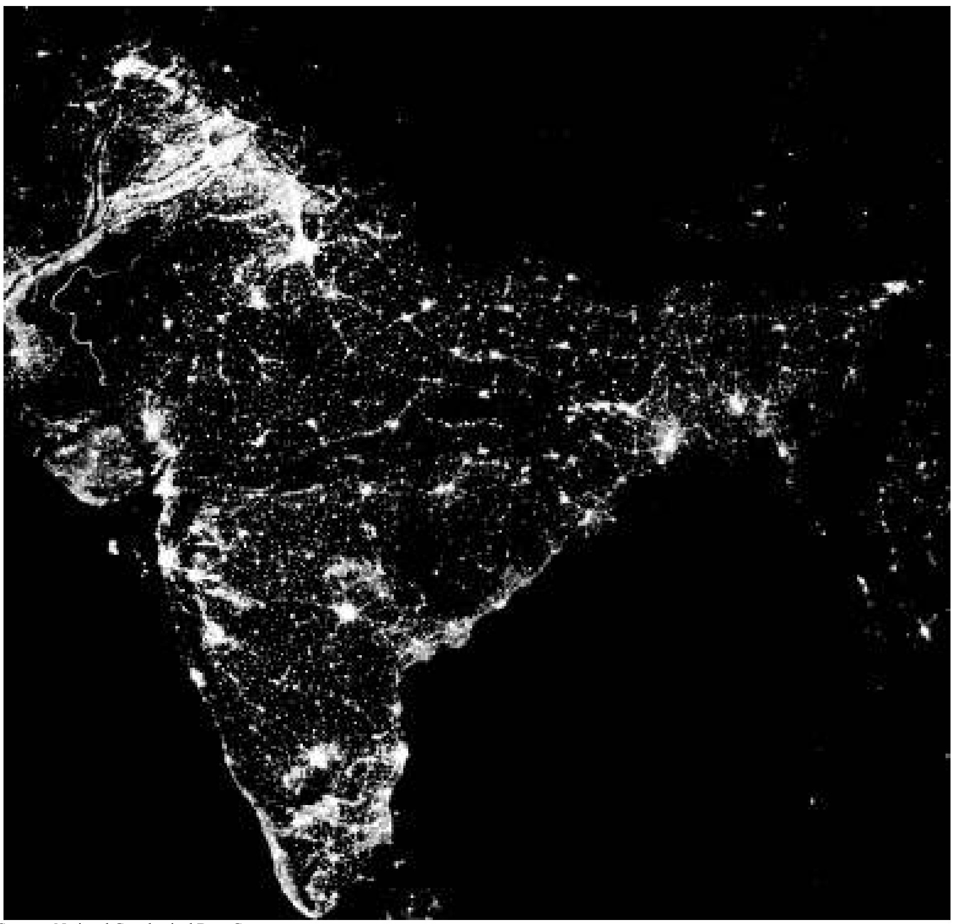
Dalberg

Global Development Advisors

WILL THE U.S.-INDIA CIVIL NUCLEAR COOPERATION INITIATIVE LIGHT INDIA?

Chapter for the Nonproliferation Policy Education Center



Source: National Geophysical Data Center

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TABLE OF CONTENTS

Executive Summary

The U.S.-India Civil Nuclear Cooperation Initiative seeks to foster the development of nuclear power generation in India, despite concerns about nonproliferation. Proponents claim this is necessary to meet electricity demand and GDP growth targets, reduce reliance on foreign sources of fossil fuels, and improve the environment. This chapter examines these assertions by assessing the current and future demand for electricity in India and the generation supply options available. Although focusing on electricity generation, for which nuclear technology is applicable, this report also recognizes that in terms of total energy needs India relies to a much greater extent on traditional biomass and cow dung than on electricity, a situation which will continue for some time. In terms of electricity, the analysis finds that generation capacity will have to increase significantly to meet demand and India cannot rely on any one supply source. While nuclear generation will contribute significantly after 2050, its contribution will remain marginal through 2016 and 2032. Even optimistic scenarios for the development of nuclear power in India, which is based on unproven thorium technologies, suggest nuclear would contribute only 9% of total generation capacity by 2032. Economic growth targets could be attained without significant increases in nuclear generation capacity and nuclear capacity will do little to reduce India's reliance on foreign sources of oil and gas. Furthermore, given the dominance of coal in all of the electricity supply scenarios through 2032, clean coal technologies, demand side management, and renewable energy would have a greater impact on reducing carbon emissions than substitution based solely on nuclear energy. Although the development of nuclear energy today could aid in the eventual exploitation of India's full nuclear potential required after 2050, it does not meet India's energy needs as expressed by proponents of the U.S.-India Civil Nuclear Cooperation Initiative.

Introduction

The U.S. and Indian governments recently established an unprecedented strategic partnership on nuclear energy through the U.S.-India Civil Nuclear Cooperation Initiative, marking a significant shift in U.S. nonproliferation policy. To many observers the choice before the U.S. Congress was between "approving the deal and damaging nuclear nonproliferation, or rejecting the deal and thereby setting back an important strategic relationship."[1] In light of this important decision, it is vital to objectively evaluate the arguments and evidence that underpin the change in policy. While many strategies and geopolitical arguments have been discussed throughout this book, it is also important to weigh this decision on an economic scale to see whether it is well balanced. It is the aim of this chapter to test the economic arguments for the agreement against a rigorous fact base.

Proponents of the shift in U.S. foreign policy towards a stronger strategic partnership through civil nuclear cooperation with India put forth three main economic and resource arguments. The first is that nuclear energy will aid India in reducing its reliance on oil and gas. Secretary of State Condoleeza Rice asserted that "civilian nuclear energy will make [India] less reliant on unstable sources of oil and gas."[2] The second is that nuclear energy is necessary to sustain India's GDP growth rate of 8-9%. Without nuclear energy, it is argued, India may not be able to sustain its GDP growth and achieve its targets for economic development. The third argument is that nuclear energy can reduce greenhouse gas emissions and improve climate change by substituting for coal-based electricity generation.

The ultimate question given the debate around U.S.-India civil nuclear cooperation is whether nuclear generation is needed to meet the electricity needs of India in the medium and long term and whether it contributes meaningfully to environmental improvements and energy independence to justify an expansion of nuclear power in India. In evaluating the validity and strength of the arguments for the agreement, this chapter will: (1) assess the current and future demand for electricity in India in the medium term to 2016 and the long term to 2032 to determine the gap between current supply and future demand; and, (2) review energy supply options by evaluating total potential capacity, relative costs, pace of development and technical constraints, the location of supply and demand, environmental issues, and the impact on energy independence.

(1) What is India's Current and Future Demand for Electricity?

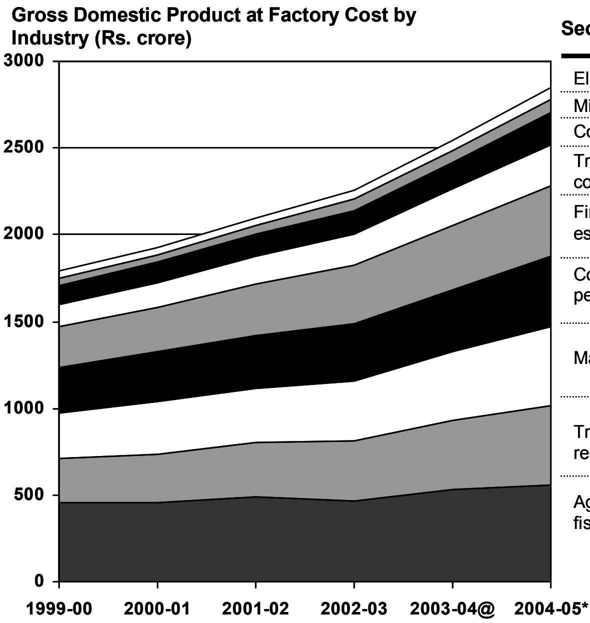
Numerous factors are involved in estimating future energy requirements and it is important to place electricity demand within the context of India's total future energy needs. The Government of India's Planning Commission highlights in its August 2006 *Integrated Energy Policy* that "long-term projections for energy requirements are based on assumptions vis-à-vis the growth of the economy, population growth, the pace at which 'non-commercial energy' is replaced by 'commercial energy,' the progress of energy conservation, increase in energy efficiency as well as societal and lifestyle changes."[3] The demand for electricity in India will undoubtedly increase significantly, but the country is still largely reliant on traditional forms of energy, including traditional biomass such as firewood and cow dung. In 2000, firewood and chips constituted 59% of total energy needs, dung cake another 22%, and electricity only 6%.[4] Long term strategies for India's development need to focus on the entire energy picture of which electricity production is but a small part. In examining the economic arguments for an expansion of nuclear generation this chapter focuses on electricity but recognizes the still marginal contribution electricity plays toward fulfilling India's energy needs.

The major driver of electricity demand is the GDP growth rate, with most estimates forecasting the Indian growth rate between 5 to 9%.[5] This wide variation demonstrates the high level of uncertainty inherent in projections about GDP growth. Historically, India's GDP has grown at 5.3% from 1978-2003[6] but most analysts forecast a higher rate of growth due to improvements in the structure of the economy and benefits derived from globalization. According to David Victor of the Council on Foreign Relations, "India's economy enjoyed an average annual growth rate of around 7% from 1994-2004… [and] most analysts expect growth to be sustained at 8% over the next few years if not longer."[7] The Planning Commission based its energy supply scenarios for its *Integrated Energy Policy* on 8% and 9% GDP growth rates, constituting a suitable upper bound when estimating future energy requirements. If less ambitious GDP growth is realized and less electricity is needed, the conclusions drawn by this report, especially with regards to the role of nuclear generation, should continue to hold true.

Indian sector composition

The sectoral composition of GDP growth has a considerable effect on the *demand* for electricity both in terms of absolute and total gigawatts required as well as the composition of electricity supply sources, i.e. centralized versus decentralized generation. As seen in Figure 1, while "agriculture, forestry, and fishing" contribute the most to India's GDP, currently at 20%, the growth rate is only 4%. By contrast, "manufacturing," historically a large consumer of electricity, comprises another 16% of GDP and is growing at 11%. Generally, "economic growth is expected to cause a shift in the Indian economy away from energy-intensive manufacturing and also engender investments that make the economy more efficient in its use of energy."[8] The Government of India has focused on lowering the energy intensity of GDP growth through greater efficiency with the result being that "the energy intensity of India's growth has been falling and is about half of what it used to be in the seventies."[9] But while a reduction in energy intensity could result in as much as 25% less electricity needed per unit of GDP than current levels,[10] most analyses forecast a growth in the overall demand for electricity and required generation capacity at approximately the same rate as the economy.[11]

Figure 1.

