by shortages in gas supplies. The Reliance group expects to ramp up gas production and delivery from its D-6 field in the KG Basin to 80-100 million standard cubic meters per day (MMSCMD) by 2011.[xxix] At this rate, assuming reserves of 300 billion SCM, the D-6 field will approach depletion by 2020, as will the older existing fields off the coast of Gujarat. At production rates of 200 MMSCMD the current Indian reserves of 1074 billion SCM will last about 15 years.[xxx] The only other significant capacity addition on the horizon is 25 MMSCMD from finds by Gujarat State Petroleum Corporation (GSPC) in the KG basin. No other major new finds have been announced since

2002, the year of the KF D-6 discovery, in spite of over 200 blocks under exploration under NELP. Assuming a 5-7 year development period for a new field to achieve production, we estimate up to 300 MMSCMD could be available from domestic production and LNG imports in the period 2010-2020. Beyond 2020 estimates of domestic production are at present highly uncertain, as they are dependent on yet to be made new finds.

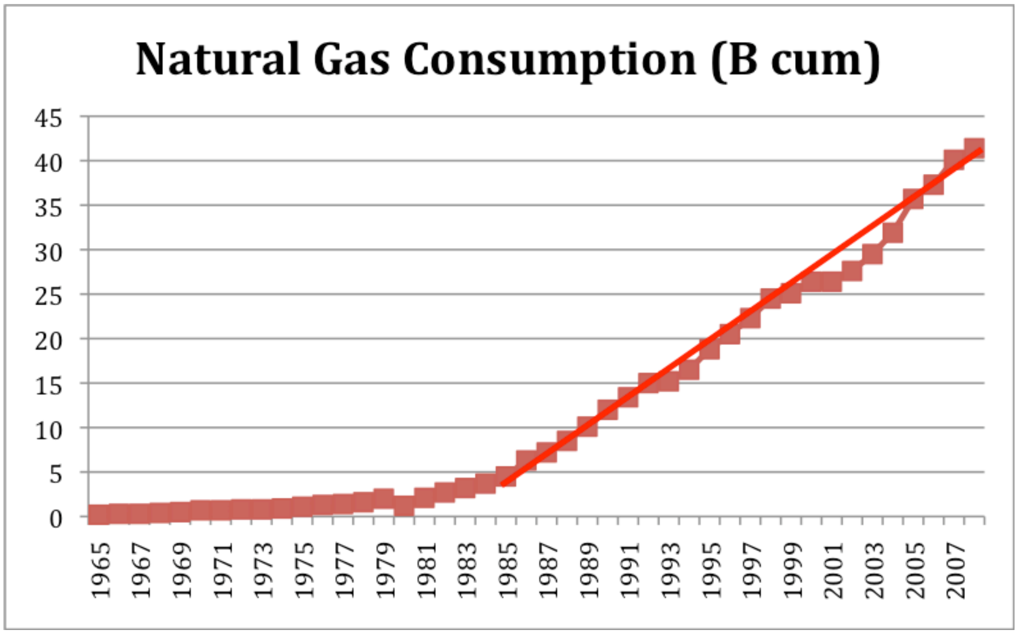

Figure 3: Annual consumption of natural gas in billion cubic meters (B cum). The line shows an annual growth rate of 1.3 billion cubic meters during 1985-2008.

In spite of the uncertainties in gas supplies gas-fired generation capacity could reach 100 GWe by 2032 for the following reasons:

- India has good relations with three of the biggest sources of natural gas, – Russia, Iran and Qatar, and is in close proximity to the Persian Gulf. Thus large-scale imports of LNG are an attractive option, limited largely by the cost and timescale of development of ports and pipelines.
- Gas is a much cleaner fuel compared to India's main option coal, and India, like most developed countries, would want gas based generation to be a significant fraction of the mix to reduce overall carbon intensity.
- CCGT in co-generation mode have demonstrated up to 80-90% energy utilization. As India industrializes, corporations that require process heat can be incentivized to locate close to gas pipelines and install grid-connected gas turbines operating in cogeneration mode.
- Gas turbines, because of their fast start and ramp-up rates, are excellent reserves for both meeting peak demand and as backup for intermittent renewable generation. Given India's immediate need and power shortages,

these turbines can initially provide base load, but over the long term should be viewed as essential for facilitating integration of wind and solar generation.

