U.S.-India Nuclear Cooperation Act:

Will this help India meet its energy needs and reduce global warming as the government promises?

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Table of Contents Page

I. Introduction

Background

On October 8, 2008, President Bush signed the "United States-India Nuclear Cooperation Approval and Nonproliferation Enhancement Act." The act allows the transfer of nuclear information, material, equipment (including reactors), and components for research and power production, previously prohibited because India has never signed the Nuclear Non-Proliferation Treaty. The United States had taken a strong stance against any nuclear exchange with India since the latter's nuclear test in 1974, and had encouraged other states to do so.

The Bush administration has made various attempts to relax U. S. law that places stringent limits on nuclear trade with states such as India. On July 18, 2005, President Bush announced his intention to adjust existing U. S. law so that Congress could approve a full nuclear cooperation with India. On December 18, 2006, the Congress waived several provisions of the Atomic Energy Act (AEA), which regulates U. S. nuclear cooperation with foreign states, to allow nuclear transfers to nations outside the International Atomic Energy Agency (IAEA) safeguards. The amendment requires the "President's submission of the finalized text of a cooperation agreement to Congress, the IAEA Board of Governor's approval of an IAEA safeguards agreement, the Nuclear Suppliers' Group's consensus agreement to make an exception for India, and the congressional passage of a joint resolution of approval of the agreement." Once these criteria are met, the amended AEA enables a nuclear cooperation with states such as India. India met with the IAEA five times to work on a safeguards agreement, following an agreement on July 27, 2007 between Washington and New Delhi on the text of nuclear cooperation. Thanks to continuous effort on the part of both governments, the nuclear cooperation bill, known as HR 7081, became law in 2008.[1]

In presenting the bill and upon signing the bill into law, the Bush administration stated four goals this act would achieve:

1. Strengthen the U. S.-India relationship.

2. Promote economic growth in the U. S., by opening the Indian civilian nuclear market to trade with and investment from the United States.

3. Help India meet its growing demand for energy in the most carbon-free manner and contribute to the global environment.

4. Integrate India into the global effort to stop nuclear proliferation.[2]

The majority of Congressional hearings, government statements, and scholastic debates about this bill have focused on the first and last goal. Numerous papers, commentaries, statements, and articles discussed the implications of this bill in the areas of strategy and national security. The environmental benefit of this act, however, has received little attention despite the boldness of the statement. A Congress Research Service report titled “U. S. Nuclear Cooperation with India: Issues for Congress” provides a striking example of this lack of attention and priority given to the environmental goal. The document briefly discusses a paper presented in a Senate hearing and two news articles that expressed skepticism about why expanding nuclear power in

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1 CRS Report for Congress, U.S. Nuclear Cooperation with India: Issues for Congress. July 30, 2008. Kerr, Paul K. http://fpc.state.gov/documents/organization/112522.pdf,

2 Statement by the President on the Occasion of Signing H.R. 7081, http://www.state.gov/p/us/rm/2007/89559.htm

India, as opposed to investing in other ways to meet energy needs, is the best option.[3] The critics of the bill argued that India should instead invest in increasing transmission efficiency, privatizing the energy market, and opening up the energy market to foreign investment. Also, they argued that nuclear power is such a small part of the Indian energy industry that the bill would not make a significant impact on the energy supply in India. In response to such criticism, the CRS document defended the bill by simply saying that it is crucial to the U. S.-India "strategic" relationship and that both governments are strongly committed to passing the agreement.[4]

Research Question and Goal

The purpose of this paper is to examine the government's rationale that nuclear is the most "green" way to meet the growing energy demands in India. The initial questions we began with were "did the U. S. government do enough research to justify the claim that the bill would bring environmental benefits?" and "what kind of statistics, figures, and numbers would support the administration's claim?" Now that we answered no to the first question, our research focused on the second question. The sub-questions included the following:

-What are the current energy demands and expected demands in India?

-What kind of sector provides energy to India and how much?

-How much carbon emission does India have?

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[3] Backing the U.S-India Nuclear Deal and Nonproliferation: What's Required. Testimony by Henry Sokolski. Presented before a Hearing of The Senate Foreign Relations Committee. "The Nonproliferation Implications of the July 18, 2005 U,S,-India Joint Statement." http://www.npec-web. "U. S. Deal is a bad choice for power generation," Chellaney, Brahma. December 27, 2005. http://www.iht.com/articles/2005/12/27/opinion/edchellaney.php

[4] CRS Report for Congress

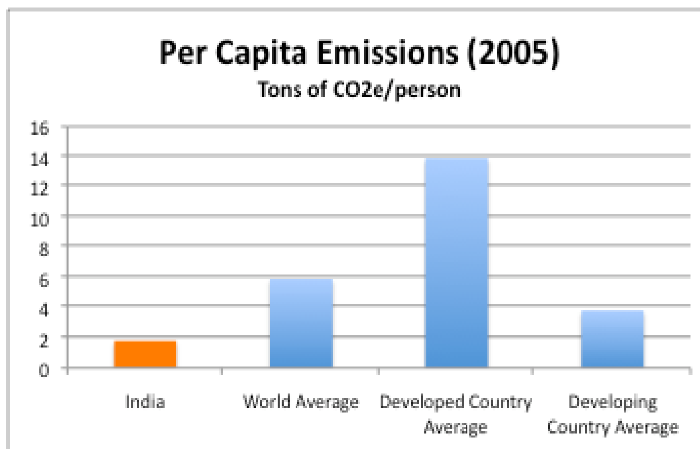
-What is the projected growth in each energy sector in India? What kind of nuclear plants does India currently have and how many more are planned?

-Most importantly, is nuclear power economically more feasible than other types of energy, such as clean coal, solar, wind, and biomass? We approach this question with government subsidy, discount factor, carbon emission, and energy price.

II. Overview of India's Energy Sector and Environmental Issues[5]

Current and Projected Emissions

Given the size of India's economy and its impressive annual GDP growth rate, the country currently emits lower carbon dioxide emissions than expected. India's economy is the fourth largest in the world, in purchasing power parity terms, with the average growth rate of 7% since the early 1990s. India is home to over 1.1 billion people, second only to China, and while manufacturing and services drive the economy (54% of total in 2005), the workforce is primarily concentrated in agriculture (60%).



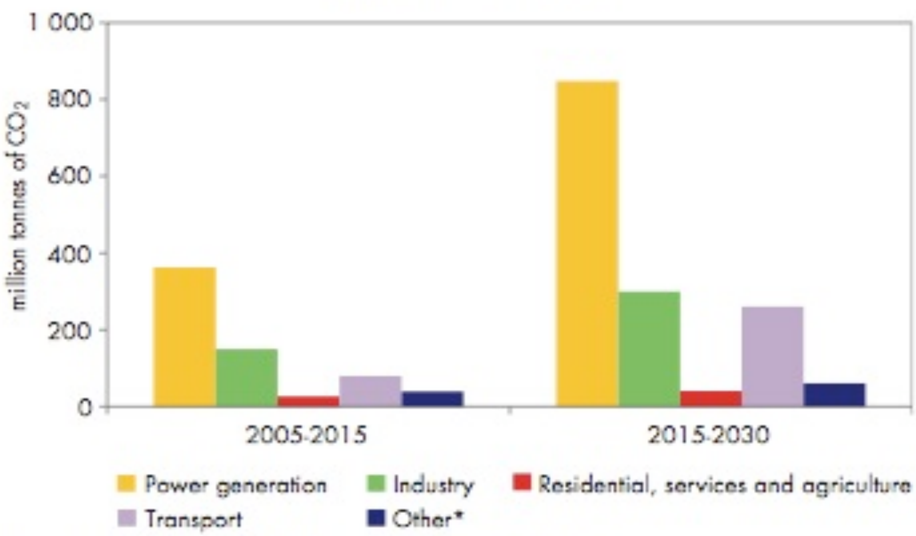
India is currently the fifth largest carbon dioxide emitter in the world, responsible for 1.1Gt of total emissions and 4% of the world total. In per capita terms, however, it is amongst

[5] All figures and graphs sourced from the International Energy Agency's "World Energy Outlook 2007" as well as "Climate Change Mitigation Measures in India" jointly published by the Pew Center for Climate Change and The Energy and Resources Institute in India, September 2008.

the lowest: 70% below the world average and less than 10% of the per capita emissions in OECD countries. If India continues its current growth, it is expected to pass Japan and Russia to become the world's third largest emitter by 2015.