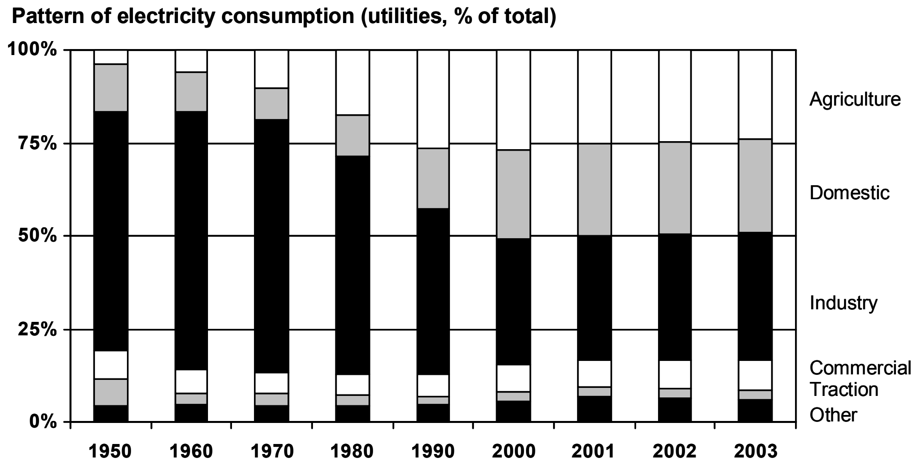


Sector	% GDP	'99-'05 CAGR
Electricity, gas & water supply	2%	6%
Mining & quarrying	3%	13%
Construction	7%	12%
Transports, storage & communication	8%	13%
Financing, insurance, real estate & business services	14%	12%
Community, social & personal services	14%	9%
Manufacturing	16%	11%
Trade, hotels & restaurants	16%	13%
Agriculture, forestry, & fishing	20%	4%

Notes: @ Provisional estimates. * Quick estimates. Source: Government of India, Ministry of Statistics and Programme Implementation. Available at: http://www.mospi.nic.in/31jan06_s3_1.htm

Changes in electricity demand across industrial, domestic, and agricultural sectors may also have implications for the *appropriateness* of supply sources. The shift in the relative consumption of electricity by sector has seen considerable growth in the share of domestic and agricultural sectors along with a significant drop in the share of industrial consumption (see Figure 2). The industrial share of electricity consumption has decreased over the last half-century from a peak of 69% in the 1960s to current levels of roughly 34% of total electricity consumption. Agricultural consumption of electricity steadily increased over the last half-century, from roughly 4% in the 1950s to more than 24% in 2003 and domestic consumption increased from roughly 13% in 1950 to approximately 25% during the same period. Agriculture is increasingly being modernized and the need for water pumping is driving the demand for electricity in the sector. The combined shift in relative electricity consumption from industrial to domestic and agricultural suggests an increased demand for decentralized, distributed generation. While urbanization may counter the decentralization of domestic consumption, with an urban population rising from 28% in 2001 to 48% in 2020,[12] electricity consumption in general could be less decentralized than in India's history due to the share of agricultural consumption and the policy goal of providing electricity to rural populations.

Figure 2.



Sources: Government of India, Ministry of Power.

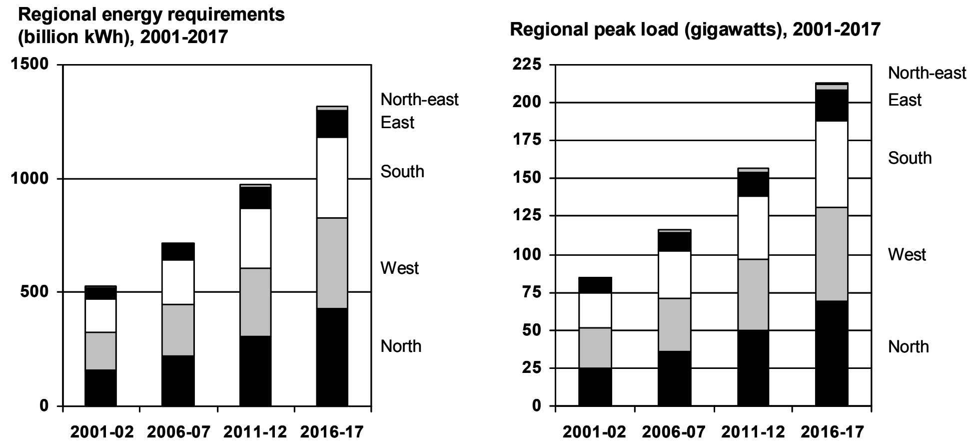
Population growth

The growth in electricity demand is also due to population growth and a policy of improving electricity access to the entire population. Population growth is approximately 1.7 percent per year with the total population "expected to touch 1.9 billion by 2010 and 1.41 million by 2020."[13] Concurrently, the government has the goal of meeting "the lifeline energy needs of all citizens" which necessitates increasing "electricity generation capacity/ supply by 5 to 6 times of their 2003-2004 levels."[14] As of 2000, approximately 57% of rural households and 12% of urban households did not have access to electricity.[15] The policy goal of reaching more of the population with electricity will result in significant increases in consumer demand for electricity and will also make non-grid, decentralized approaches such as renewables energy sources, more appropriate. With a large rural population, even in light of urbanization trends, much of India's population does not live close to transmission and distribution lines.

Geographic distribution

Geographically, electricity demand is concentrated in the North, South, and Western regions of India (see Figure 3). The North-eastern and East regions comprise only approximately 11-12% of the electricity demand of the country, whereas the other three regions each comprise 27-33% of total demand. As such, meeting GDP growth targets will require meeting electricity demand primarily in these areas and determining how best to share energy resources from the North-eastern and Eastern regions which are well endowed with hydropower and coal resources respectively.

Figure 3.

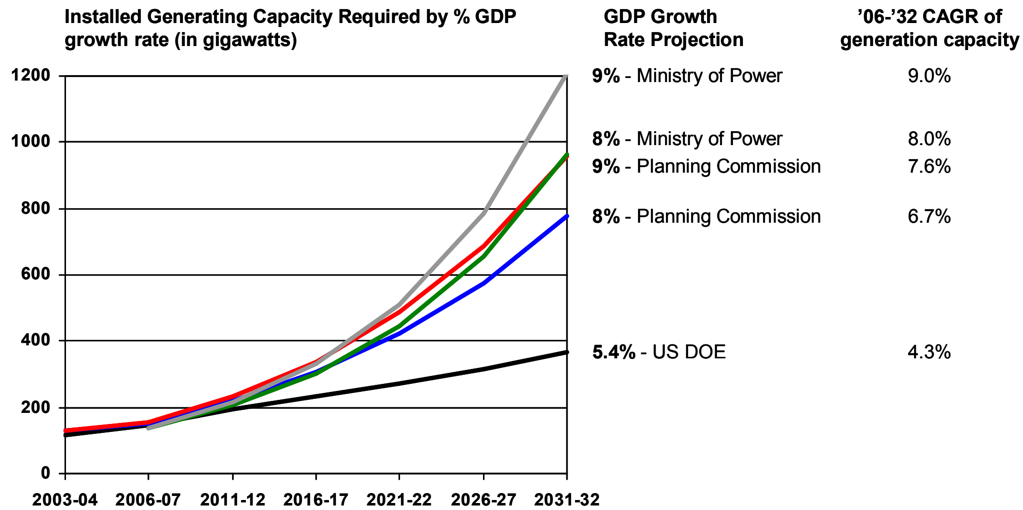


Sources: Kakodkar, Dr. Anil. "Nuclear Power in India: An Inevitable Option for Sustainable Development of a Sixth of Humanity," World Nuclear Association Symposium, 4-6 September 2002, London.

Electricity demand projections

Given strong forecasted GDP growth, population growth, and policy goals of improving access to electricity for the entire population, India's *electricity demand* and corresponding *electricity generation capacity* to meet that demand will grow significantly. On the demand side, whereas India's 2003-04 per capita consumption of electricity was 553 kilowatt hours (kWh), GDP growth of 8-9% would suggest per capita consumption at 2,471 kWh in 2032, a five fold increase over 25 years. Placed in a global context, this per capita consumption would be just over the world average in 2003, at 2,429 kWh per capita, and India's 2031-32 level would constitute only 19% of the American 2003 per capita consumption of 13,006 kWh. On the supply side, to satisfy India's forecasted electricity consumption based on GDP growth rates of 8-9%, the Government of India's Planning Commission projects a need of 306-337 gigawatts of total *generation capacity* by 2016-17 and 778-960 gigawatts by 2031-32 (see Figure 4). With current generation of 127 gigawatts, this means closing a gap of 180-211 gigawatts by 2016-17 and 652-834 gigawatts by 2031-32. We use these GDP growth rate projections of 8-9% as the basis for this chapter's analysis of electricity demand and supply to ensure that any conclusions drawn will also remain valid at lower rates of realized GDP growth.

Figure 4.



Sources: U.S. Department of Energy. *International Energy Outlook, 2006*, Energy Information Administration, Office of Integrated Analysis and Forecasting, Washington, DC, June 2006. Government of India, Planning Commission. *Integrated Energy Policy: Report of the Expert Committee*, New Delhi, August 2006.

(2) What Electricity Supply Options Are Available to India?

Historically and currently, the majority of India's electricity has been supplied by domestic coal. In 2006, coal constituted 54% of total installed capacity, with hydro supplying 26%, gas 11%, renewables 5%, nuclear 3%, and diesel generation 1%.[16] The fastest growing generation source has been natural gas, which increased 16% from 1971-1998, with coal and nuclear growing at 8-9%, hydro growing at 4%, and oil growing at only 1%.[17] Overall, the forecasts to sustain an 8-9% GDP growth rate suggest 6-8% growth in total installed capacity from 2006-2032. The total potential sources for additional electricity generation in India are both vast and diverse. Coal will most likely remain the primary source given its availability and low cost, but India's hydro potential is significant, natural gas is sizable, and both renewables and nuclear are also options.

In considering the different generation options to meet the required growth rates for electricity generation, a number of factors must be considered by government officials and private investors. These include:

i) the total potential capacity of a given supply option;
ii) the relative cost, including upfront investment and ongoing operational costs;
iii) the pace of development, technological innovation, and technical constraints;
iv) the location of supply and efficient distribution to electricity demand centers;
v) environmental issues and costs associated with the supply source; and,
vi) national issues of energy independence.

Each of these factors is prioritized by different stakeholder groups. Investors interested in deciding between particular projects focus on the relative costs to find the highest net present value (NPV) projects for providing electric power to the most stable demand centers. The pace of development, technological innovations required for exploitation, linkages of supply to electricity demand centers, and energy independence are typically focused on by policymakers who have the national interest to consider and must make political and economic trade-offs. Environmental issues tend to be emphasized by those populations disrupted by, or within proximity to, supply sources such as hydro dams, coal plants, or nuclear power plants, although climate change makes carbon emissions a global concern. Proponents of specific supply options often focus on a single criterion to justify support for their preferred generation supply. By looking at these multiple criteria across the range of supply options, this chapter seeks to highlight the relative benefits and the feasibility of developing these generation sources.