The large jump from the current 16.5 GWe to 100 GWe capacity represents a very healthy 6-fold increase, i.e., a sustained annual growth rate of 8% in CCGT plants, and in line with the overall projected growth of 8-10% in GDP. Assuming all power generation is from, on average, 50% efficient CCGT plants run at 80-85% PLF, 100 GWe of generation capacity will require 350 MMSCMD gas supply and annually generate 700 TW hours of electric energy based on a gas consumption rate of 0.2 MMSCM per GW hour. To provide 350 MMSCMD for power production India would need a total of over 600 MMSCMD of gas. This would have to come from the following possible sources:

- New domestic finds: Domestic production could remain around 100 MMSCMD as the probability of continued multiple finds as large as the KG D-6 field is low and NELP has not succeeded in generating the vaunted enthusiasm amongst investors. If India were to meet its entire demand of 600 MMSCMD from domestic sources it would need to discover at least twelve new KG D6 size fields over the next 22 years whereas there have been none in the last seven. Anticipated unconventional production from coal/shale bed methane and coal gasification is included in this 100 MMSCMD estimate.
- Pipelines: If some combination of the proposed pipelines – Myanmar-Bangladesh-India, Iran-Pakistan-India and Turkmenistan-Afghanistan-Pakistan-India – actually materialize, they could provide up to 100 MMSCMD. If these pipelines do not get constructed then the only remaining option is large-scale imports of LNG.
- LNG terminals would have to provide up to 400-500 MMSCMD depending on whether the proposed pipelines come into existence and if new finds do not occur at the desired pace. This would require a 10 fold increase over the 40 MMSCMD LNG capacity operational in 2009 as listed in Table 2:

Terminal	Operator	Current Capacity in 2009 (MMSCMD)	Additional Capacity (MMSCMD)
Dahej, Gujarat[xxxi]	Petronet LNG Ltd	20	20 more under study
Kochi, Kerala[xxxi]	Petronet LNG Ltd		10 by 2012
Hazira, Gujarat[xxxii]	Hazira LNG Pvt Ltd	10	Up to 40 possible
Dabhol, Maharashtra[xxxiii]	Ratnagiri (RGPPL)	10	Breakwater needed to reach 10

Table 2: Current and planned LNG terminals and their capacity

These estimates have two caveats. First, the precise split between domestic production and imports through pipelines and LNG terminals depends on many unknowns, so these estimates should be considered highly uncertain. Second, even anticipating alternate process technologies and substitute materials, there will be growth in demand from the fertilizer, petrochemical, transport, and other industries that was about 150 MMSCMD in 2008.[xxx] This introduces further uncertainty in the fraction of gas supply that the government will allocate to the power sector (currently a highly contentious issue due to restrictive government policies and subsidies). We advocate a commitment to adequate supply through imports, otherwise gas will remain a major factor limiting growth in generation capacity.

Such growth does have important long-term economic consequences. First, importing 500 MMSCMD with long-term contracts could cost India $62 billion per year. Today, the spot price of gas is about $4-$7 per million BTU. However, Qatar recently signed a take-or-pay 20-year contract with South Korea to provide LNG at $10 per million BTU (i.e. $0.35 per cubic meter).[xxxiv] The market could be even more volatile by 2032. To put the volume needed in perspective it should be noted that 600 MMSCMD is more than a third of the US's rate of consumption in 2008!

Second, the cost of adding 85 GWe generating capacity at today's price of $0.7 per Watt for combined cycle plants will require $60 billion. Another $40 billion would be needed for infrastructure development (LNG terminals and pipelines) besides an annual fuel cost of $62 billion by 2032.

I.5 Hydroelectric Power Generation:

India's hydroelectric power potential was first evaluated in 1953-57 and a reassessment was undertaken by the Central Electricity Authority (CEA) during 1978-1987.[xxxv] CEA listed resources of about 150 GW of hydroelectric capacity exploitable at 60% PLF, 95 GWe of pumped storage and about 7 GW of small, mini and micro capacity. To exploit this potential, the Prime Minister launched the 50 GW scheme in 2003 based on a 2001 prioritization of projects by the CEA.[xxxv,xxxvi]

Of the estimated resource of 150 GW only about 40 GW has been exploited so far as shown in Figure 4. The best annual load factor between 2000-08 (which includes a number of good rainfall years) is only 38% (Figure 4), much lower than the CEA estimate of 60%.[iii,xxxv] Allowing for improvements, we use an optimistic 40% for average load factor. Extrapolating the 2 GW per year growth in capacity that has taken place between 2000-2009 we estimate India could have 90 GW of hydroelectric capacity by 2032. Under this scenario 90 GW installed capacity will provide about 300 TW hours of electric energy per year at 40% PLF. The cost of this additional capacity is dependent on details of the projects and terrain. Taking $1.6 per Watt as the average cost, the 50 GWe additional capacity will require an investment of $80 billion.