Responsible for 60% of the country's total, the power generation sector is the key driver of carbon dioxide emissions and projected future emissions. Industry and transport are not insignificant, for transport comprise 8% of the India's emissions compared to 24% in the European Union. India's inefficient power stations that release 943 grams of carbon dioxide per kWh of electricity produced, however, cause main emissions problems. This figure is 50% higher than the world average.

Figure 16.12: **Increase in India's CO_2 Emissions by Sector in the Reference Scenario**



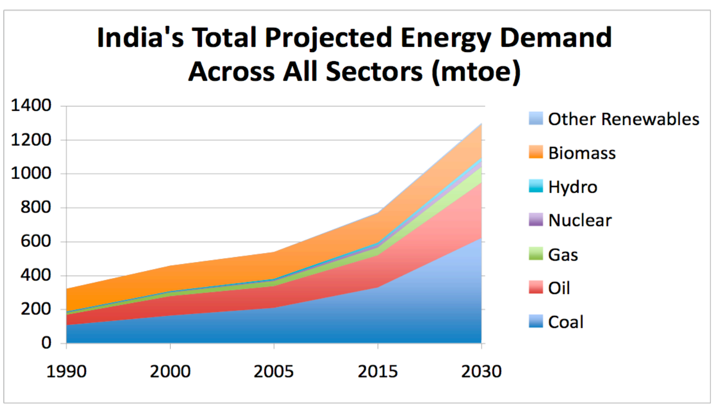
* Includes other energy sector, non-energy use and non-specified energy use.

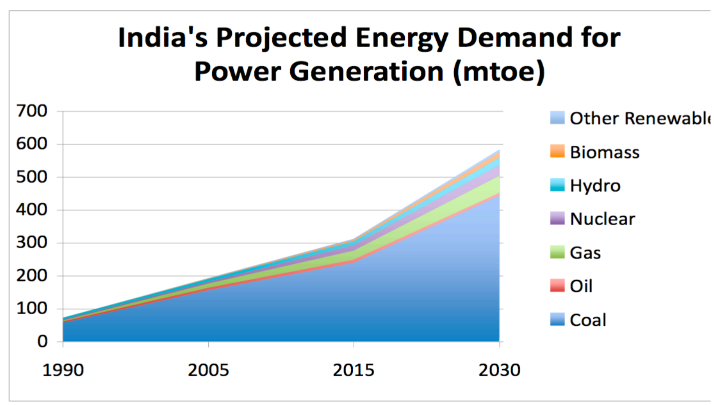
Current projections for India's carbon emissions are based on expected increases in demand without any major policy changes, such as eliminating tariff subsidies to shift demand.

Current and Projected Energy Supply and Demand

While total energy demand in India is expected to more than double between 2005 and 2030, energy demand for the power generation sector is expected to nearly triple. Currently, India has a 9% overall electrical energy shortage and a 14% peaking shortage,[6] which will continue to deteriorate unless there is new investment in capacity.

Biomass and oil, two non-significant energy sources in the power generation sector, comprise a significant portion of total energy demand. The substantial use of biomass in residential heating and cooking illustrates the large rural population unconnected to the grid living in poverty. An estimated 40-45% of Indians do not have access to electricity. Oil is used primarily for transportation fuel and hence does not impact the generation sector.





The potential for the U. S.-India nuclear agreement to affect India's ability to meet its environmental and energy demand goals is rooted in the power generation sector. Increased nuclear capacity will be tied to the grid and can directly offset other grid-tied generation sources. The projected power generation demand highlights the substantial role of coal in India's

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[6] http://www.investmentcommission.in/power.htm

generation mix. Currently comprising over 80% of current total demand and 76% of generation demand by 2030, coal is expected to be only slightly replaced by other sources. Nuclear increases from 2.6% to 5.7%, but it should be noted that this reference case predates the U. S.-India nuclear agreement.

Current Energy Policy

Publicly Owned Energy Production

State-owned companies dominate India's energy market. In the coal sector, Coal India accounts for 84% of domestic coal production, while Singareni Collieries, a joint firm between the central government and the Andhra Pradesh state, produces 9%. Private-sector companies that use their production for their own purposes account for the remaining 7% of the coal generation. The government also controls most of the oil sector: Oil and Natural Gas Corporation and Oil India dominate the upstream oil sector, while the Indian Oil Corporation is the largest producer in the downstream oil sector. Until 2006, GAIL, a public firm, exercised a monopoly on pipeline gas transport. Except a few independent power producers, electricity-generating capacity is owned by the state.

The state also owns the majority of the power sector. In 2005, 34GW of generating capacity belonged to the State Electricity Boards (SEBs). Government-owned companies, including the National Thermal Power Corporation, the National Hydroelectric Power Corporation and the Nuclear Power Corporation, produced about 27% of total capacity.

Energy Price: Subsidy, Taxes, and Tariffs

The Indian government heavily subsidizes energy price, especially on LPG and kerosene. The price of kerosene was $0.22 per liter in India in August 2007, which was less than a third in Nepal and less than half of Singapore's. The government also places price controls on gasoline and diesel. The large amount of electricity subsidies in the agricultural sector, in an effort to industrialize the rural areas, encourages inefficient use of energy. In 2005/6, gross electricity subsidies totaled $9 billion; such a large subsidy on electricity gives the State Electricity Boards big financial losses. Subsidies on natural gas and oil discourages investors and public oil companies, who bear the difference between refinery-gate prices and selling price of oil in addition to heavy tax. In 2006, the total loss in the publicly owned oil sector was $4.6 billion; post-tax price of gasoline is $1.06 in India while the OECD average is $0.80.

Average residential electricity tariffs in India, excluding taxes, is 7 U. S. cents per kWh , which is only half of OECD average. Industry tariffs of 9 U. S. cents per kWh are slightly higher than the OECD average.

Recent Reforms

Reforms in the energy sector that started in early 1990's have increased private participation including foreign companies, especially oil and gas. (See Table 15.2 and Figure 17.18)[7]

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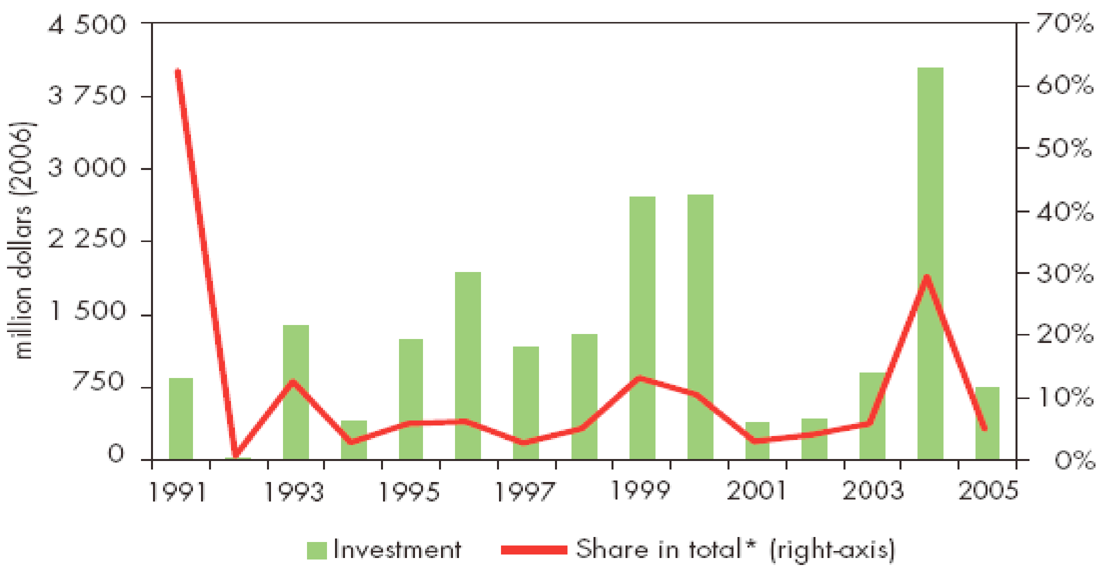
[7] World Energy Outlook 2007, China and India Insights. International Energy Agency

Table 15.2: **Private Participation in India's Energy Sector, 2005**

	Ownership	
	Public (%)	**Private** (%)
Electricity		
Generation*	76	24
Transmission	100	0
Distribution and end-user supply	87	13
Trade	93	7
Oil and gas		
Crude oil exploration and production	86	14
Natural gas production	77	23
Oil refining	74	26
Marketing	86	14
Coal		
Exploration, production and marketing	93	7**

* Includes industrial autoproducers.
** Includes captive mines.
Note: The first public-private partnership in transmission became operational in 2007 (see Box 15.3).
Source: The Energy and Resources Institute of India.