In choosing an optimal mix of electricity generation to meet forecasted demand, it is also important to keep in mind the differences between *peak and base load capacity* as well as *centralized and decentralized generation*. Base-load generating capacity is operated throughout a twenty-four hour period to meet minimum loads using mechanically and thermally efficient equipment to reduce operating costs and provide consistent, low cost electricity. Other resources, like natural gas, are reserved primarily for meeting peak loads. Peak and base loads vary throughout a twenty-four hour period and can fluctuate seasonally based on increases or decreases in end user demand.[18]

Centralized versus decentralized generation is also dependent on the characteristics of end user demand. Centralized generation leverages large plants to serve sizable and consistent demand centers, such as cities. Electricity is delivered over transmission lines and distributed to end users, whether industrial, commercial, or domestic. Decentralized generation links smaller demand centers with discrete generating capacity that does not link up to a state, regional, or national grid. Renewables such as mini-hydros are a good example of decentralized generation with the ability to satisfy a cluster of villages' electricity demands or local commercial centers. With current constraints to effective transmission and distribution in India, decentralized generation often offers the only option for certain populations.

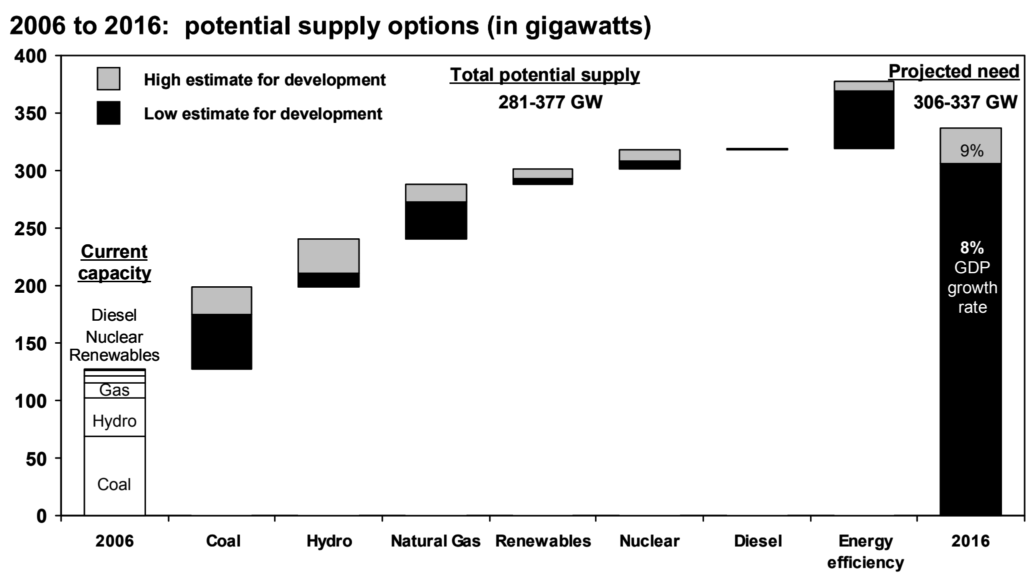
With these issues in mind, we now examine the supply options along the six criteria detailed above to develop an understanding of the likely contribution of each option towards meeting the electricity demand in 2016 and 2032.

i) TOTAL POTENTIAL CAPACITY

Given the forecasted requirements to meet electricity demand in 2016 and 2032, India must build out installed capacity using a range of supply options. The required total installed capacity by 2016 is 306-337 GW (see Figure 5) and the range for 2032 is 778-960 GW (see Figure 6). Various scenarios from the Government of India's Planning Commission and the United States Department of Energy employ ambitious and conservative growth rate estimates for the supply options, both of which are captured in Figures 5 and 6. To meet the targets for 2016 and 2032, at least a few of the options will likely have to meet their maximum potential.

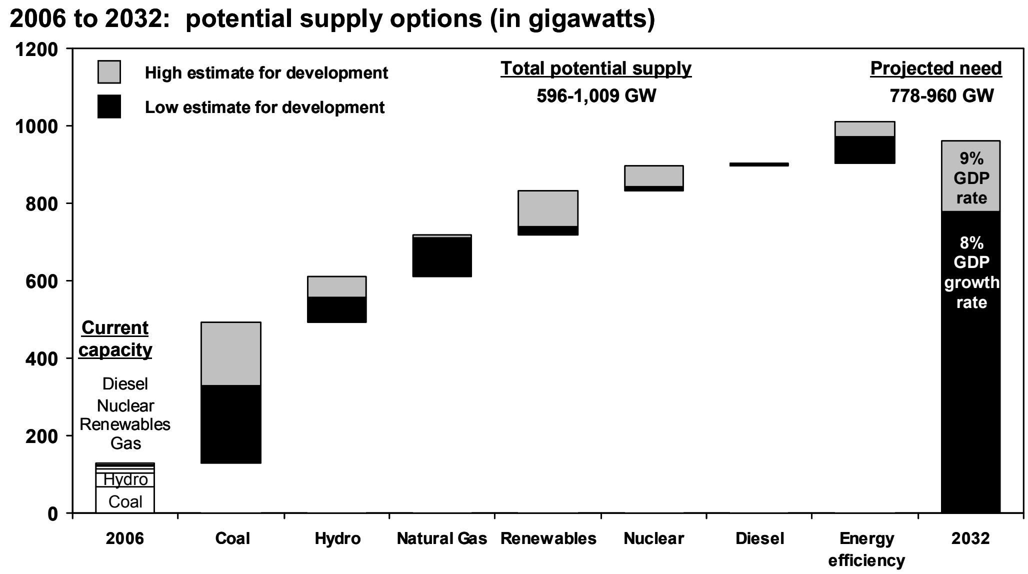
Most likely, it is through a mix of coal, hydro, natural gas, nuclear, renewables, diesel, and energy efficiency improvements that sufficient generation capacity can be developed to meet demand in both 2016 and 2032. While there are trade-offs in the sequence of developing energy resources, nearly all options need further development to meet demand and GDP growth targets and "no single energy resource or technology constitutes a panacea."[19] To extend coal resources past 45 years, and to offset carbon emissions, all other energy sources like hydro, natural gas, nuclear, and renewables need development.[20] However, if exploitation and development of any of these supply sources lags, coal-based generation will likely be the backstop. Significantly, *energy efficiency efforts* offer an opportunity to 'virtually generate' gigawatts in excess of what nuclear could provide in the same timeframe.

Figure 5.



Sources: U.S. Department of Energy. *International Energy Outlook, 2006*, Energy Information Administration, Office of Integrated Analysis and Forecasting, Washington, DC, June 2006. Government of India, Planning Commission. *Integrated Energy Policy: Report of the Expert Committee*, New Delhi, August 2006.

Figure 6.



Sources: U.S. Department of Energy. *International Energy Outlook, 2006*, Energy Information Administration, Office of Integrated Analysis and Forecasting, Washington, DC, June 2006. Government of India, Planning Commission. *Integrated Energy Policy: Report of the Expert Committee*, New Delhi, August 2006.

It is notable that nuclear will constitute a marginal contribution through 2032 and is not critical to meeting the GDP growth targets. If the development of all other options were maximized, it could be possible to meet the generation capacity required for 9% GDP growth with only minimal development of nuclear power. Nuclear's contribution will only become sizable in 2050 and then only if significant technological obstacles are overcome. Even though nuclear is not itself critical to meet the electricity demand projections for 8-9% GDP growth, full development at a later stage would probably warrant some level of development as would a prudent energy supply strategy based on diversification to mitigate risk.

The total potential capacity of each supply option is discussed in detail.

Coal

No matter what other energy sources are available, coal will continue to dominate electricity generation due to its abundance, suitability for base load needs, and relatively low cost. Coal has a variety of energy uses, but in 2006 approximately 78% of coal was used for power generation.[21] The total extractable coal reserves are roughly 22,540 million tons of oil equivalent (Mtoe). The current utilization of coal supply sources is approximately 184 Mtoe, and the range of utilization of coal in 2032 is expected to between 573 and 1,082 Mtoe.[22] Given current production rates and barring technological advancements, the extractable reserves could last 80 years and if "all inferred reserves also materialize then coal and lignite can last for over 140 years at the current rate of extraction."[23] Other estimates suggest that at current consumption and production rates India's coal could last as many as 200 years.[24] But with a moderate projected growth rate of

5% in domestic production, currently extractable coal resources may be exhausted in approximately 45 years. The extent of extractable coal reserves may rise in the future, however, since only about 45% of the potential coal bearing area has been covered by regional surveys."[25] Given the abundance of Indian coal, all estimates and projections for future installed generation capacity suggest coal will remain the major supply for electricity generation until 2032 and possibly beyond.[26]

Hydro

India has a significant large-scale hydro power potential of roughly 150 gigawatts.[27] Only about 33 gigawatts have been installed as of 2006,[28] leaving 117 gigawatts available, of which roughly 5-8% is currently being developed.[29] While hydro comprises a significant percentage of current generation capacity, approximately 26% of 127 total gigawatts generated, full exploitation of the resource by 2032 would reduce the contribution of hydro to the total installed capacity to 16-19% of 776-960 total gigawatts. India could further expand its hydropower generated electricity by importing from neighboring Nepal or Bhutan, "whose combined economically feasible potentials is estimated to be in excess of 55,000 MW."[30] Given the absolute size of the hydropower potential, and its benefits, it will remain a significant contributor to India's electricity generation and seen as particularly useful given its flexibility and suitability to meet peak demand.[31]

Natural gas

India has limited, but considerable, natural gas reserves and currently generates 11% of total current electricity from gas. To date, 90% of natural gas demand has been met by domestic sources[32] and discoveries of 700 bcm over the last decade "hold promise for gas reserves in India,"[33] such as the discoveries in the Krishna-Godavari basin which "have added to the gas reserves substantially."[34] Gas reserves have grown from 62 bcm to 1100 bcm from 1970 to 2006 and production has risen from 1.4 bcm to 32.2 bcm in the same period. With a total need of 100-197 Mtoe of natural gas for the various scenarios laid out by the Planning Commission, India could require imports ranging from 0-49% of its total natural gas demand by 2032.[35] But in all the scenarios developed out by the Planning Commission, even when "pushed for power generation, only 16% of the power generated comes from gas."[36] This is true even when the scenario supplements natural gas with coal-bed methane, in-situ gasification of coal, and natural gas imports.

The potential natural gas resource available for power generation is constrained by strong demand from other sectors. Natural gas is used to produce fertilizers and chemicals and cannot be economically substituted for those uses.[37] The Planning Commission has emphasized that "gas should be used for power generation only after it meets the above demand"[38] and suggests that gas be made available "to those end-uses that best extract its economic value… such as fertilizer, petrochemicals, CNG vehicles, and power in that order."[39] With such competition for end-uses, natural gas power generation may be constrained during the time period that coal is readily available, at least through 2032.