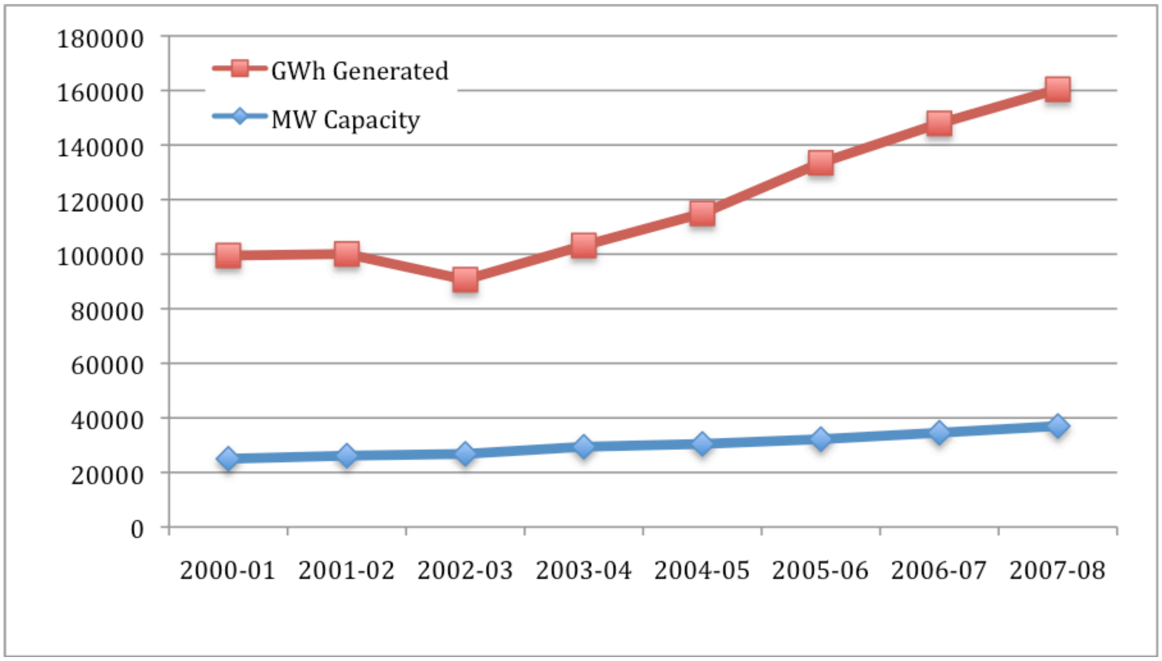

Figure 4: Installed hydroelectric generation capacity in MW and generated power in GW hours for the years 2000-2008. Data are from CEA.

1.6 Transportation Sector – Crude Oil Production and Imports:

India today consumes about 3 million barrels of crude oil per day. Data from BP (Figure 5) show that the current annual growth rate is about 0.1 million barrels per day (bpd). Growth in automobile sales indicates that it is unlikely that this increase in demand will stop in the near term. Extrapolating this trend gives a consumption figure of 5.3 million bpd in 2032. This study uses the slightly higher number projected in the 2006 Integrated Energy Policy Report of 6 million bpd.[iii] It is reasonable to assume that domestic production remains at 0.7 million bpd based on the historic production rate of 0.7-0.8 million bpd between 1998-2008 even though this will require new finds to maintain the reserves replacement ratio at a minimum of one. To import 5.3 million bpd of crude oil at even $100 per barrel India will need to earmark $194 billion per year in foreign exchange.

The good news in the oil sector is that India will have developed a refining capacity of 5.3 million bpd along with the requisite oil ports as early as 2013 due to a very aggressive private sector. The additional infrastructure required, therefore, will mostly be product distribution pipelines. These will require about $20 billion.