Figure 17.18: **Private Investment in India's Electricity Sector, 1991- 2005**



* Total in low- and middle-income countries as defined by the World Bank, including the transition economies.
Source: IEA analysis based on the World Bank's Private Participation in Infrastructure database.

Nuclear Sector

According to a presentation before a Senate hearing, India plans to invest $143 billion in its energy sector to add 83GW over the next decade. The plan requires significant increases in foreign direct investment, privatization, and market discipline. However, this is not targeted at the nuclear energy, making nuclear power the only source of energy that is not open to direct foreign investment or local or private ownership. Also, nuclear has seen little private investment, compared to more significant increases in other energy sectors.[8]

Current Renewable Energy Policy[9]

The Ministry of New and Renewable Energy in India oversees a working group and Planning Commission on five-year plans for non-conventional energy sources. The most recent proposal for the 11th Five Year Plan (2007-2012) was made in 2006. To achieve better focus and more effective coordination than the previous five year plan, 5 main programs were illustrated in the proposal:

1) Grid-Interactive and Distributed Renewable Power

The government aims to have 10% of the power generation installed capacity in the country from renewables by the end of 2012, with the total subsidy of Rs.3,925 crore. The following

[8] Backing the U.S-India Nuclear Deal and Nonproliferation: What's Required. Testimony by Henry Sokolski. Presented before a Hearing of The Senate Foreign Relations Committee. "The Nonproliferation Implications of the July 18, 2005 U,S,-India Joint Statement." http://www.npec-web.org/

[9] Figures were taken from the Ministry of New and Renewable Energy: 11th Plan Proposals for New and Renewable Energy, December 2006. http://mnes.nic.in/pdf/11th-plan-proposal.pdf.

table shows the breakup of the physical target of 15,000MW of installed capacity by resources and proposed subsidy for each.[10]

Resource	Capacity (MW)	Subsidy (Rs. crore)
Wind	10,500	75
Small Hydro	1,400	700
Co-generation Biomass Power	1,200 500	600 200
Urban Waste to Energy	200	150
Industrial Waste to Energy	200	75
Solar Power (Grid-interactive/ Distributed Renewable Power Systems)	50	200
DRPS (excluding Solar)	950	1900
Performance Testing		25
Total	15,000	3,925

2) Renewable Energy for Rural Applications

-Remote Village Renewable Energy Program (RVREP)

-Grid-Interactive Village Renewable Energy Program (GVREP):

(a) solar-thermal for cooking, hot water, and drying applications (target collector area: 1 million m^2 for flat plate collectors for hot water; 0.5 million m^2 for cooking and drying applications, 0.1 million m^2 for concentrating type cooker applications)

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[10] Summary of Physical Targets and Proposed Outlay for the 11th Plan, page 21. 11th Plan Proposals for New and Renewable Energy, Ministry of New and Renewable Energy. Government of India, December 2006. http://mnes.nic.in/pdf/11th-plan-proposal.pdf

(b) biogas plants for family type and cooking applications (target collector area: 2 million m^2)

3) Renewable Energy for Urban, Industrial and Commercial Applications

-Continued focus on:

(a) solar passive architecture (physical target: 5 million m^2 floor area)

(b) solar thermal systems/devices (physical target: 10 million m^2 collector area)

(c) energy recovery from urban wastes-potential for power generation is 3650MW for 2012, 5200MW for 2017

(d) energy recovery from industrial wastes (potential of 1598MWe for 2012, 1997MWe for 2017)

(e) renewable energy/solar/eco/green cities

4) Research, Design and Development for New and Renewable Energy

-total budget: Rs.1500crore

-Grid interactive renewable power: 10% share in grid power installed capacity by 2012, 15% by 2032

-alternate fuels: substitution up to 10% oil by alternate fuels by 2032

-energy recovery from municipal waste: make available in 423 class-1 cities including 107 municipal corporations by 2032

-solar water heating systems: 50 million m^2 by 2032

-cogeneration: 5000MW by 2032

III. Nuclear Power[11]

Current Nuclear Plants and New Potential

India's current nuclear energy is supplied by a 17 reactor fleet owned and operated by the government, which consists of fifteen reactors classified as "small" (400MW capacity or less) and two "midsize" (450MW – 900MW capacity) reactors. Of these seventeen reactors, only one, a 150MW boiling water reactor, requires enriched uranium as fuel; the other sixteen reactors are pressurized heavy water reactors and can use natural uranium.

The current 17 reactor fleet that has a net capacity of 3,779MW (table 1) supplied 15.8 billion kWh of India's electricity in 2007, accounting for 2.5% of their total power need. 300MW of the total capacity requires enriched uranium fuel, and the remaining 3,479MW is produced from natural uranium fuel.

[11] Figures for this section have been taken from the World Nuclear Association, www.world-nuclear.org .

Table 1: Current Nuclear Reactors			
Reactor	**Type**	**MW (net)**	**Uranium type**
Tarapur 1 & 2	BWR	150	enriched
Tarapur 3 & 4	PHWR	490	natural
Kaiga 1 & 2	PHWR	202	natural
Kaiga 3	PHWR	202	natural
Kalpakkam 1 & 2	PHWR	202	natural
Kakrapar 1 & 2	PHWR	202	natural
Narora 1 & 2	PHWR	202	natural
Rawatbhata 1	PHWR	90	natural
Rawatbhata 2	PHWR	187	natural
Rawatbhata 3 & 4	PHWR	202	natural
Total 17		**3779**	
BWR: Boiling water reactor; PHWR: Pressurized heavy water reactor			

To produce the 15.8 billion kWh of electricity in 2007, 978 tons of uranium (1153.35 tons U_3O_8) was required. 14.5 billion kWh were produced from 900 tons of natural uranium, with the remaining 1.3 billion kWh being produced from Tarapur 1 & 2 which required 78 tons of enriched uranium. However, in 2008 these uranium requirements could not be met, leaving the reactors running at about half their total capacity.

There are six new reactors under construction; five are expected to connect to the grid in 2009, and the sixth to come online in 2010. Two large (950MW) pressurized water reactors are being funded by Russia and will require enriched uranium fuel from Russia. India will keep and reprocess the waste. Three of the reactors will be small, pressurized heavy water reactors, and the last a large fast breeder reactor.

The new reactors, when run at full capacity, will provide an additional 2,976MW (table 2) or 12.4 billion kWh of electricity, which will increase the amount of uranium required by 774 tons per year. 280 tons of natural uranium will be used in the three PHWRs and the FBR to produce 4.5 billion kWh, and 494 tons of enriched uranium (provided by Russia) will be used in the two PWRs to produce the other 7.9 billion kWh.