Nuclear
India has quite limited domestic uranium resources but vast thorium resources for potential nuclear power generation. The available uranium resources of 61,000 tons can fuel only about 10 gigawatts using Pressurized Heavy Water Reactors.[40] The current estimate of yearly demand for uranium is roughly 475 tons, while production has only reached 300 tons per year.[41] Imports of uranium could potentially come from "stable countries such as Canada and Australia, so interruptions to supplies are unlikely"[42] but with the three stage process of nuclear development planned by the Department of Atomic Energy in India, the hope is to generate 500 GW capacity "based on plutonium bred from indigenously available uranium."[43]

A much greater potential exists if the domestic thorium reserves of 225,000 tons can be used commercially to generate extremely large amounts of electricity.[44] This could constitute a vast source for electricity generation but the technological advancements needed for this to take place prevent nuclear generation from dominating the electricity supply in the 2016 or 2032 timeframes. Full exploitation of India's domestic thorium resources will likely not occur until after 2050. With only 3.9 gigawatts generated by nuclear power in 2006, or approximately 3% of total generating capacity,[45] the most optimistic scenarios for nuclear power generation put its contribution at 20 gigawatts by 2016 and 68 gigawatts by 2032. As such, nuclear generation will likely not exceed 9% of the total generation in 2032. While the potential for nuclear generation is large, tapping this potential is not likely for some time.

Renewables
The potential for renewable energy resources to generate electricity is not insignificant in India, which has already proven itself committed to exploiting these resources. Currently, renewables provide more electricity than nuclear, with 6.2 gigawatts and 5% of the total.[46] While estimates vary, it is generally believed that the total potential includes 45 gigawatts of wind power, 15 gigawatts from small hydro, 19.5-85 gigawatts from biomass power/ cogeneration, and 10 gigawatts from solar.[47] As such, over 90% of the potential has yet to be harnessed. The Planning Commission has recognized the importance of renewable energy resources and has emphasized the importance of building out capacity. However, even achieving ambitious targets for renewables' contribution to the electricity supply, they will only account for only about 5-6% by 2032.[48]

Energy efficiency: virtual resources of "Negawatts"
In addition to the potential of new installed capacity, as discussed above, significant 'virtual resources' also exist to enhance the likelihood that India will meet its ambitious targets for generation capacity to sustain 8-9% GDP growth. These include efforts to improve industrial, end-user, and generation efficiencies as well as reducing system losses. Currently India's Bureau of Energy Efficiency reports that potential efficiency savings in the industrial sector alone amount to 15

gigawatts and another 3-5 gigawatts are possible by making households more efficient.[49] Thermal generation of electricity is also not as efficient as it could be. With current generation efficiencies in India of about 30.5%, experts believe that an increase to 42% could produce significant savings.[50] By moving to 36.5% by 2016, 20-25 gigawatts may be virtually generated and by moving to 42% by 2032, 40-65 gigawatts may be virtually generated.[51] The Indian government understands the need to lower the energy intensity of GDP growth and argues that:

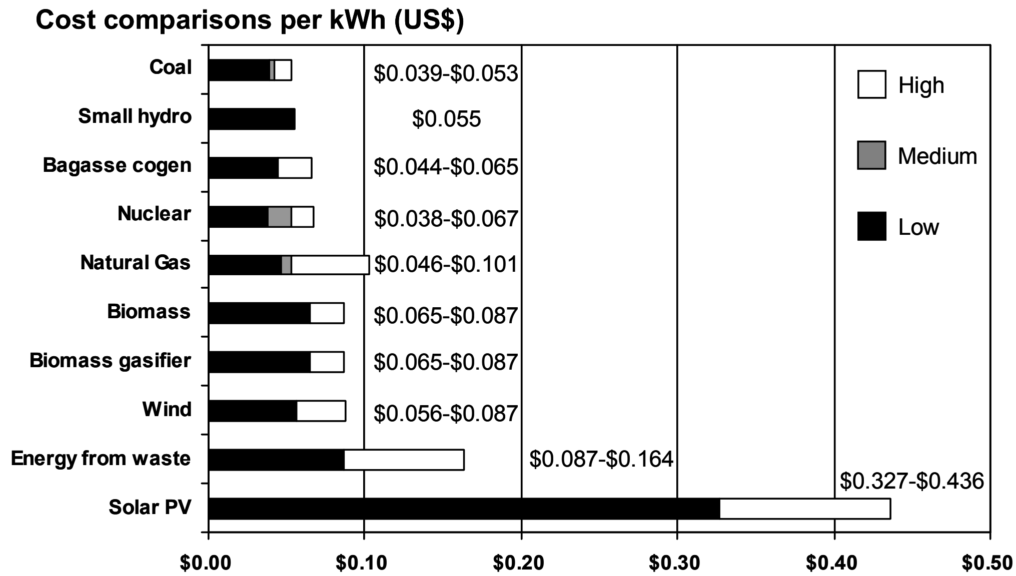
> Lowering energy intensity through higher efficiency is equivalent to creating a virtual source of untapped domestic energy. It may be noted that a unit of energy saved by a user is greater than a unit produced, as it saves on production losses as well as transport, transmission and distribution losses. Thus a 'Negawatt,' produced by a reduction of energy need has more value than a Megawatt generated.… It is possible to reduce India's energy intensity by up to 25% from current levels.[52]

Similarly, India's transmission and distribution system losses are quite high and could be improved. Some experts put current system losses at 20-30%[53] while others, including the Planning Commission highlight that "losses which include theft, non-billing, incorrect billing, inefficiency in collection, and transmission and distribution losses, exceed 40% for the country as a whole."[54] A five percent reduction in such losses could offer 11-15 gigawatt savings by 2016, with an additional five percent between 2016-2032 offering 25-39 gigawatts. A ten percent reduction in each time period could yield 22-30 gigawatts in 2016 and an additional 50-78 gigawatts by 2032. In total, combining energy efficiency efforts and reducing system losses, 49-58 gigawatts could be virtually generated by 2016 and an additional 67-106 gigawatts could be virtually generated by 2032.

ii) Relative Costs

The decision to develop certain energy supplies will most often center on the issue of relative costs. Cost estimates range widely but suggest that coal, nuclear, hydro, and natural gas generated electricity can possibly be produced for roughly the same amount on a per kWh basis, depending on discount rates and the cost of fuel (see Figure 7, which includes both India and U.S. cost benchmarks to show relative costs). Nuclear and hydro options require large upfront investments and so their relative cost depends greatly on the financing available. The International Energy Agency recently calculated that "at current levels,… nuclear power is cheaper than gas and almost as cheap as coal" but one concern is that "new reactors, based on unproven technology, will cost more than expected to build and run."[55] Coal and nuclear also need to take into account environmental externalities, which do not often factor into project cost estimates. For renewables, there are no fuel costs and upfront costs are low in absolute terms. High per kWh costs of renewable sources should not preclude development, as demonstrated by successful business models around the world that pair micro-finance and renewable technologies to provide self-financed, decentralized electricity generation for remote populations. Ultimately, meeting India's sizable demand in 2016 and 2032 will require development of almost all supply options, with very little room for trading one supply alternative completely for another. Even if one option were significantly and continuously cheaper than all others, a risk mitigation strategy would preclude over-reliance on one resource.

Figure 7.



Sources: Energy Information Administration. *Annual Energy Outlook, 2006.* DOE/EIA-0383(2006), Washington, DC, February 2006. Government of India, Planning Commission. *Integrated Energy Policy: Report of the Expert Committee*, New Delhi, August 2006. Victor, David G. "The India Nuclear Deal: Implications for Global Climate Change," Testimony before the U.S. Senate Committee on Energy and Natural Resources, July 18, 2006. Available at: http://www.cfr.org/publication/11123/india_nuclear_deal.html. Notes: For the levelized cost comparison of coal, natural gas (advanced combined cycle), the low estimate for wind, and nuclear, the cost comparison is for U.S. plants that would come online in 2015. The high end nuclear estimate includes the fact that "India is extracting Uranium from extremely low grade ores…. This makes Indian nuclear fuel 2-3 times costlier than international suppliers." Planning Commission, *Integrated Energy Policy*, page 35. For the nuclear generation estimates by David Victor, for Light Water Reactors: the lowest at 3.8 US cents comes from Bharadwaj, Anshu; Rahul Tongia, and V.S. Arunachalam (2006). "Whither Nuclear Power?" *Economic and Political Weekly* 41(12): 1203-1212. The medium cost of 4.2 cents per kWh and 6.7 cents per kWh come from Massachusetts Institute of Technology (2003). *The Future of Nuclear Power: an Interdisciplinary Study*. Using the US DOE's levelized costs and incorporating the fact that Indian fuel is 2-3 times costlier, a cost of 6.6 cents per kWh is estimated.

Coal

The primary use of coal for generation can partly be attributed to the fact that it is one of the cheapest forms of generation. The estimates for the cost per kWh range from 3.9 US cents to 5.3 US cents (see Figure 7). India's abundance of coal makes it particularly inexpensive to exploit, even though the calorific content is only about two-thirds that of imported coal.[56] Coal plant capital costs are typically more expensive than natural gas, but are significantly less expensive than nuclear.[57] Comparative fuel costs are just the opposite, with coal being less expensive than natural gas and more expensive than nuclear.[58] Adding in environmental externalities, or including research and development costs for clean coal technologies, would increase per kWh costs but would unlikely make coal uncompetitive.

Hydro
Despite high upfront investment costs, hydropower offers one of the least expensive sources of power generation. The cost estimates for small hydropower are roughly $0.055 per kWh and large hydro is considerably less. Estimates for the costs of large hydro in the U.S. range from 0.55-0.85 U.S. cents per kWh.[59] Additionally, hydropower has one of the best energy conversion efficiency rates, turning nearly 90% of the available energy into electricity.[60] The large scale upfront investment needed for developing hydro resources often require associated costs of relocating populations and mitigating environmental damage. Additionally, adequate planning to ensure access to demand centers is needed to ensure cost recovery, which often requires significant additional infrastructure investments in transmission and distribution lines.

Natural gas
Natural gas plants have low upfront investment costs, but large fluctuations in fuel prices can make them uncompetitive. Natural gas plants are generally used for peak load generation rather than base load generation "in which case [they] will have to compete against alternative sources of peaking power,… the cheapest alternative which would most likely be a coal-based plant."[61] For the Government of India's Planning Commission scenarios, natural gas was found to not be economically viable when prices were US$4.5 per MMBtu or higher for peaking power when coal remained at or below US$2.27 per MMBtu, or $45 per tonne of imported coal at 6,000 kcal/kg.[62] Energy analysts expect that delivered prices will remain high, probably in the range of $7-$8 per MMBtu.[63] Rising prices of natural gas would only make it increasingly unattractive for use in the power sector.[64] As India's Ministry of Finance commented, "it has not been possible to harness the advantages of gas/LNG as a fuel for power generation effectively, primarily because of its limited availability and lack of price competitiveness vis-à-vis coal. Fuel price, constituting about 60 per cent of the total cost of thermal power generation, is a critical determinant of long-term sustainability of a thermal plant."[65] With natural gas prices likely to remain high, natural gas generation could remain uncompetitive for large scale development.