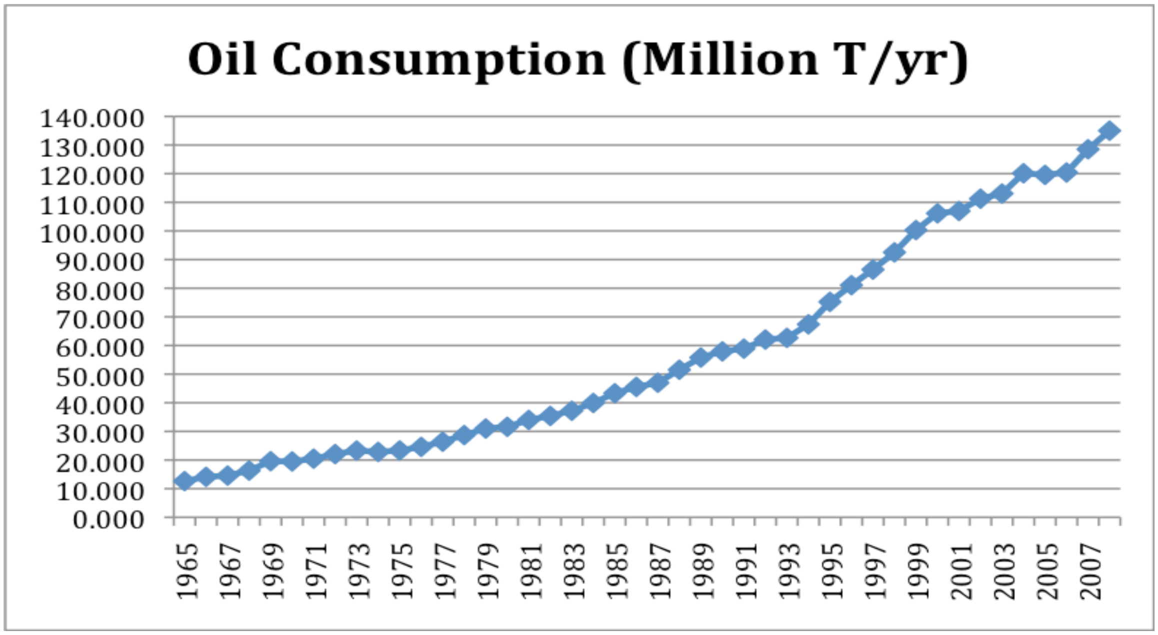

Figure 5: The data from 2008 BP Statistical Review Tables show the growth of crude oil consumption in India. The data show two approximately linear growth trends. The annual growth rate between 1965-1994 was about 37000 bpd and changed to 96000 bpd during 1995-2008. The break around 1994 coincides with liberalization in the automobile industry.

I.7 Energy Security and Green House Gas Emissions in 2032

The optimistic but minimum required growth scenario outlined above results in the following installed electric power capacity and annual generation by 2032:

- 300 GWe of coal-fired plants generating 2200 TW hours.
- 40 GWe of nuclear reactors generating 300 TW hours.
- 100 GWe of combined cycle gas turbines generating 700 TW hours.
- 90 GW of hydroelectric generating 300 TW hours.

In addition, WEO-2009 estimates almost $1 trillion will be required for the transmission and distribution infrastructure needed to support this growth in capacity.[xxxvii] Even if India could raise the necessary capital to meet the goal of achieving 0.25 kW per person, the long-term payback of this investment would depend on India being able to import most of its primary energy:

- 300 million tonnes of coal annually in addition to a domestic production of 1000 million tonnes.
- 500 MMSCMD of natural gas (85% of total) if domestic production stagnates at 100 MMSCMD because of low investments and no major new finds.

- 5.3 million barrels per day of crude oil (88% of total) in addition to domestic production of 0.7 million barrels per day.
- Uranium for about 25 GWe of light water nuclear reactors.

In this scenario India will, by 2032, be highly dependent on imports, and therefore subject to global markets and geo- politics, for most of its primary energy supplies. Furthermore, emissions of CO_2 will also have risen from the current 1.2 billion tonnes to a peak value of about 4.5 billion tonnes per year. This, however, represents a very modest 3 tonnes CO_2 per capita that any realistic climate treaty should accept.

This scenario is summarized in Table 3. Recognizing it will require about 0.7 trillion dollars in capital investment for new generation capacity over the next 22 years, about $1 trillion for transmission and distribution infrastructure, and about $275 billion per year in fuel import costs by 2032, it is hard to foresee a scenario in which India could develop a bigger fossil fuel driven economy. Thus, India does not really sacrifice its ability to grow by agreeing to cap its total CO_2 emissions at 5 billion tonnes per year.

	2009 installed Capacity / Use	2032 projected Capacity	Cost of New Plants	Imported Fuel	Cost of Imported Fuel/year	Domestic Fuel	Cost of Domestic Fuel/year	Additional Infrastructure Cost
Coal	80 GW	300	$220B	300 MT	$18 B	1000 MT	$40 B	$50 B
Gas	16 GW	100 GW	$60B	500 MMSCMD	$62 B	100 MMSCMD	$10 B	$40B
Hydro	40 GW	90	$80B					
Nuclear	3.8 GW	40	$150B	4 kT of U	$0.8 B			$25B
Crude Oil	3 MB/day	6.0 MB/day		5.3 MB/day	$194 B	0.7 MB/day	$26 B	$20 B
TOTAL			$510B		$275 B			$135 B