Table 2: Nuclear Reactors Under Construction			
Reactor	**Type**	**MWe (net)**	**Uranium type**
Kundankulam 1 & 2	PWR	950	enriched
Kaiga 4	PHWR	202	natural
Rawatbhata 5 & 6	PHWR	202	natural
Kalpakkam PFBR	FBR	470	MOX natural
Total 5		**2976**	
PWR: Pressurized water reactor; PHWR: Pressurized heavy water reactor			
MOX: Mixed oxide (includes PuO_2)			

After the new reactors are connected to the grid, the total capacity will be 6,755MW. India hopes to have 25% of their electricity provided by nuclear power by 2050. To reach this goal, they plan to have total reactor capacity of 20GW by 2020, and 50GW by 2050. There are ten reactors — 6 large pressurized water reactors and 4 midsize pressurized heavy water reactors — planned and fifteen reactors — 6 large pressurized water reactors, 4 midsize pressurized water reactors, 1 advanced heavy water reactor and 4 fast breeder reactors — proposed. At an average construction time of 48-54 months per reactor, this is a reasonable timeline. The cost for these projects, at an average of $1.5 million/MW, will be $19.9 billion for 2020 and an additional $45.0 billion for the 2050 goal.

Nuclear Fuel Resources

To power the current and future reactors, India will not only need to continue and expand their own uranium mining, milling, and processing, but also look to foreign countries for aid. India has approximately 54,000 tons of Uranium in assured resources and estimates up to 23,000 tons of additional resources. However, only 365 tons of Uranium is produced yearly from the currently running 6 mines and 2 mills.

Uranium ore is the substance extracted from uranium mines, which must be processed further before use as fuel in nuclear reactors. The first step of processing takes place in a mill where a uranium oxide concentrate, U_3O_8 — referred to as "yellow cake", is produced that contains approximately 80% uranium. The second step of processing takes place at a conversion facility, where the yellow cake is refined to uranium dioxide, UO_2. The uranium dioxide naturally contains about 0.7% of the fissionable U-235 (most of the rest, 99.27%, is U-238), and can be used for fuel in reactors that do not require enriched uranium. If enriched fuel is desired (3-5% U-235), the uranium dioxide is converted to uranium hexafluoride, UF_6, and sent to an enrichment facility. At the enrichment facility the UF_6 is enriched in U-235 by removing some of the U-238. To complete the process, the enriched UF_6 is reconverted to enriched UO_2, and is now ready to fuel nuclear reactors.

The mills in India can, on average, process 2,500 tons of uranium ore per day. However, the uranium in the ore is not very concentrated and can contain as little as 0.1% uranium. To meet the growing demand for uranium, there are plans to open a new mine and mill in 2010 that will produce an additional 220 tons of yellow cake per year, for a total of 585 tons of yellow cake per year. Commissioned for 2012 are two additional mines and mills (at $270 million per mine/mill combination) bringing the total yellow cake production to 1055 tons per year.

However, without proper processing facilities, all the yellow cake mined will not help meet the uranium fuel needs.

India has a few small facilities to convert U_3O_8 from the mills or imported, to uranium dioxide needed for the nuclear reactors. The main refinery produces fuel for the pressurized heavy water reactors that do not require the uranium to be enriched. This plant can manufacture 400 tons of uranium per year. To meet fuel demands, India currently needs 900 tons of natural uranium per year and after construction they will need 1180 tons per year. The deficit of natively manufactured fuel is currently 500 tons of natural uranium per year and will soon be 780 tons per year.

One of the new reactors coming online will be a fast breeder reactor, which can use mixed oxide (MOX) fuel consisting of natural uranium dioxide and plutonium dioxide (PuO_2), and some thorium (see below), instead of only natural uranium. One of the byproducts of a U-235 reaction is fissile plutonium, which can continue to fuel the reactor. The MOX fuel is fabricated at a few small plants from spent, reprocessed fuel — with a total capacity of 150 tons per year. This reprocessed fuel will help reduce the uranium dioxide demand, leaving an after reactor-construction fuel deficit of only 630 tons per year, as opposed to 780 tons per year.

A smaller refinery, 25 tons of uranium per year, produces enriched uranium fuel for the boiling water reactors. Currently 73 tons of uranium per year is needed and this number will jump to 473 tons when the new reactors come online. The enriched fuel deficit, however, is currently 53 tons per year and that number will not increase with the new reactors, as Russia is to provide the fuel.

By the end of 2009, India will need to import 683 tons of fuel. Although there are plans for Kazakhstan, Brazil, and South Africa to sell uranium to India, in order to alleviate the demand for uranium India is working to develop a new type of reactor that can be fueled by thorium. Approximately 290,000 tons of thorium, a quarter of the world's resources, is found in India.

The thorium reactor would have a three-step fuel cycle. The first step would be fuelled by natural uranium to produce plutonium. Step two would then use fast neutron reactors burning the plutonium from step one to breed fissile U-233 (and further plutonium) from thorium. Finally, step three would use an advanced heavy water reactor to burn the U-233, the new plutonium, and remaining thorium. Two thirds of the power from this reactor is expected to be from the thorium, with the uranium and plutonium together making up the rest. The 470MW fast breeder reactor coming online in 2010 (see table 1) is the prototype for the step 2 reactor.

Nuclear Safety and Recycling

The currently operating reactors were not built in accordance with IAEA standards. However, the U. S.-India nuclear agreement sets dates by which the reactors must comply with IAEA safeguards, and any new reactors (including those under construction) will be built in accordance with the IAEA safeguards. As previously mentioned, India has a reprocessing plant for recycling spent nuclear fuel. The recycled fuel will then be used to fuel the new fast breeder reactor, and eventually fuel the thorium reactors. A geological depository is being researched for disposal of high level waste, which may contain the used fuel from fuel rods, or waste arising from reprocessing (or both).

Impact of Nuclear Cooperation between the U. S. and India

The cooperation between the United States and India could affect nuclear power development in India in a number of ways. First, the U. S. sale of uranium to India would help alleviate the fuel shortages in 2008 and quickly bring the current reactors back to full capacity as well as allowing the new reactors to be connected to the grid on schedule. Secondly, as previously mentioned, not all current reactors meet the IAEA safety standards, and this bill commits India to following such standards. Finally, this bill would allow India to purchase new technology from the United States. Therefore, the bill will assist India in meeting short term fuel requirements, but the technology transfer may be of limited use if India continues to pursue thorium technology.

IV. Coal Power

Environmental and Economic Impact of Coal

As a practical matter, coal-fired generation will continue to be the primary means for supplying India's existing and growing electricity demand. At present, 66 to 70 percent of India's electricity is generated with coal. The impact on greenhouse emissions is substantial. Generation of electricity takes up eighty percent of all coal burned and carbon emissions in India.[12] Switching away from coal to zero emission-generating resources like nuclear or solar could take care of most of India's contribution to world Greenhouse Gas (GHG) totals. However, it would not be economically or politically viable for India to abandon its existing

[12] World Energy Outlook 2007, China and India Insights. International Energy Agency.

77GW coal fleet or even abandon coal as a fuel for most of the new generation in the next 20 years.[13]

Coal is too abundant, inexpensive and secure a resource to abandon. India has 5% of the world's proven reserves of coal, enough for 110 years of supply.[14] Nevertheless, it has increased its imports of hard coal in recent years. Indigenous coal is produced and sold at auction by a governmental agency, Coal India Limited (CIL). Prices for domestic coal range from $12.00 to $32.33 a tonne depending on quality. The landed cost in India for international coal has risen as high as $120 a tonne.

The vast discrepancy in price is due in part to pricing practices of the CIL but to a large extent to the low quality of indigenous Indian coal in comparison to imports. Indian coal has an extremely high ash content, 45% by weight vs. 10% by weight of world market coal.[15] This substantially lowers the heat produced when it is burned (heat value). In addition, 7 per cent of Indian coal is lignite, or brown coal, a form of coal that is closer to peat than hard coal, has high moisture levels and consequent low heat value.[16] Lignite is expensive (relative to value) to

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[13] Chikkatur, Ananth P, A Resource and Technology Assessment of Coal Utilization in India (October 2008) at 27. Available at www.pewclimatechange.org/docUploads/india-coal-technology.pdf (hereinafter " Pew Technology Assessment."