Nuclear
Nuclear has the potential to be relatively low cost. The cost estimates for nuclear range from 3.8 to 6.7 U.S. cents per kWh. However, India's limited uranium resources come from particularly low grade ore (as low as 0.1% compared to 12-14%)[66] thereby making the cost of fuel for nuclear generation 2-3 times that of international nuclear fuel. Also, due to its capital intensiveness, the cost of nuclear power varies considerably with financing options. Analysis of the levelized cost of electricity from different power plants in India found that nuclear power was cheaper than coal power at a 2% discount rate, roughly equivalent at a 3-4% discount rate, and more expensive at a 5-6% discount rate. At the lower discount rates, nuclear power was no more than 18% less expensive while at the higher discount rates it was more than 30% more expensive than coal. Analysts

have noted that with "multiple demands on capital for infrastructural projects, including for electricity generation, such low discount rates are not realistic."[67]

Nuclear power is even less competitive if externalities and additional costs are taken into account. The methodology used did not include the costs of managing radioactive waste[68] or the cost of reprocessing in India which "would increase the unit cost by roughly one cent."[69] India also lacks "insurance liability against accidents,"[70] the provision of which would increase the per kWh costs, and the high costs of eventual decommissioning of nuclear reactors is often ignored. Finally, India is pursuing unproven nuclear technologies which could increase the cost to both build and run nuclear power plants.[71]

Renewables

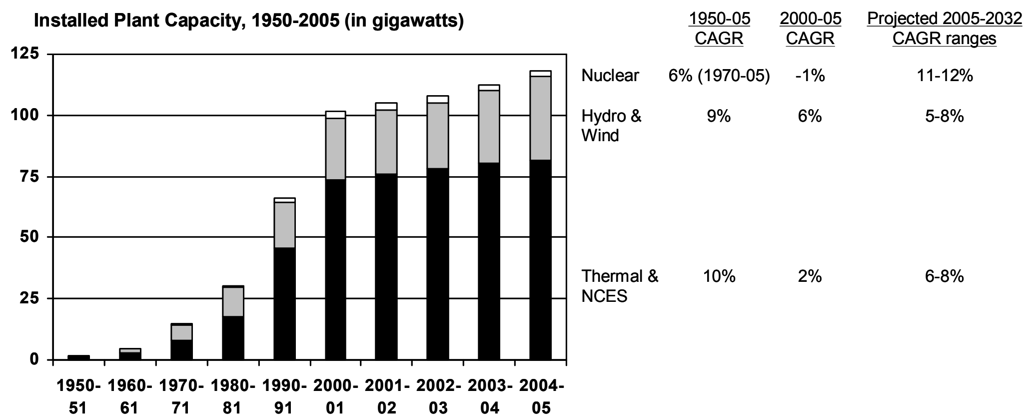
On a per kWh basis, renewable energy remains an expensive source for electricity. Solar power can cost more than $0.30 per kWh and wind power typically starts at the high end of the price range for coal, gas, and nuclear. Some analysts argue and have demonstrated, however, that "new nuclear plants and central coal- or gas-fired power plants are all uncompetitive with various decentralized renewables, combined heat and power installations, and efficient end use of electricity."[72] Whether renewables are cheaper on a per kWh basis or not, the low upfront investment costs make renewables an attractive option for non-grid connected rural populations. Numerous sustainable business models have been demonstrated throughout the world that combine micro-finance and renewable energy technologies, such as Grameen Shakti in Bangladesh. Systems can begin meeting local demand for electricity in a few months for a few thousand dollars, as opposed to the years and millions (or billions) of dollars it requires for traditional plants.

iii) PACE OF DEVELOPMENT AND TECHNOLOGICAL INNOVATION

Nearly all of the electricity supply options face challenges in the pace of development to 2016 and 2032 and require technological innovation for full exploitation. Coal resources must be made cleaner and more fully exploitable economically; hydropower must avoid environmental and social disruptions; full exploitation of nuclear must overcome significant technological challenges; and renewable energy technologies need improvement to increase adoption rates. Historically, India's generation capacity has historically grown by 5.87% each year over the last 25 years.[73] During the same period, improvements in efficiencies have enabled the total supply of electricity to grow at 7.2%.[74] As detailed above for the given scenarios of 8-9% GDP growth, total generation capacity will need to increase 6-7% per annum from 2006-2032 which means the pace of development for most supply options will have to be hastened through technological innovations.

Thermal generation has grown the fastest historically at 10% CAGR (see Figure 8) while nuclear generation has grown the slowest at 6%. One determinant of the pace of development is the extent to which the private sector is involved. The private sector has been a major factor in the development of natural gas capacity, which has increased its contribution to electricity at a 16% growth rate from 1971-1998.[75] In those areas where the private sector participates more, the pace of development can be faster. Where the public sector retains a monopoly, the pace of development will not likely be as fast.

Figure 8.



Sources: Government of India, Ministry of Power. Available at: http://indiabudget.nic.in. "NCES" indicates non-conventional energy sources other than wind. Projected CAGR ranges based on analysis in Figures 7 & 8.

Privatization offers considerable advantages over public sector development of generation capacity. Recognizing this, reform in the Indian energy sector has been emphasized, including a need to bring prices closer to global market levels; ensuring the sector operates on a fiscally sound basis; and increasing private sector participation.[76] Privatization can not only help unlock development but also enable India to maximize its potential gains from efficiency and system loss reduction. For example, the power sector of Delhi was privatized and distribution companies were expected to reduce Aggregate Technical and Commercial (AT&C) losses by 17% over five years. With a sound financial incentive to do so, the companies have exceeded their targets over a three year period with some having reduced losses to 33.79%.[77] Additional improvements include higher quality power with significant reductions in load shedding and full payment being made to central power sector utilities for the electricity purchased and distributed.[78] Of course other factors influence the pace of development for different resource options and the technological innovations needed for full exploitation, and these will be examined in greater detail for coal, hydro, and nuclear.

Coal

Given India's abundance of coal, the pace of development and contribution of coal to the electricity supply has been strong, at approximately 9%.[79] Relatively fewer constraints hinder the development of coal generation and it is acknowledged by the government that to the extent other alternatives do not develop "as projected… coal-based generation will need to fill the gap."[80] In recent years there has been some concern about the production of domestic coal "not keeping pace with the growing demand for coal in the power sector."[81] These production concerns need to be addressed to ensure that domestic coal-based generation can fill the gap if the development of other resources falters in order to meet future demand.[82]

Technological innovation could significantly enhance and extend the timeframe for India's coal resources as well as make it cleaner. In-situ coal gasification "can tap energy from coal reserves that cannot be extracted economically based on available open cast/ underground extraction technologies."[83] While commercial development has not yet occurred,[84] the technology has garnered greater attention worldwide largely due to significant increases in natural gas prices.[85] Such technologies would considerably increase India's extractable coal reserves.

Hydro

Hydro power generation has grown at a rate of 4.2% per annum. Projections suggest that an estimated 45 gigawatts will be added within the next ten years[86] while more conservative estimates suggest 50 gigawatts will be added in the next 20 years.[87] This pace is significantly below the historical growth rate. To maximize the exploitation of the full 150 gigawatts by 2032, hydro power will have to grow at approximately 6% per year. The pace of developing hydropower can often slow due to social and environmental considerations. As highlighted by the Planning Commission, "the need to mitigate environmental and social impact of storage schemes often delays hydro development thereby causing huge cost overruns."[88]

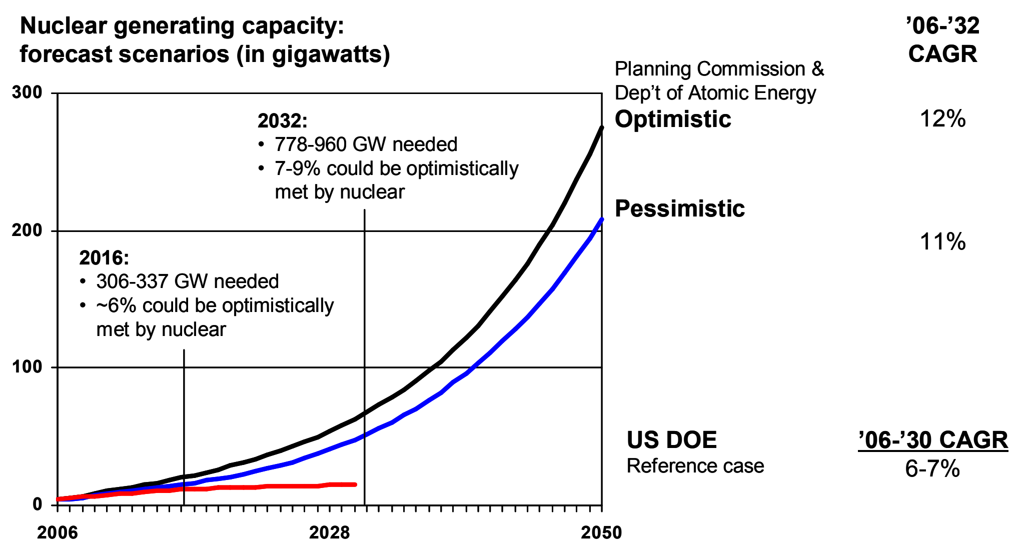
The technologies involved in hydropower generation are generally well developed and new technologies are not required for the full exploitation of the 150 gigawatt potential. However, new 'run of the river' schemes are being developed to reduce the impact of hydropower generation on the environment and local populations. Of the 50 gigawatts planned for the medium term, nearly 62% are run of the river schemes to mitigate potential environmental and social risks.[89]

Nuclear

The historical pace of development of nuclear power in India has been marked by ambitious projections and slow actual development. Twenty-five to thirty year projections made in the 1960s suggested that India would have an installed nuclear capacity of 20-25 gigawatts by 1987 and 43.5 gigawatts by 2000.[90] Instead of meeting these projections, India had only 600 megawatts by 1980, 950 megawatts in 1987, and 2.7 gigawatts in 2000,[91] or roughly 5-8% of the projected capacity. While current projections are extremely ambitious, there is cause for concern that the actual technological development going forward may actually be more difficult than the development thus far, and therefore fall even shorter than expected.