Table 3: A summary of current capacity and projections for 2032 including estimates of capital costs for new installs and fuel imports. The following prices have been used in 2009 dollar value: $100 per barrel for imported crude oil; $10 per million BTU for LNG; $40 per tonne for domestic and $60 per tonne for imported coal; and $200 per kg of un-enriched Uranium. The reader can scale these numbers and use his/her favorite estimates of prices during 2010-2032 to create alternate scenarios. Also note, we have not included the cost of and structural impediments to enlarging the electric transmission and distribution infrastructure, which WEO-2009 [xxxvii] *estimates at close to $1 trillion between 2008-2030 in its Reference Scenario.*

India's real dilemma arises from agreeing to a particular timetable ("peaking" year with decrease thereafter) given the existing technological uncertainties and the vagaries of future economic cycles in the face of the imperative for growth needed to alleviate widespread poverty in the country. Agreeing to a 5 giga-tonnes cap, without a definite peaking year can in fact demonstrate the shared urgency and create the necessary national will to gradually wean the economy away from fossil fuels to a carbon-neutral economy. Five giga tonnes of CO_2 per year at peak consumption, while large in terms of the global climate change scenarios, still corresponds to about 3 tonnes per capita – which is about one seventh that of the USA, a third of Europe's and half of China's. Thus, India would cap its emissions at much lower levels than the developed world and the total integrated amount will also be much lower. This conclusion remains valid even if industrialized nations are given reasonable CO_2 credits for developing much of the technology.

The second key question is: how can India accelerate the transition to carbon-neutral systems pre and post 2032 and meet its climate change mitigation responsibilities? The following outline addressing this question is also proposed as a framework for India to take to international negotiations on Climate.

II. CAN INDIA LEAD AT CLIMATE NEGOTIATIONS?

There are in our view six basic criteria that any international framework on emissions reductions to address global warming must satisfy if there is to be trust and cooperation between the developed and developing countries. Climate policies have to:

- **Be equitable:** Policies and treaties should be sensitive and responsive to the needs of both developed and developing countries and of people with different economic status within countries.
- **Be open and transparent with non-intrusive emission monitoring systems:** The goal should not be to create huge international bureaucracies to monitor emissions that lead to rent seeking by both domestic and international inspectors but to promote transparency so that there is minimal need for monitoring and/or verification.
- **Have growth time lines aligned with existing/plausible technologies:** Lacking sufficient human and infrastructure resources to adopt or to maintain evolving systems, developing countries are much less likely to accept options involving technologies that are still maturing.
- **Be Cost-effective:** Most developing countries with huge unmet needs do not have adequate capital to deploy even the "cheapest" base power option – coal-fired power generation. Total cost, including deployment, operation and

maintenance, transmission grid and fuel linkages, needs to be given high priority in planning and execution.

- **Incentivize good behavior and not be punitive:** many options such as cap and trade or carbon taxes purportedly use the market to reward good behavior. The developing world fears that the creation of such policy framework will result in new markets and bureaucracies that mainly benefit the rich. Most of the developing world is rightly concerned that these mechanisms will further increase inequity as the rich will have the option and resources to pay for their current lifestyle without significantly reducing their carbon footprint while most of the additional costs due to restrictions will be borne by the end-users, especially the poor.
- **Lead to a long-term and sustainable vision and end-state that can be achieved through a realistic roadmap.** In this document we exemplify such a strategy by looking at a possible midpoint (2032) when CO_2 emissions in India would peak and be followed by a transition to carbon-neutral systems. This transition, we hypothesize, will be driven by cost-effective renewable generation and a closed nuclear fuel cycle whereby fossil fuel based systems will steadily be replaced and India will achieve a carbon-neutral economy post 2050, very much in sync with the developed world.

These six criteria capture in essence the very strong sentiment articulated a number of times during international negotiations: *The developed world can reduce its carbon footprint very significantly by just tightening its belt (lifestyle changes and improvements in efficiency) whereas the developing world would need to condemn hundreds of million people to abject poverty if asked to stop growth in the near term through use of fossil fuels.* Keeping these criteria in the forefront of negotiations will create an environment of trust that will allow the developing and developed countries to work together.

II.1 Global Win-Win options:

In keeping with the above criteria there exist a number of global win-win options that address climate change mitigation through development. These options would be in the interest of India to implement, as they are part of India's avowed goals and mesh strongly with its timelines to achieve them:

II.2 Power Sector:

CO_2 emissions from the power sector account for approximately 40% of the global budget. Today, there are only two well-developed and exercised technologies for providing cost-effective base load capacity viz. coal-fired and nuclear power plants. Both have their drawbacks. Coal plants are major emitters of criteria (SOx, NOx, volatile organics, particulate matter, etc) and toxic (lead, mercury, etc.) pollutants in addition to green house gasses (CO_2, N_2O, etc) while nuclear power still invokes serious concerns of safety, proliferation and waste disposal. Balancing the need to develop against currently available cost-effective technologies, the best options available in the short to medium term are the following:

- Pursue aggressive deployment of the most energy efficient coal and gas-fired technology to address development needs[iv] realizing that even a peak value of 5 giga tonnes CO_2 emissions will, in any case, be dictated by the amount of fungible carbon India can buy in the international market, rather than by the capacity it can install or by its wants and needs.