[14] Coal and India's Energy Future. Chikkatur, Ananth. ERG Colloquium, University of California, Berkeley. October 17, 2007. http://belfercenter.ksg.harvard.edu/files/ERG_Colloquium_final.pdf slide 1.4

[15] Fly ash, the particulate matter that results from burning coal with high ash value in conventional pulverized coal plants, fouls machinery causing higher operating and maintenance costs and increasing outages, making more plants necessary to fulfill the same demand and increasing the price of electricity. Zamuda at 6 to 9. See also, Pew Technology Assessment at 27.

[16] World Energy Outlook at 508. Lignite has between 9 and 17 mbtu's of heat per ton . EIA glossary http://www.eia.doe.gov/glossary/glossary_l.htm.

In contrast, bituminous coal, the coal most often used in U. S. coal plants, has 21 and 30 MBtu/ton. On average, Indian coal has a heat value of only 13,000 to 21,000 KJ/kg compared with 15,000 to 27,9000 KJ/kg for U. S. lignite and U. S. bituminous respectively. The Future of Coal, MIT (2007), at 23, Table 3.2. http://web.mit.edu/coal/

transport is generally consumed in pithead (minemouth) plants. Lower heat value means more coal must be burned to produce the same amount of electricity. If demand growth is met in India by plants burning coal similar to that burned in the present fleet, the outlook for GHG is indeed grim.

India's existing coal fleet consists of approximately 47.6GW capacity.[17] But India's plants are among the least efficient in the world.[18] While the average thermal efficiency of coal plants worldwide is 40%, the average coal plant in India is 29% with some larger plants achieving 33%. [19] The difference not only decreases over all supply and increases price, but also substantially increases carbon emissions. Each 1% increase in thermal efficiency decreases carbon emissions by 1%. Just bringing the current fleet to world standards would decrease India's emissions by close to 10%.

[17] Zamuda, Carl and Sharpe, Mark, A Case for Enhanced Use of Clean Coal in India (2007)

[18] World Energy Outlook at 462

[19] http://belfercenter.ksg.harvard.edu/files/ERG_Colloquium_final.pdf

Thermal efficiency is the percentage of the thermal energy of fuel that ends up in electricity output of a generating plant. With the small, less efficient plants dominating the fleet, the average across the fleet is likely closer to the low end of all plants which range from 20% to 30% with a few 500 MW plants achieving as high as 33%.

Age	Installed Capacity (up to end of 2005)					Installation Year
Unit Size	**<100**	**100/110/120/ 140/150**	**200/210/250**	**500**	**Total**	
< 5 years		490	3165	4500	**8155**	2001–2005
5–10 years	75	740	5280	2000	**8095**	1996–2000
10–14 years	205	120	8060	3500	**11885**	1991–1995
15–19 years	332	890	8370	5500	**15092**	1986–1990
20–24 years	540	1670	8270	500	**10980**	1981–1985
25–29 years	120	2640	3290		**6050**	1976–1980
30–34 years	460	2710			**3170**	1971–1975
35–39 years	2210	720			**2930**	1966–1970
40+ years	1466	430			**1896**	< 1965
Total	**5408**	**10410**	**36435**	**16000**	**68253**	

The unit size and vintage of current installed capacity of Indian coal and lignite power plants up to the end of 2005 is shown in five-year periods.

Source: Chikkatur and Sagar, 2007.

Moreover, India's coal plants do not run at full capacity because of the age of the equipment and the harsh conditions of running on low quality coal.[20] This presents an opportunity to replace some of the oldest plants. If new plants are inexpensive relative to continuing to run the older plants, this replacement will happen faster.

[20] Pew Technology Assessment, at 27. The contribution to the low load factors is the state of disrepair of the transmission system.

Current Types of Coal Plants and New Potential Options

Virtually all of the operating plants in India use a technology called subcritical pulverized coal boilers. Most of the plants are small (200MW or less), but the technology can be scaled up and some subcritical plants are as large as 500MW. Subcritical pulverized coal technology is the most widely used technology around the world. In a subcritical pulverized coal plant, the coal is crushed and then injected into burners and into the furnace with combustion air. The coal particles ignite, are mixed with more combustion air and then burn.[21] Because they operate at low temperatures and pressures (less than 1025^{O}F and 3200psi), such units are relatively easy and inexpensive to build and operate. They can also use a variety of coal types, specifically the low quality coal that is abundant in India.[22] India's generators are increasingly blending higher quality imported coal with local coal to increase the thermal efficiency of the plants and lower the particulate fly ash.

While pulverized coal plants usually crush coal to a talcum powder like fineness,[23] Indian coal contains a large amount of mineral content (not just ash) which is hard to crush. As a result, coal plants in India may burn coal that is less finely crushed and less efficiently burned.[24] Without expensive and efficiency-reducing pollution controls, these plants spew large amounts of equipment-fouling fly ash.

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[21] Future of Coal, (MIT 2007) at http://web.mit.edu/coal/The_Future_of_Coal.pdf ("Future of Coal") at 20

[22] Future of Coal, at 21

[23] Future of Coal at 20

[24] See, generally, discussion of preparation of coal for burning in Zamuda

An additional technology is already operating in India: Circulating Fluidized Bed Combustion. CFBC plants use lower temperatures (800^{O}F) than other subcritical plants, but the coal is fed along with limestone into a circulating fluid bed where it is burned.[25] It is a tested and commercialized technology used in many countries.[26] This technology increases the thermal efficiency of the plants. Moreover, it can use a wider range of quality of coal and can even use other fuel sources such as biomass. An added bonus is that it reduces SO2 and NOx emissions as well. The technology works particularly well with low heat value coal such as lignite. [27]

One large CFBC plant is already operating in India under relatively adverse conditions. The Suratgarh plant burns lignite and was constructed far from urban areas in desert conditions with constraints on water. Nevertheless, the plant has a high (for India) thermal efficiency of 32.1% and an impressive operating record of approximately 94% load factor. Most subcritical plants in India operate with load factors closer to 70% and as low as 20% or lower.[28] This proven technology, well adapted for India's local coals and harsh weather conditions, has not been widely adopted.

There are cutting edge technologies that can increase the thermal efficiency of plant by burning at higher temperatures (1050 degrees F) and pressures (3530 psi).[29] These "supercritical"

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[25] Future of Coal at 20.

[26] Chikkatur, Ananth P. and Ambuj D. Sagar. "Towards a Better Technology Policy for Coal-Based Power in India." Chap. in *Advances in Energy Research (AER - 2006) : Proceedings of the 1st National Conference on Advances in Energy Research*, pages 28-33, Mumbai, India: Macmillan India, December 2006. at 31. (available at http://belfercenter.ksg.harvard.edu/files/chikkatur_sagar_aer2006.pdf)

[27] Future of Coal at 21 to 22.

[28] http://mjunction.in/market_news/coal_1/india_misses_energy_generation.php (citing a Central Electricity Agency October 2008 report.)