The current Planning Commission projections for installed capacity of nuclear power, predicated on a number of crucial assumptions about technological innovation and development, are 15-20 gigawatts by 2016, 52-68 gigawatts by 2032, and 208-275 gigawatts by 2050 (see Figure 9). The assumptions are threefold. First, Fast Breeder Reactor technology must be successfully demonstrated by the 500 megawatt installation currently being constructed. Second, new uranium mines must be opened and provide fuel for additional Pressurized Heavy Water Reactors. And third, India must import and assimilate Light Water Reactor technology, including nearly 8 gigawatts over the next ten years (in the optimistic scenario), as well as develop Advanced Heavy Water Reactors to use thorium by 2020.[92] The full development of nuclear power in India requires exploitation of its vast thorium resources and therefore requires significant technological advancement to commercialize thorium-based production. Nuclear power in India requires "robust technologies… for both the front end and back end of the fuel cycle" and until thorium-based generation becomes commercialized "the nuclear energy programme will be uranium based"[93] and significantly constrained.

Figure 9.



Sources: Energy Information Administration. Annual Energy Outlook, 2006. DOE/EIA-0383(2006), Washington, DC, February 2006. Government of India, Planning Commission. Integrated Energy Policy: Report of the Expert Committee, New Delhi, August 2006. Notes: Percentages of nuclear potential contribution to installed capacity needs based on Planning Commission 8% and 9% GDP growth rates. Both the optimistic and pessimistic scenarios are based on a number of important assumptions: "These estimates assume that the FBR technology is successfully demonstrated by the 500 MW PFBR currently under construction, new Uranium mines are opened for providing fuel for setting up additional PHWRs, India succeeds in assimilating the LWR technology through import and develops the Advanced Heavy Water Reactor for utilising Thorium by 2020." For the optimistic scenario, "it is assumed that India will be able to import 8,000 MW of Light Water Reactors with fuel over the next ten years."

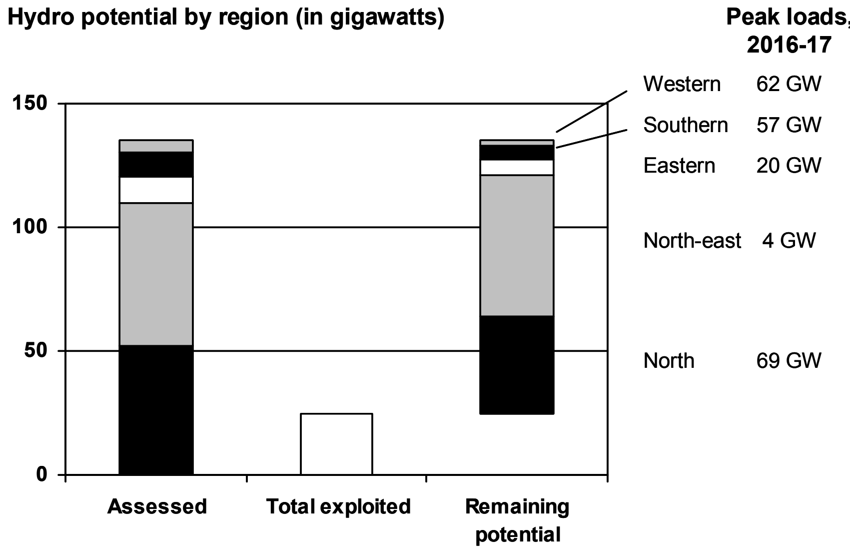
This list of assumptions is considerable, and analysts argue that chances of achieving the targets are slim.[94] One major criticism is the focus on Fast Breeder technology which, some argue, has proven "unreliable in most countries that have experimented with it."[95] Given the technological hurdles, the growth rate may be slower, rather than faster, than historical trends. From 1950 to today, nuclear power capacity increased at a rate of 6%[96], from 1980 to 2000 it increased at 8% per annum,[97] and in recent years growth has slowed considerably. Despite this, current projections require a growth rate of 11-12% from 2006 to 2032. Although there have been some indications that nuclear development has improved recently, such as the 540 MW PHWR unit at Tarapur that went critical 8 months ahead of schedule,[98] it remains unlikely that development will significantly outpace historical rates and achieve the targets. Furthermore, even if these ambitious targets are met, nuclear power will still provide only 6-7% of India's capacity in 2016 and 8-9% in 2032. Only by 2050 will nuclear represent a significant portion of India's total installed capacity, at potentially 20%.[99]

iv) LOCATION OF SUPPLY AND DEMAND

In addition to the issues previously highlighted, a range of electricity supply options should be pursued due to the locations of supply and demand. The largest demand centers are in the North, South, and West (see Figure 3). The Northeast and East have the potential to be electricity exporters, if the Northeast fully exploits its considerable remaining hydropower potential and the East continues to supply coal throughout India (see Appendix C). The demand in the North can be increasingly supplied by its available hydropower and the South and West have the ability to economically import coal after domestic reserves decline. Renewables and nuclear can contribute throughout the country, with renewables focused on decentralized demand centers and rural areas.

Integral to matching supply with demand throughout the country is greater investment and attention to improving and extending the transmission grid. Five strong regional grids currently exist and an envisioned 'National Grid' seeks to increase inter-regional transmission capacity "from its present 9.450 MW to about 37.150 MW by 2012."[100] As in distribution and generation, private sector participation is increasingly being encouraged, with the Ministry of Power finalizing policy guidelines for private investment.[101] This will help enable the country to benefit uniformly from the electricity supply options available. In the case of coal, reserves are concentrated in certain areas of the country[102] and while there are thermal power plants throughout India (see Appendix B), the majority of the coal supply originates in the East. India recognizes the need to improve the inter-state and intra-state transmission system to ensure more equitable sharing of resources like domestic coal and prevent high transportation costs. Similarly, matching the supply of hydropower to demand centers will require better transmission to ensure economical development of the potential. As seen with the case of the Northeast region, significant remaining potential exists far in excess of that regions future peak demands (see Figure 10).

Figure 10.



Sources: Government of India, Ministry of Power. Available at: http://powermin.nic.in/generation/accelerating_developement.htm

Improving distribution also presents a key challenge for meeting demand. Although 70% of India's population lives in rural areas, they use just 13% of power from the grid.[103] Nation-wide, only 55% of Indian households have grid connections. One solution to this issue is to approach the issue through decentralized generation, which highlights the importance of renewable energy resource generation. The distributed nature of renewable energy technologies enables widespread electrification of even remote and rural areas. While many of the technologies requires specific environmental and geographical conditions for optimal efficiency, renewables generally can provide supply closer to demand in areas far from the grid. By producing electricity "by distributed generation [it] flows shorter distances to consumers,… [and] is cheaper than relying on a vast transmission and distribution network."[104] Given the policy initiatives to provide electricity to rural populations, and the greater relative consumption of electricity by decentralized domestic and agricultural end-users (see Figure 2), decentralized generation options are increasingly important.

The supply of natural gas is of particular concern to both India and to the United States. Although most of India's current gas needs have been met from domestic sources, "India has… been energetic in seeking out long-term gas deals"[105] with countries including Iran, Qatar, Australia, Malaysia, Oman, and Turkmenistan. Cross-border gas pipelines originating from some of these countries, such as Iran, would introduce political obstacles and potential vulnerabilities as the pipe would transit through Pakistan.[106] Bangladesh has also been a focus of Indian efforts to obtain gas supplies but these efforts have not "materialized, partly because of political pressures in Bangladesh."[107] Some analysts argue that the potential solution is liquefied natural gas (LNG) in lieu of cross-border pipelines,[108] but it is acknowledged that "considerable technological progress… has to be made in terms of extraction, transportation, and delivery of LNG."[109] While vast gas reserves exist in Iran, the best technology for LNG remains in the United States and Great Britain.

In terms of nuclear, power plants are technically not constrained by the location of any fuel resource. Nuclear power plants "can be built close to populations they serve, without risk of interrupted supply of fuel."[110] However, they are generally better positioned to serve higher population densities rather than decentralized communities. As some experts argue, "installing a centralized nuclear reactor or thermal plant and extending the grid to cover distant villages is an inefficient way of providing lighting to the primarily rural societies that characterizes India…. Such communities are better served by distributed renewable energy systems based on a number of different technologies and sources – micro hydel plants, windmills, photovoltaics, and biomass based power."[111] As such, efficient development of nuclear power generating capacity may require alignment with concentrated demand centers rather than rural electrification and distributed demand like agriculture.

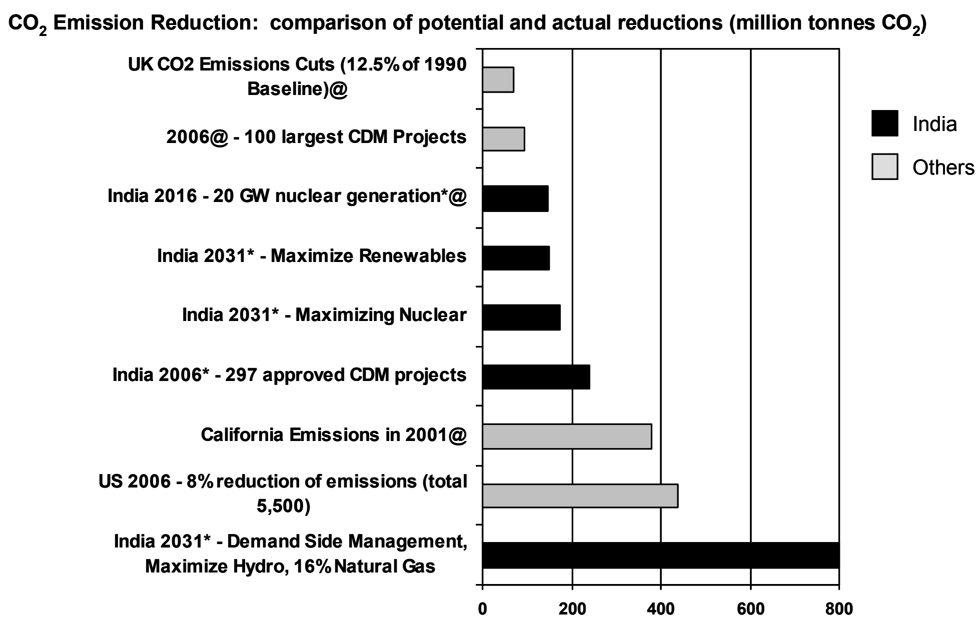
v) ENVIRONMENTAL CONSIDERATIONS

With increasing concern about climate change, environmental considerations have become integral to discussions of energy and electricity generation in India. As emphasized by William Rosenberg of Harvard University, "an energy policy is also an environmental policy is also an economic policy. They are not separate policies."[112] As such, strategies to reduce carbon emissions from fossil fuel generation, or replace fossil fuel generation with zero-emission generation, have been highlighted as desirable policy goals. To make prudent tradeoffs, the scope and potential impact of the alternatives needs to be examined. In light of the U.S.-India Civil Nuclear Cooperation Initiative, the focus of this analysis will be on coal and nuclear and the likelihood that nuclear would substitute for coal-based generation.