- Focus on the development and maturation of nuclear energy technology (fast breeder and thorium based reactors) so that there can be rapid build up of indigenous nuclear capacity post 2032.

- In addition to the 3-stage nuclear energy program, India should partner in the R&D for small and medium size modular reactors. In the long-run, these will be more cost-effective as they do not require expensive containment vessels, can be mass produced in factories and pose smaller financial risks. These factors would greatly facilitate private participation. Small and modular reactors also have the potential to provide a better match between supply and demand by being locatable near demand/urban centers. If their cost comes down sufficiently one can envisage a scenario in which they replace coal-fired boilers, partially preserving the investment in coal-fired power plants (turbines, generators, water linkages) and the transmission infrastructure connecting them to the grid.

- India should continue to fund R&D and multiple demonstration projects of various scales to gain experience with integration of utility scale distributed generation of solar, wind and geothermal power so that large-scale deployment can take place as and when these technologies (especially solar) become cost-effective. A highly reasonable but optimistic goal for 2032 is that 5% of energy generated (~160 TWatt hours in our scenario) should be from renewables excluding hydroelectric. This small fraction would be an incredible achievement and in line with WEO-2009 450 Scenario [xxxvii] that calls for India to deploy almost 60 GWpeak wind and 40 GWpeak other non-hydro renewable capacity by 2030. Assuming a 20% conversion factor from peak rating to dispatched power (current figure for wind and solar), a 100 GW peak capacity would provide 175 TW hours. So, in reality, even the aggressive WEO 450 scenario yields a small fraction of the needed energy! Furthermore, very significant R&D is needed to automate and control the current and planned grid so that it can integrate these intermittent resources and evolve smoothly to a smart green grid. India should definitely partner in the global R&D effort to help develop this technology and share the intellectual property rights.

- Very large reduction in total energy used is possible in heating, cooling and lighting of buildings through efficiency gains and better planning. Solar thermal systems for hot water, heating and evaporative cooling can substitute large electric HVAC systems. Geothermal systems with heat pumps can provide air conditioning for buildings. Passive solar building design with good insulation, natural lighting and well-designed air circulation can reduce energy cost of buildings and improve the comfort of occupants. Most of these systems are already cost-effective and the challenges are educating architects, builders and customers, and incentivizing the use of these technologies. Rapid adoption of these systems can be achieved by amending Municipal bye-laws to mandate desired standards for urban buildings.

- India should partner in the global R&D effort to reduce the cost of solar PV systems and the development of cost-effective and industrial scale technologies for photo-chemical and thermal splitting of water into hydrogen or to hydrocarbon fuels directly.

The paper makes no quantitative recommendation for carbon capture and sequestration (CCS) nor sets a target. The lack of knowledge of the location and characteristics of sufficiently large geological sequestration sites in India[iv] and the pressing need to first develop large enough energy generation systems will preclude investment in CCS. Except for special cases of enhanced oil and gas recovery, India should limit its participation in this arena to sharing in the global R&D effort and gaining better understanding of its on-shore and off-shore potential. On the other hand forestation, with its multiple benefits, should be targeted vigorously.

II.3 Transportation Sector:

There exist real opportunities for improving efficiency in the transportation sector and reducing its carbon intensity. Win-Win options include:

- Higher gasoline mileage standards: India should demand, by setting an example, an all-car (including SUV) international standard for an average of at least 25 km/liter (60 miles per gallon) by 2032. This is an achievable goal as two technologies (hybrids and small cars) for achieving this target already exist – Toyota Prius today gives about 20 km/liter and the Tata Nano gives 25 km/liter – and address the needs of both the developed and developing world.

- Build effective public transport systems for planned smart eco-cities as India urbanizes. India faces rapid growth in its urban population from 27% (320 million) to over 50% (over 850 million) in the next 40 years. New and growing cities should plan and deploy (i) pedestrian and bicycle corridors, (ii) exclusive corridors for public transport including buses, taxis and 3-wheelers and (iii) metro trains. The first two are essential for towns and cities of all sizes, whereas metro trains would be needed for the larger metropolitan centers. An integrated plan should be developed at early stages of urbanization with all three options evaluated as they serve different populations and needs.