[29] Future of Coal at 21

technologies have been deployed in other parts of the world but have high maintenance and operating costs. While the technology is "commercialized" there is only one such plant under construction in India, which is expected (but not yet demonstrated) to have a thermal capacity of 35%.[30] In addition, India has plans for a number of "ultra-super critical" plants that require even higher temperatures (1112 to 1130^{O}F) and pressures (4640psi)[31] using technology which is not yet deemed "commercial", although it has been deployed elsewhere in the world.[32]

Coal Benefaction

One technology attacks the emission problem at the source: the coal itself. Coal benefaction, or coal washing, is a process by which mineral matter (like ash or rock) is removed from coal, raising the heat value and thus the thermal efficiency of the plants burning it. One 2000 study by USAID stated that coal washing presents the greatest potential for reducing GHG emissions in India, more than increasing plant efficiency, switching fuels and even slightly more than switching to renewables.[33]

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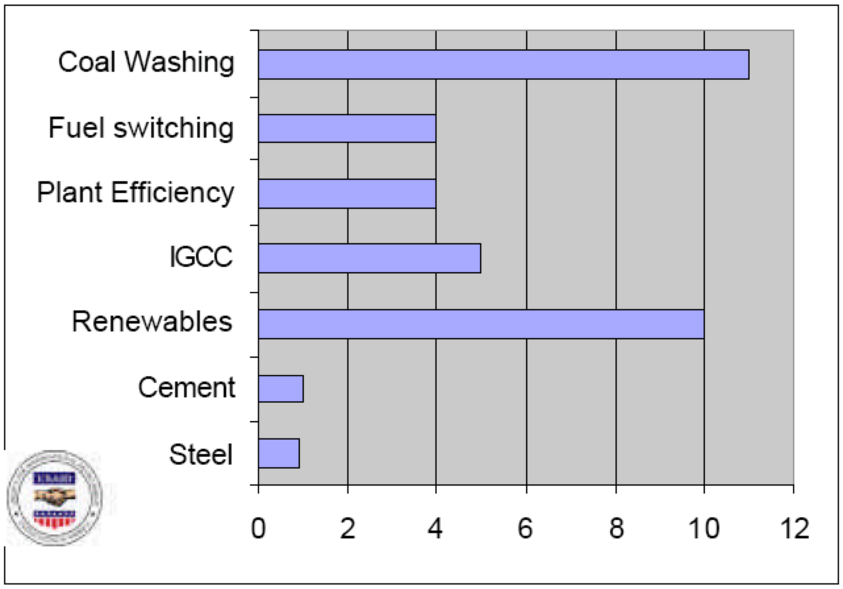
[30] Toward a Better Technology Policy, supra.

[31] Future of Coal at 21. A more extensive description of each of these technologies along with charts can be found in Towards A Better Technology, supra.

[32] Id. Finally, there is Integrated Gasification Combined Cycle(IGCC), a promising technology that burns coal very efficiently by first gasifying the solid coal. IGCC releases little carbon and is highly compatible with carbon sequestration. We did not research IGCC for this paper as it is not practical in the near to mid term and no such plants are presently planned for India. It is an option being considered around the world for future deployment.

[33] Sharpe, Mark, Thermal Coal Benefaction. Presentation at DOE conference on Coal Washery August 2007 http://fossil.energy.gov/international/International_Partners/August_2007_CWG_Meeting.html



There are a number of benefits from burning washed coal: By reducing the fly ash and particulate emissions at the plant site, ash related damage and maintenance costs of plants is reduced, significantly raising plant load factors (and thus output).[34] Moreover, use of washed coal can reduce capital costs of building new coal plants, even those using traditional subcritical technologies. Coal washing guarantees more uniform quality of coal produced. Plants that must be designed to burn a wide range of coal qualities are more expensive to build than those designed for a reliable target quality. Thus, the availability of washed coals reduces the capital cost of building new plants. Recently enacted Indian law requires that coal, which must be transported more than 1000km or burned in sensitive urban areas, can have no more than 34% ash. For domestic coal to meet this standard, it must be washed. Yet, despite all of these

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[34] Presentation at DOE coal washeries conference, August 2007
http://fossil.energy.gov/international/Publications/Coal_Beneficiation_Workshop/NP_Bhati_Aniruddh_Vaidya-Spectrumcoal_CB.pdf (73% to 96%)

advantages, at present, India's washeries are being run at only about 44% of capacity and only about 5% of all coal burned in India is cleaned in this manner.[35]

One major reason that coal benefaction has not been embraced by India to the full extent of its potential is the present perception that it increases the cost of electricity. Unprocessed coal can be up to 44% waste material. Recent case studies have shown that the "high" cost of using washed coal is in large part due to unrecognized cost of burning unwashed coal including plant downtime from the corrosive effects of emissions and transportation for the tons of noncombustible material included in unwashed coal. A test, using a presently operating 210MW plant of the type common to the generating fleet in India, reduced its marginal cost of producing electricity by $1.4 million dollars a year while also increasing its load factor by 33 percentage points and its thermal efficiency by 3%.[36] If all existing plants used washed coal, the increase in load factor alone has been estimated to instantly create the equivalent of 14 new 500MW power plants![37]

These cost savings quoted above were achieved even without monatizing the environmental impact of the emissions. A carbon tax or trading regime would significantly increase the advantage of burning washed coal. Computer simulations using specifications and history of three additional, larger plants in India showed potential for even greater savings.[38] It has been estimated that use of washed coal (without any other changes in technology) could increase the thermal efficiency of existing coal plants in India by at least 2%, with a resulting

[35] Zamuda at 5.

[36] Id at 6

[37] Zamuda at 14.

[38] Id.

reduction of 17 million tons of CO_2 annually. While existing facilities are not sufficient to process the country's total needs, simply using the existing washeries to their full capacity would more than double the present amount of washery coal burned.

The waste materials taken from the washed coal present further potential savings and efficiencies opportunities. This material has relatively high residual heat value.[39] It can be burned efficiently in CFBC plants. A combination minemouth washery and CFBC plant would not only reduce the fuel price per kWh, it would reduce the waste problem. Usually ash and other unburned product must be disposed of at the plant site. While ash can often be sold for use in brick and concrete, there is still a significant amount of other waste materials. In a minemouth setting, these materials can be disposed of by returning them to the mine.

A final advantage to coal benefaction is that it will bring domestic coal up to the reliable uniform quality needed for efficient combustion in new ultra critical and IGCC plants planned. Without washed domestic coal to use these promising new technologies, India's coal imports will have to increase; along with the increases in transportation cost and reduction in energy security that shift would create.

Remarkably, the biggest barrier to achieving these significant advantages is not capital, but regulation and government pricing policies. The coal industry is the only key energy subsector that has not seen fundamental economic reform in its legal and organizational structure in over thirty years.[40] The Coal India Limited or CIL, a governmental agency that is responsible for pricing and allocating supply, produces most coal in India. It also owns the existing mine

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[39] In fact, the combustible nature of the "washings" can present a storage problem if they are not reburned.

[40] World Energy Outlook at 448

mouth washeries. The marginal cost to CIL of producing ROM (run of mine) coal is lower than producing washed coals. It sells all coal (washed and unwashed) on the basis of Useful Heat Value (UHV) in contrast to world market coal which is priced on the basis of Gross Calorific Value (GCV). UHV pricing masks the price impact of ash content and other noncombustibles by averaging heat value across wide grouping of coal types. GCV coal prices are calibrated more finely and specifically, allowing more precise valuing of coals with different heating values. GCV pricing of washed coals would better reflect the increased heating value of coals giving generating plant operators a better calculation of the marginal cost of burning washed versus unwashed coals.[41] Without changing coal pricing to GCV, there is little incentive for CIL or anyone else to invest in new washery capacity and little incentive for coal plant operators to demand it. The government's recent initiatives to implement GCV pricing were rebuffed by industry.[42] In a step in the right direction, the government has very recently announced breaking the eight "bands" of UHV quality into 30 bands.[43] This should increase the price sensitivity of coal to carbon content and make the value of coal benefaction more apparent.

Conclusions for Coal

India recognizes that it will likely continue to use coal as a primary fuel for the medium term. The question is which technology will be used for the next generation of coal plants. Will it be large subcritical plants like Suratgahr or more experimental supercritical plants, or perhaps a compromise of large scale but well tested circulating fluidized bed plants? The question is not

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[41] Bhattacharya, S. Usage of Washed Coals in India, Issues and Challenges. Presentation at DOE conference, August 2007, http://fossil.energy.gov/international/Publications/Coal_Beneficiation_Workshop/6th_Dr_S_Bhattacharya.