Coal produces the majority of carbon dioxide emissions in India, comprising 68% of the total in 1990 and 65% in 2003. With electricity generation the major consumer of coal,[113] the environmental impact of coal-based electricity is a serious concern. The dominant role that coal plays in all projections of electricity generation at least until 2032 suggest a strong need to mitigate the risks to climate change by pursuing clean coal technologies. The Planning Commission acknowledges this and highlights the need for research and development of clean coal technologies for "improving the efficiency of energy conversion and limiting emissions."[114] In-situ gasification is especially beneficial to the environment by eliminating the issues of "overburden removal and ash disposal faced by conventional coal mining" as well as enabling sequestration in the mine or "pump[ing] back in oil or gas fields to enhance oil or gas recovery."[115] These techniques could enhance the clean exploitation of coal resources and extend the exploitation of this domestic resource.

Efforts to reduce coal-based carbon emissions are exceedingly important, but contributions should be put into global and historical perspective. India's coal-based carbon dioxide emissions were 22% of the United States' coal-based carbon dioxide emissions in 1990 and 32% in 2003. Whereas the U.S. produced 7.2 metric tons of coal-based carbon dioxide emissions per capita, India produced 0.62. In absolute terms, the United States produced 2,100 million metric tons of carbon dioxide emissions from coal in 2003 compared to India's 666 million metric tons. Using the U.S. Department of Energy's reference case for projecting coal-based carbon dioxide emissions, India could produce 1,372 million metric tons of coal-based emissions in 2030, which is approximately 65% of what the United States produced in 2003. On a per capita basis, India's 2030 projected coal-based carbon emissions is just 0.95 metric tons, or just 13% of what the U.S. produced on a per capita basis in 2003.[116] As Michael Levi and Charles Ferguson of the Council on Foreign Relations point out "absent much broader efforts on that front… modest reductions in Indian emissions will have little effect."[117]

Figure 11.

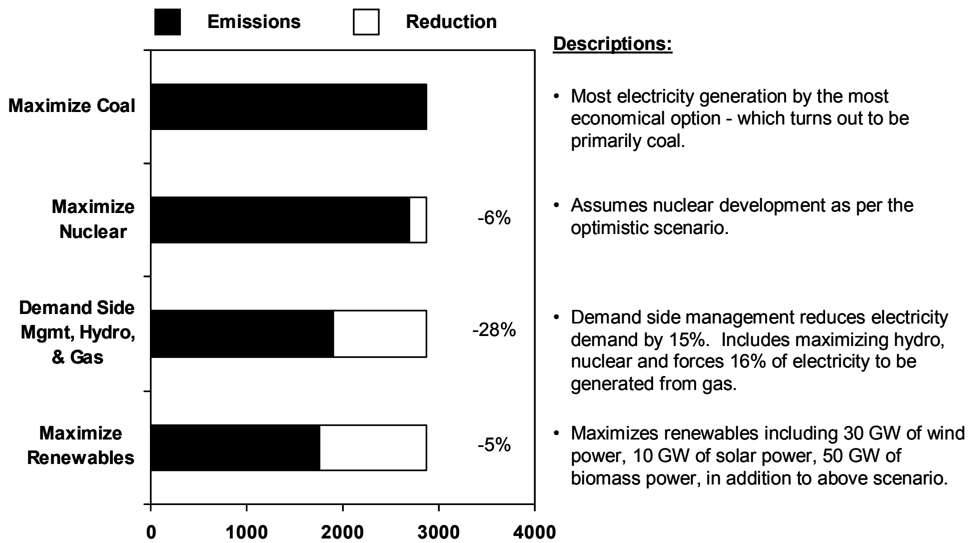


Sources:
"Government of India, Planning Commission. *Integrated Energy Policy: Report of the Expert Committee*, New Delhi, August 2006. Dalberg analysis of incremental reductions across 2031/32 scenarios. @ Victor, David G. "The India Nuclear Deal: Implications for Global Climate Change," Testimony before the U.S. Senate Committee on Energy and Natural Resources, July 18, 2006. Available at: http://www.cfr.org/publication/11123/india_nuclear_deal.html.
Notes: Emissions are visual approximations of the contributions from electricity as depicted in the graph on page 50 of the Integrated Energy Policy report. India's 297 approved CDM projects from the Integrated Energy Policy, page xxix. India's 20 GW nuclear generation substitution effect on emissions based on David Victor's data and compared to the optimistic scenario of hitting 20 GW, which is 2016.

Examining India's options for carbon emission reduction in relative terms helps to contextualize the possible gains (see Figure 11). The estimates of carbon off-set for nuclear's substitution ranges from 145 million tons of carbon emissions by developing 20 GW[118] of nuclear generation capacity to a more conservative total of 175 million tons for 68 GW by 2032.[119] The Planning Commission analyses suggest nuclear alone would reduce emissions from a coal-dominant scenario by only 6%. By comparison, demand side management, maximizing hydro, and natural gas generation would reduce emissions by as much as 800 million tons,[120] constituting an additional 28% reduction from a coal-dominant scenario (see Figure 12). Given the technological limitations of the development of nuclear, and the dominance of coal at least through 2032, "burning coal more cheaply and more cleanly would do more for India's economy and the environment than would expanding the country's nuclear power capacity."[121]

Figure 12.

CO_2 Emissions: scenarios for reductions from electricity generation, 2031-32 (million tonnes) with incremental % reduction from previous scenario



Sources: Dalberg analysis. Government of India, Planning Commission. *Integrated Energy Policy: Report of the Expert Committee*, New Delhi, August 2006. Notes: Emissions are visual approximations of the contributions from electricity as depicted in the graph on page 50 of the *Integrated Energy Policy* report.

Nuclear power's substitution effect with carbon emitting generation options can be minimal and nuclear is not without its own unique environmental concerns. For some countries an increase in nuclear generation did not occur commensurate with a decrease in carbon emissions. In the case of Japan, nuclear generation capacity increased by 40 gigawatts from 1965 to 1995 and carbon emissions rose from 400 to 1,200 million tonnes at the same time.[122] For a country like India which ambitiously seeks an increase in electricity consumption to 2,741 kWh per capita by 2032, it may not be an 'either-or' scenario. The coal resource offers economical and technologically accessible electricity generation that will not be directly substituted. And to the extent that any of the other options fail to meet their growth targets, coal-based generation will likely fill the gap. With regard to other environmental considerations, nuclear reactors "produce a lot of highly radioactive waste… for which safe storage for the tens of thousands of years required for it to become harmless is yet to be found."[123] While disposal can be done in a safe and effective manner, the environmental concerns are not insignificant.

vi) ENERGY INDEPENDENCE

The issue of energy independence is particularly important for the Government of India, which seeks to limit international supply risks by leveraging domestic resources to the greatest extent possible. Although understandable and a theoretically worthwhile goal, some would argue that a strict focus on energy independence is unattainable; would actually drive prices up; and disrupt market access needed for efficiently meeting energy demands. Despite these arguments against a strict focus on energy independence, it is interesting to evaluate the best option for attaining this goal. Through 2016 and 2032, energy independence is most reinforced through coal-based generation and by fully exploiting the hydropower potential. Only in the very long term does nuclear energy hold the promise to provide energy security and independence which,[124] as described above, requires significant technological advancements in thorium-based production and will not occur before 2050.

Abundant coal resources provide a degree of energy independence in the near and medium terms, but exhaustion of these resources will require increasing reliance on coal imports or other forms of energy. The degree to which India will rely on coal imports in the future will depend on the extent to which it can develop hydropower, natural gas, nuclear, and renewable alternatives as well as initiate demand side management and energy efficiency efforts. The coal-dominant energy scenario developed by the Planning Commission suggests as much as 45% of the coal required to be imported in 2032 with 8% GDP growth while the least coal dependent scenario suggests 11% could come from imports.[125] The cost of imported coal remains economically competitive for power generation in certain areas of India due to the low calorific value of domestic coal. With domestic coal having a calorific value of 3,500 kcal/kg versus 6,000 kcal/kg for imported coal, the cost of imported coal transported under 500 kilometers is cheaper than domestic coal transported greater than 1,400 kilometers.[126] As such, the exhaustion of coal resources could reduce the energy independence of the country but only in the long term and only if technological innovations do not occur to prolong the life of the resource.

Full exploitation of domestic hydropower would contribute meaningfully to a policy of energy independence. When fully exploited, hydropower could comprise 16-19% of total generation capacity by 2032. Maximizing the hydro potential some regions well endowed with the resource could offset the use of other resources, like coal, and extend its availability to areas less well endowed with hydro. Once domestic resources have been fully tapped, potential also exists to import some of the 55 gigawatts of hydropower from neighboring Nepal and

Bhutan.[127] While importing hydro could degrade the degree of energy independence somewhat, India's neighbors offer less political instability than some of India's options for natural gas.

The contribution of natural gas to energy independence will depend greatly on the extent and continuation of domestic reserves. As the Planning Commission's scenarios project, imports of natural gas could range from 0-49% of total demand for the resource in 2016-2032. Although many neighboring countries have large resources of natural gas, such as Iran, Turkmenistan, Bangladesh and Myanmar, the option to utilize cross-border pipelines create concerns about energy security[128] where India "may face potential supply disruption if political issues emerge."[129]

Finally, while nuclear has been emphasized as a key to India's energy independence, this is not likely to happen before 2050. If thorium-based production technologies are not found, India would become dependent on uranium imports to fuel its nuclear power plants. Increasing the installed nuclear capacity under this scenario would significantly impinge on India's energy independence. The uranium shortage has already forced India "to operate even the small nuclear generation capacity that we have at a load factor below what is technically possible."[130] The promise of energy independence based on nuclear power, then, is predicated on successful development of thorium-based production and will not take place until well beyond 2050.

Conclusions

It has been argued that the recent U.S.-India Civil Nuclear Cooperation Initiative makes considerable sense from an economic and resource perspective. Among these arguments are the assertions that: it will make India less reliant on unstable sources of oil and gas; that India requires nuclear energy to meet its GDP growth targets; and nuclear energy can significantly improve the environment and enhance energy independence. Strategic and geopolitical justifications notwithstanding, the economic and resource arguments are overstated. In this analysis, we have sought to assess the central question of whether nuclear energy will meet India's future energy needs by analyzing the demand for electricity and evaluating each supply option's: i) total potential capacity; ii) relative costs; iii) the pace of development, technological innovations, and technical constraints; iv) locations of supply and efficient distribution to electricity demand centers; v) environmental considerations; and vi) impacts on energy independence.