- Accelerate the creation of dedicated rail freight corridors for long-haul movement of goods by train instead of trucks. India has already created a Special Purpose Vehicle called Dedicated Freight Corridor Corporation of India (DFCCIL) and proposed two such corridors – Delhi to Mumbai and Ludhiana to Kolkata – shown in Figure 6.[xxxviii] Both corridors are envisaged to be ready by 2017. Further growth of railway infrastructure for moving people and freight should be given the highest priority.

- Accelerate the transition to cleaner fuel, such as CNG, for all surface public transport systems (buses, taxis, and three-wheelers) and incentivize their use. India should build on its success in implementing this transition in Delhi.

Figure 6: Two dedicated rail freight corridors – Delhi to Mumbai (black line) and Ludhiana to Kolkata (red line) – to be developed by Dedicated Freight Corridor Corporation of India (DFCCIL) by 2017. [xxxviii]

II.4 Unconventional Options:

Three win-win options that are not often included (or at least not pursued vigorously) in energy-development-climate discussions are:

i. Accelerating population stabilization has direct and indirect impacts on every area of development, environment and resource management. To give a specific example we estimate the consequences for energy security and climate change if we use the number 0.5 kW per person of electric power required to access 21st century opportunities. Using the value of 1 kg CO_2 emitted per kWh generated by coal plants implies 4.4 tonnes of CO_2 emissions per person per year. If India could reduce its anticipated population in 2050 from 1.7 billion to 1.5 billion, about 120 GWe less generation capacity would be required and the CO_2 savings, if this capacity was all coal fired, would be almost one giga tonne per year.

Cost-effective technology for achieving voluntary population stabilization exists (for example, one year's supply of high quality birth control pills costs about $5 per person) and the recent success stories of Iran and Bangladesh in reducing fertility rates suggest that education and easy and free access to modern birth control methods can lead to dramatic reduction in population growth.[i] Both in planning and in policy India supports family planning programs, the weakness is implementation – delivery of modern methods is erratic, inadequate and often of poor quality. Population stabilization should be integrated with better overall health services that are accessible to one and all. Creating a global fund to provide free birth control methods to all people of reproductive age would cost $10-15 billion per year and remove quality and supply issues worldwide. India, in its own self-interest, should lead the climate and environment discussions to bring focus to the overall issue of population stabilization and integrated resource management.

ii. Reducing emissions of black carbon: There is mounting evidence that emissions of black carbon have sufficiently long lifetime in the atmosphere (weeks) to have a warming effect three to four times greater than prevailing estimates.[xxxix] India should offer to reduce its contribution to climate change by helping rural households transition from cooking with biomass or dung based solid fuel to LPG or kerosene. (Smokeless biomass stoves still need localized R&D and have proven difficult to adapt to local food habits when implemented in a centralized top-down manner.) The distribution system and subsidies needed to achieve these transitions are by no means small and India should be firm in asking for support from developed nations to make this transition as part of the Clean Development Mechanism (CDM) program. These options have the added benefit of reducing the very significant health hazards of smoke inhalation during indoor cooking suffered by a large fraction of India's rural and poor populations.

iii. The Copenhagen meeting and ongoing negotiations should consider multi-benefit negative-cost forms of geo-engineering such as increasing the albedo of all buildings. One example is painting all roofs white. Such architectural improvements would pay for themselves by saving owners electric energy by decreasing the need for air conditioning in summer months. Forestation also increases the albedo of land in addition to sequestering carbon and providing multiple ecological services.

Most of these conventional and unconventional win-win options are neither simple to achieve nor have easy technological fixes. They will require an unprecedented change in planning, policy and implementation, and buy in and cooperative action from individuals and state and central governments. If India can make firm commitments to achieving these goals and help other developing countries along the same path, it will have created a new paradigm for international cooperation. India will have moved the discussion from counting giga tonnes of CO_2 emitted and traded to developing actual long-term solutions that will enrich the lives of the global population and protect the environment.

CONCLUSION:

First, India must immediately accelerate growth in electric power generation to address its development and poverty-alleviation goals. In an optimistic scenario, electric energy generation will increase from the current 800 TW hours to over 3250 TW hours per year by 2032. This capacity will correspond to 0.25 kW per person and will achieve what we designate as a poverty elimination goal. Under this scenario CO_2 emissions will, of course, grow from 1.2 to 4.5 giga tonnes per year, however, this growth represents a "peak" value of only 3 tonnes per capita.