[42] http://www.financialexpress.com/news/coal-ministry-scraps-plan-to-finalise-prices-on-gcv-basis/198087/

[43] http://steelguru.com/news/index/2008/03/31/NDA2OTk=/CIL_plans_extending_coal_varieties_based_on_useful_heat_value.html

an easy one. A recent extensive study by Harvard's Energy Technology Innovation Policy research group has attempted to compare the pros and cons of each technology.[44] In it, the authors weigh factors such as ability to use domestic coal, maturity of technology, ability to use local technically trained staff, low capital cost, efficiency and low emissions. Using this method, subcritical CFBC units like Suratgarh are as useful in the short and medium term than less tested supercritical units. For the future, many technologies may provide benefits, including cutting edge technologies that use coal gasification. The author suggests that India not make a commitment to developing any single technology for the future.

In that same vein, it seems prudent for India not to wait for new technology when there are existing technologies that could make their existing coal fleet more efficient and their next coal plants reliable and secure (in being able to use local coals). Rather than leap-frogging to Ultra-Super Critical plants or experimental IGCC based technologies, India can cheaply and easily build CFBC plants that are efficient using a range of local fuels.

Yet the greatest untapped source of clean coal technology is washery coal. Using higher heat value coal in the huge existing fleet and exploiting the heat value of "rejects" in new CFBC plants can increase output and decrease emissions without building a single new power plant.

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[44]http://belfercenter.ksg.harvard.edu/publication/18186/cleaner_power_in_india.html?breadcrumb=%2Fproject%2F10%2Fenergy_technology_innovation_policy

V. Natural Gas

Should India turn to natural gas fired power plants to limit emissions? Nine percent of India's existing generating fleet uses natural gas,[45] a less carbon intensive fuel than coal. However, the economics of building new large scale efficient combined cycle natural gas plants in India are limited by the price and quantity of natural gas reserves available.[46] India has approximately 0.6% of the world's proven natural gas reserves. Much of this is in undeveloped offshore basins.[47] It is estimated that India's richest developed fields are already 49% depleted[48] and development of additional reserves will require significant time and investment. Moreover, the undeveloped offshore fields are not near present pipeline infrastructure and it is unclear that demand can support the substantial investment that would be needed to build the miles of new transmission and distribution pipe. While India presently allows gas to be sold at market prices, it is unclear whether power plants would be willing to pay the cost of India gas.[49]

In the short run, new Indian natural gas plants would have to be fueled with imported LNG. LNG imports have steadily increased and are projected to double in the next 20 years.[50] This increased reliance on imported fuels decreases energy security. For this reason, even with

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[45] World Energy Outlook at 515

[46] Id

[47] Id at 449.

[48] Id

[49] Id at 503

[50] Id

a carbon tax, it is unclear whether natural gas plants are economically viable even in the medium term as substitute for coal plants.[51]

VI. Renewables: Solar, Wind, Hydro

With the expected increase in energy demand, the focus on the environment and the importance of energy security, India is promoting the use of renewables as a low-carbon, secure energy source of the future. This section will focus on what impact renewables could play in the future generation mix.

Current and Potential Capacity of Wind Generation

India is the fourth largest wind power generator in the world, with over 8GW currently installed and a 35% year-on-year growth rate in the past three years.[52] This growth has been driven both by the potential for wind energy in the north and east as well as by promotion of the domestic private sector: based in India, Suzlon is one of the world's largest wind turbine manufacturers, with an 8% global market share and over 50% penetration in the Indian wind market. While the installed nameplate capacity of wind comprises 6% of total Indian generation capacity, wind only provides 1.6% of the country's power. This is due to the lower than average plant load factors, which hover around 15%, compared to a global average of 25-30%.[53] Critics

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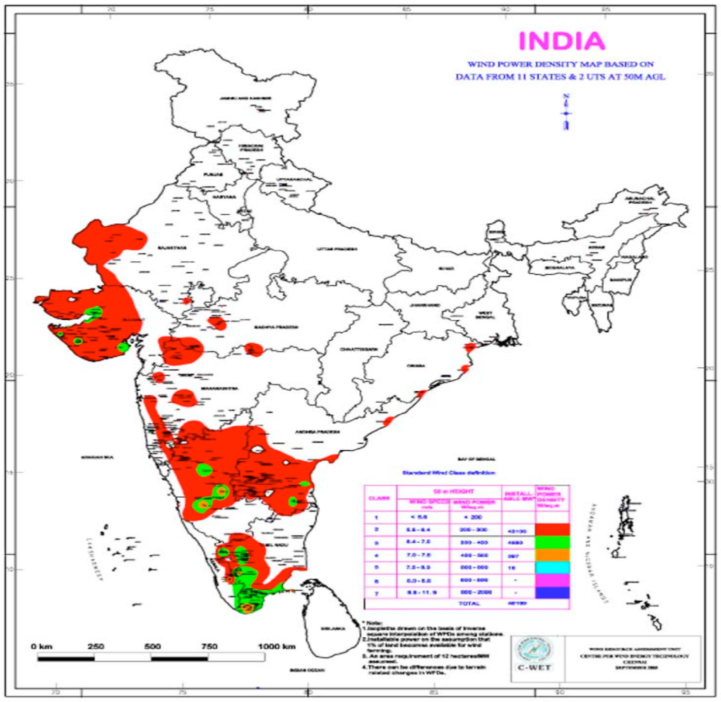
[51] The World Energy Outlook projected only a total 2% increase in electricity generation by natural gas by 2030. Id at 514.

[52] Ministry of New and Renewable Energy, 2007-2008 Annual Report

[53] http://www.peopleandplanet.net/doc.php?id=3357

blame the disparity on government policy, which currently benefits investment in capacity rather than energy output.



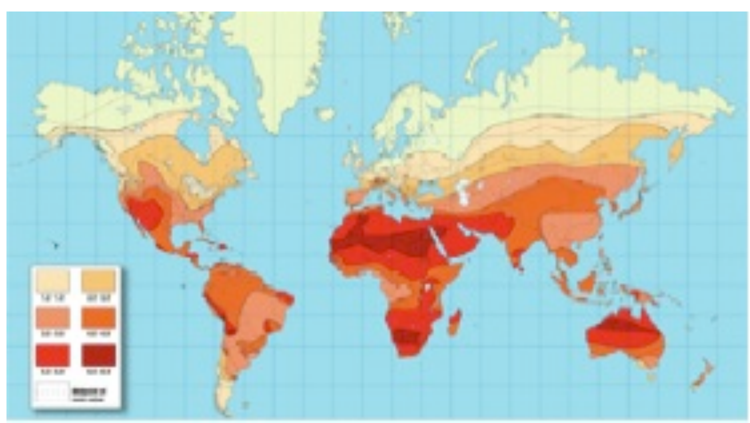
The Indian Ministry of New and Renewable Energy estimates that the total onshore potential for wind generation is 45GW, assuming 1% of land availability for wind farms requiring 12 hectares/MW in sites having wind power density in excess of 200 W/m^2. Others believe this figure could be higher, including the IEA. Future supply will be directly tied to the economics of the wind model, based on government policy, transmission availability and load factors. The government is targeting 27GW of total wind capacity by 2030.

Current and Potential Capacity of Hydropower[54]

Large scale hydropower is a significant but declining component of India's generation mix. In the 1970s, hydropower provided 40% of electricity, but with 36GW of installed capacity, it is only currently providing 14% of generation. This change is due mainly to negative public perception, stemming from the well known environmental and social problems of previous dam projects that also suffered well publicized economic setbacks. Despite these hindrances, the government is planning to expand hydropower capacity, targeting an additional 50GW by 2030. 15GW of this total is focused on the development of small hydropower plants with an average capacity of 25MW each.

Current and Potential Capacity of Solar

Despite India's abundant amounts of solar radiation, the industry has been slow to develop, due mainly to the high capital costs of photovolataics (PV) and largescale thermal plants. Usage of solar technology has been common in rural areas for off-grid applications such as water pumps, water heaters, cooking and lighting. As of 2007, only 2MW of grid-connected solar arrays had been installed.[55]



Recently, two major Indian PV producers have

[54] All figures for this section were taken from the IEA's World Energy Outlook 2007, the Pew Center for Climate Change India Brief, and the Indian Ministry of New and Renewable Energy.