In the final assessment this report finds that nuclear energy will not likely reduce India's dependence on oil and gas, will play a marginal role in sustaining economic growth through 2032, and is either not the most significant option for reducing greenhouse gas emissions or is unlikely to reduce such emissions. In terms of lessening India's dependence on imported fossil fuels, nuclear energy does not fulfill the same end uses as the majority of imports of foreign fossil fuels and therefore will not substitute for them. As Dr. Ashton Carter of Harvard University succinctly underscored:

> Nuclear power can play a part in helping India address these problems, but it will not make a critical difference. Electricity in India will be mostly produced by coal-burning power plants for the foreseeable future; even under the most extravagant projections, nuclear plants will provide less than ten percent of India's electricity…. [As such, nuclear power] can do little to slake the thirst of the principal consuming sector in India – transportation – because cars and trucks do not run off the electrical grid and will not for a long time.[131]

Michael Levi and Charles Ferguson of the Council on Foreign Relations reinforce this point by highlighting that "most Indian oil is used by cars and trucks, not by power plants, so nuclear power will not significantly change the demand for oil."[132]

In terms of the electricity supply, estimates generally agree that India will remain primarily dependent on domestic coal and hydropower, providing roughly 60-80% of electricity through 2032. In the most optimistic scenarios, natural gas generation could reach 16% and nuclear energy could constitute 9% of generation capacity by 2032. But if the development of hydro, natural gas, or nuclear generation is delayed, coal-based generation will fill the gap. In general, India has considerable domestic resources – in the form of coal, hydro, efficiency improvements, and renewables – to meet demand for the next 10-25 years and most likely the next 45 years. The electricity demands of economic growth can be met with India's diverse and vast resource base, of which nuclear will remain a marginal contributor at least through 2050.

In terms of energy independence and environmental improvements, coal also dominates the scenarios through 2032. Although domestic coal could be exhausted in 45 years if additional technologies or reserves are not found, imported coal can be economical for a significant portion of India and technological improvements could extend the coal resource base and significantly enhance energy independence. Since India lacks sufficient domestic sources of uranium, an increase in nuclear generation would result in greater dependence on imports of ore and technology until India's abundant domestic resources of thorium can be commercialized for significant production of electricity, which is not likely until after 2050. In terms of environmental improvements, the development of nuclear generation has not necessarily led to a reduction in greenhouse gases and the dominance of coal in the energy mix well through 2050 means that clean-coal technologies, hydro power, demand side management, and renewables could do more to reduce carbon dioxide emissions than nuclear generation.

In sum, the economic and resource arguments for the U.S.-India Civil Cooperation Initiative are overstated. Nuclear energy will not significantly reduce India's reliance on foreign fossil fuels, is not vital to sustain India's economic growth through 2032, and does not necessarily provide the best option for environmental improvements and energy independence.

APPENDIX A: KEY FINDINGS BY CRITERION

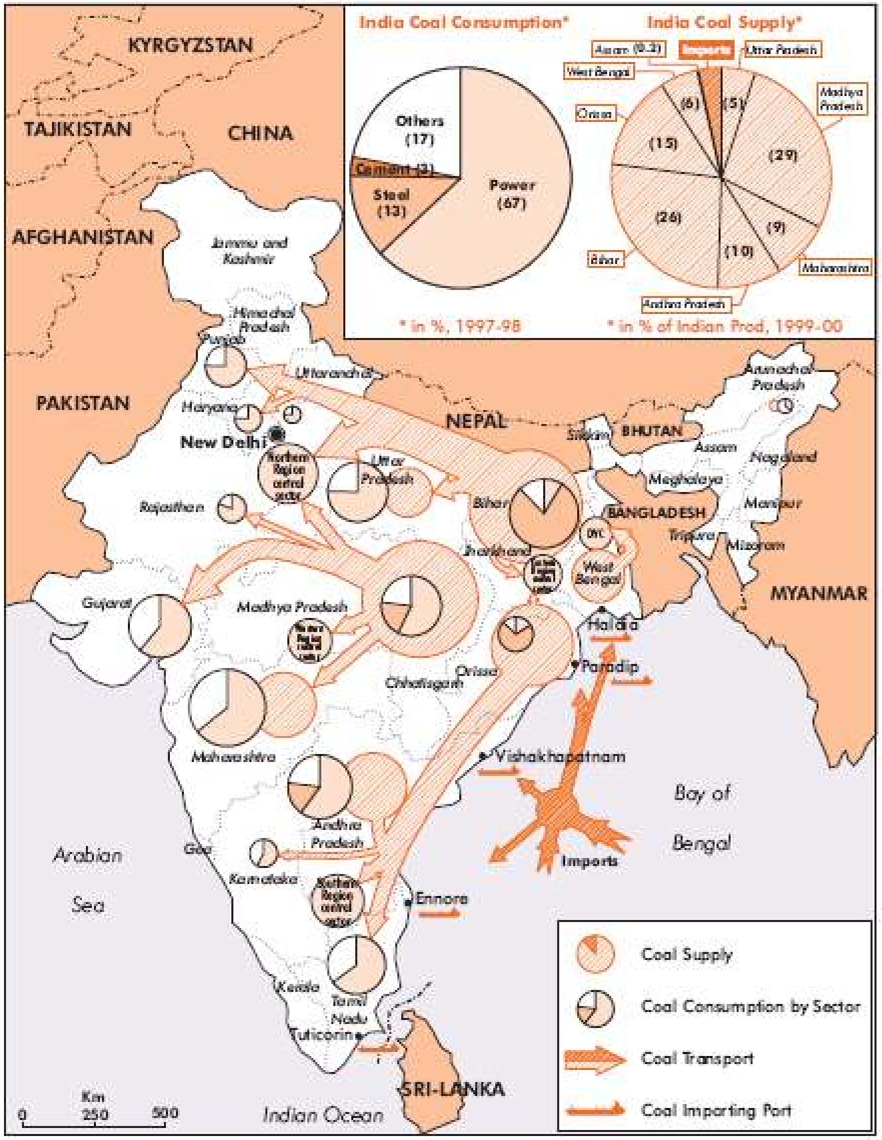
Criterion	Key findings
Total potential capacity	• Coal will contribute the majority of electricity for the next 45+ years • Hydropower remains significant, at ~16-20% of 2032 demand • Nuclear potential optimistically contributes only 8-9% by 2032
Relative costs	• Relative costs may impact the sequence of development, but all supply options are necessary to some degree to meet future demand • Hydropower is currently among the cheapest, coal and nuclear are potentially equivalent, depending on discount rate, natural gas is potentially expensive if fuel prices remain high and renewables remain expensive per kWh but small installation costs make them accessible for rural populations
Pace of development, technological innovation, and technical constraints	• Nuclear has historically fallen short of projections and current estimates employ many assumptions • Optimistic nuclear projections require overcoming significant technological hurdles (e.g. commercializing thorium) • Hydropower is often hindered by social pressures and current plans are slower than historical rates of development through 2016 • Clean use of coal and extending life of coal resources requires significant technological hurdles (e.g. in-situ gasification), but exploitation for next 45 years does not • Significant technological hurdles are needed to make renewables cheaper on a per kWh basis
Locations of supply and linkages to demand	• Hydropower potential remains primarily in those areas where importation of coal would not be economically competitive • Transmission and distribution network improvements are vital • Decentralized generation can help meet the policy goals of increasing electricity access among rural populations
Environmental considerations	• Demand side management, improving coal efficiency, and full exploitation of renewables contributes more to CO2 reductions than optimistic nuclear projections • Unlikely that nuclear would substitute for coal-based generation
Energy independence	• Extending coal resources reinforces independence the most • Hydropower contributes meaningfully to independence until fully exploited • Uranium-based nuclear power makes India dependent due to limited domestic resources • Nuclear contributes meaningfully to energy independence only after thorium generation is realized and ramped up, probably after 2050

APPENDIX B: MAIN POWER PLANTS IN INDIA

Source: TERI, 2000.

Source: International Energy Agency. *Electricity in India: Providing Power for the Millions*, OECD/IEA, Paris, 2002.

APPENDIX C: COAL PRODUCTION, USE AND IMPORTS



Sources: IEA analysis.

Source: International Energy Agency. *Electricity in India: Providing Power for the Millions*, OECD/IEA, Paris, 2002.

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John Stephenson is a Consultant in Dalberg's Washington DC office. He has consulted to the senior management teams of leading multinational corporations, multilateral organizations, and international financial institutions on strategy, organizational effectiveness, stakeholder & change management, and development policy. He has experience in several development sectors, including energy, post-conflict reconstruction, private sector development, and governance & public sector reform. Some of his most recent engagements include assisting the East African Community to formulate an energy access scale-up strategy to support attainment of the Millennium Development goals and evaluating an organizational effectiveness pilot for a multilateral development agency.

Prior to joining Dalberg, John was a Junior Professional Associate at the World Bank where he participated in the formulation of the Bank's first Country Assistance Strategy for the Democratic Republic of Congo. John holds a Master's degree in International Security from Georgetown University's School of Foreign Service and a Bachelor's degree *magna cum laude* in Government and East Asian Studies from Harvard University.

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Peter Tynan is a Manager in Dalberg's Washington DC office. Peter's focus has been advising multilateral development institutions and corporations on private sector development, emerging markets strategy, as well as investor groups on international investments. For example, he worked for the Inter-American Development Bank to analyze Indian economic growth, a Fortune 50 company to analyze the international NGO community, and for a private investor group to develop a medical project in the Bahamas.

Prior to joining Dalberg, Peter advised the Minister of Finance in the Democratic Republic of the Congo, where he wrote the private sector revitalization plan and studied the competitiveness of major Congolese industries, and worked for the Minister of Finance in Egypt reorganizing the Egyptian Customs Authority. For the US Government, he advised the CFO of the General Services Administration (GSA) in strategy, strategic planning and organizational reform. He helped lead the reorganization of the GSA, merging the Supply Service and the Technology Service; and designed and managed the strategic planning process used across the Agency.

Peter has also worked for J.P. Morgan in Hong Kong and as an Investment Executive in private equity in Australia, where he sourced and evaluated middle market private equity investments.

Peter holds an MBA from Harvard Business School, a Masters in Public Policy from the Kennedy School of Government at Harvard University and a Bachelor in Business with honors from the University of Technology in Sydney Australia. He is the co-author of *Imagining Australia: Ideas For Our Future* (Allen&Unwin, 2004).

Dalberg Global Development Advisors

Dalberg is a professional services firm specializing in serving international organizations and large corporations in the areas of development and globalization. Dalberg operates from New York, Copenhagen, Geneva, Washington, DC, Johannesburg, and Santiago and serves clients in Africa, Asia, North & South America, and Europe.

The key drivers of Dalberg's success are our staff and network in the field of international development and business. All our consultants have highly targeted backgrounds, combining:

- Top-tier professional training from leading management consultancy firms, such as McKinsey, Bain, and Accenture
- First-hand working experience in the field of international development
- Academic backgrounds in policy, management, and economics from leading institutions such as Harvard, Yale and Oxford

Dalberg's operating model combines several elements which give us a distinct advantage in strategy engagements in the development sector:

- Interactive problem solving approach ideal for the dynamics of real time strategy development
- Structured team-based model creates exponential improvement in quality over individual models
- Skilled research staff who provide a fact based foundation for analysis

Over the past 4 years Dalberg has successfully completed over 100 engagements for leading international organizations and has a keen understanding of the dynamics and priorities of organizations in the sector.

End Notes

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[132] Levi, and Ferguson, page 9.