Second, India must accomplish this near-term growth in electric power in ways that simultaneously create a robust framework for rapid transition to a carbon-neutral economy post 2032 and commit to cap its CO_2 emissions at a maximum of 5 giga tonnes per year. Five most significant India-specific recommendations for this growth and transition are:

i) The most cost-effective option (assuming no tax on CO_2 emissions) that can lead to significant new capacity in the near term is coal-fired generation. In the growth scenario presented here coal, natural gas, hydroelectric and nuclear will have roughly 70%, 22%, 9% and 9% share respectively of the energy generated by our target year 2032.

ii) Even though the share of nuclear at 40 GW will still be small, the good news is that by 2032 India will have matured four nuclear technologies – pressurized heavy water reactors, light water reactors, uranium/plutonium based fast breeder reactors and thorium based reactors. Large-scale deployment of these nuclear technologies will serve in part as an insurance policy that could support post 2032 growth even if anticipated reductions in cost of wind, solar PV panels and other renewable generation, and emergence of new carbon-neutral technologies do not occur in time.

iii) By 2032 India will be dependent on imports for most of its oil (90%) and natural gas (85%) needs unless India pursues aggressive exploration policies to bring in investments and technologies resulting in the discovery of new mega fields. India would also need to import 300 million tonnes of coal and mine one giga tonne of domestic coal per year. The economic and political costs of all these imports will place very severe constraints on India's security. In short, India's ability to sustain its industrial complex, let alone expand it, using fossil fuels will be subject to world markets, international treaties, and geopolitics and not merely driven by its need. For this reason we contend that development, energy security and climate change mitigation are one and the same goal. Consequently, India can agree to cap its CO_2 emissions at 5 giga tonnes because its energy infrastructure and growth have few options but to transition to renewable and other carbon-neutral energy options well before this level is reached. The window of opportunity for the Indian economy to grow using fossil fuels while simultaneously developing long-term carbon neutral options is, in the above analysis, about 25 years.

iv) This growth in the energy sector requires very significant investment and is, therefore, predicated on India maintaining a GDP annual growth rate of 7% or higher, i.e., a doubling time of 10 years or less. To guarantee success, the state and the central governments must work together to plan and execute, improve efficiency, reduce waste, streamline bureaucracy, reward merit and incentivize good behavior. Timely implementation must follow holistic planning.

v) Additional unconventional options should be pursed vigorously. India must redouble its efforts to stabilize its population through education and voluntary use of modern birth control methods. It can also contribute to climate change mitigation by eliminating emissions of black carbon by aggressively providing modern substitutes for traditional biomass as cooking fuel. (This fuel substitution will also reduce the associated health hazard of toxic smoke inhalation.) Finally, there should be a concerted effort to increase the albedo of the land, increase energy efficiency of all transport, buildings and structures, and invest in forestation.

The challenges are daunting. Nevertheless, the recipe for success is clear: A national will to recognize the many simultaneous challenges, creating sound long-term policy and demonstrating timely and efficient execution.

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Appendix

A NOTE ON THE GLOBAL ENERGY OBSERVATORY (GEO)

Global energy systems are very complex with multiple factors driving growth and change. To understand the dynamics of change in these systems and to engage the global population we are developing an open collaborative web tool called the Global Energy Observatory (GEO). The goal of this tool is to provide a one-stop site for information on energy systems (power plants, fuels and resources, and transmission infrastructure) and use this data for integrated analysis. In short, to bring transparency to the discussion by providing a tool to all with sufficient background to carry out an integrated analysis in real time.

The beta version of the GEO framework and analysis tools is available at http://GlobalEnergyObservatory.org/. It has been built using a traditional web-based LAMP (Linux, Apache, MySQL and PHP) infrastructure. [xli,xlii] It is designed to house information on

- Power Plants and their emissions: coal, gas, geothermal, hydroelectric, nuclear, oil/diesel, solar PV, solar thermal, waste and wind.

- Fuels and Resources: gas and oilfields, coal and uranium mines, crude oil refineries, solar and wind potential, water and biomass resource and CO_2 sequestration sites.

- Transmission Infrastructure: gas and oil pipelines; coal, LNG and oil ports; rail, road and shipping links; and the electric power grid.

GEO is a wiki like framework that allows anyone to provide data on these systems. These public contributed data are, however, reviewed and moderated for scientific integrity and accuracy before being integrated into the moderated database. Simple analysis tools are being developed as an integral part of GEO to query and process the data. This database, moderation process and analysis tools are open to the public and we invite global participation.

A number of collaborators with area expertise are helping build the database. One such example is the Observer Research Foundation[xliii] for India specific data. A large part of this analysis of India's energy systems was facilitated by data already collected. We welcome other individuals and organizations to help us build the global database.

The alpha version of GEO, developed in 2008-2009, demonstrated that sufficient data is available in open literature (unfortunately in many different formats and highly fragmented) to create an integrated analysis tool to understand energy systems and to provide a baseline for estimating emissions and their regional distributions. Based on the lessons learned from the alpha version, the beta version of the framework was developed and made available in March 2010.

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