[55] http://ecoworld.com/features/2007/05/15/indias-solar-power/

established solar manufacturing businesses: Moser Baer, which is producing thin film PV with efficiencies around 10%, and the Tata Group, which is producing monocrystalline PV as well as rural solar products.[56] Given this development and the Indian government's recent investment incentive policies, it is likely that the sector will expand rapidly in the next decade. The IEA estimates that solar will expand to comprise 4% of India's generation capacity in 2030. However, if technologies develop and price points are reduced dramatically, as is expected in the thin film PV industry, this may change the Indian generation mix.

VII. *Negawatts:* Options to Increase Efficiencies

Increasing Capacity by Upgrading the Grid

India's transmission and distribution network is the third largest in the world,[57] but its losses are amongst the highest in the world, estimated at 32%, compared to an average of 14% in OECD countries.[58] Over half of India's T&D losses are from lack of maintenance and investment, whereas 15% are from theft. This inefficiency simultaneously reduces energy capacity and deters investment in generation assets.

Furthermore, India's grid architecture is regional, without a national grid to enable the smoothing of energy availability. For

[56] www.moserbaer.in/ and http://www.tatabpsolar.com/

[57] http://www.investmentcommission.in/power.htm

[58] IEA, World Energy Outlook 2007

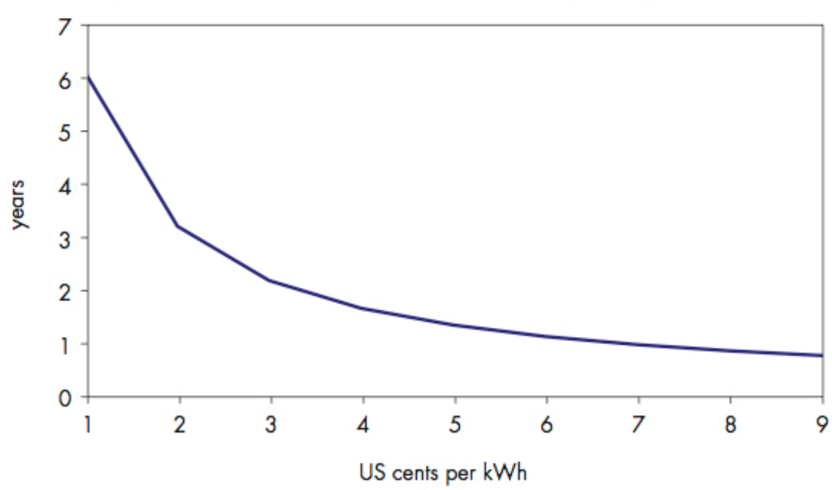
example, hydropower capacity is concentrated in the northeast, and thermal generation is in the east, whereas there are significant energy needs in the south and southwest.[59] A national grid is planned, which would lower overall market prices address shortages in peak demand.

The IEA estimates that India needs to invest $164 billion in transmission networks and $357 billion in distribution networks, although it does not break those figures down between maintenance, new national grid construction and modernizing distribution systems.

Lowering Demand by Increasing Efficiencies of Agricultural and Industrial Usage

24% of India's electricity is consumed by the agricultural sector, due to the government's continued tariff subsidies and the increased mechanization of irrigation.[60] One study estimates that 20% of agricultural electricity uses is to power water pumps. Due to subsidies, which offer the agricultural sector electricity prices at 10% of the industrial sector prices and in some states offer electricity free, farmers are not incentivized to

Figure 18.14: **Payback Period for Electrical Pumps in Agriculture**



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[59] "Key Inputs for Accelerated Development of Indian Power Sector for 11th Plan and Beyond," Central Electrical Authority, Ministry of Power, India

60 http://www.indiaenergyportal.org/subthemes_link.php?text=agriculture&themeid=15

purchase the energy efficient pumps on the market. These efficient pumps would use 20-25% less energy than their inefficient counterparts, which are still in use by 90% of the population.[61] Therefore, if the government eliminated subsidies, driving farmers to more efficient pumps, or at least incentivize farmers to buy the more efficient pumps, the study estimates that this would reduce total Indian energy demand by between 1-2%. This is illustrated in the graph from the IEA, which analyzes how the payback period for efficient pumps reduces sharply with a slight increase in tariff rates.

Another area to source substantial efficiency gains, reducing overall energy demand, is adding combined heat and power (CHP) capabilities to India's industrial sector, and eventually to the thermal generation fleet as a whole. The IEA estimates that 63% of energy is lost during the thermal generation process,[62] and CHP can capture half of this wasted energy, thereby dramatically increasing the capacity factors of power plants. India currently only sources about 4% of its energy supply from CHP, compared to a world average of 9% and with neighbors such as China already at 12%. One recent study of 300 industrial generation plants concluded that an additional 7.5GW of potential exists in those plants alone.[63] As with many other efficiency-related opportunities, responsibility lies with the government to implement policy to incentivize the private sector to make the investment.

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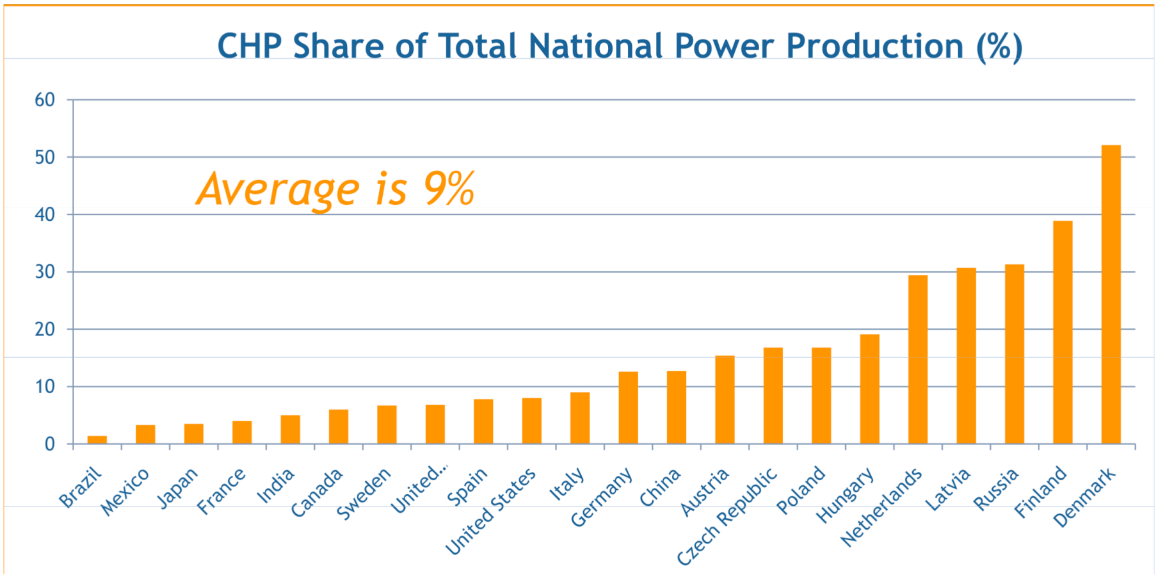
[61] http://www.energymanagertraining.com/announcements/EE20_result/04GSubramanyam.pdf

[62] CHP figures are drawn from this IEA presentation: http://www.iea.org/textbase/work/2008/chp/Kerr.pdf

[63] The Energy Resource Institute of India (TERI), CHP study, quoted by the IEA



VII. Economic Analysis of India's Energy Options

In the same way that U. S. government officials did not assess the qualitative aspects of India's energy strategy in the preparation for the U. S.-India nuclear agreement, they also did not analyze the quantitative aspects: the economics of India's energy options. In order to do so, two different approaches are utilized in this report: Net Present Value (NPV) and Levelized Cost of Energy (LCOE).

The NPV approach calculates in dollar terms how attractive it is to invest in and operate generation facilities, taking into account the cost of capital and the timing of capital costs and operating cash flows. For example, the fact that it takes double or triple the time to build a nuclear power plant than a coal plant heavily penalizes the nuclear plant with a lower NPV. At its most basic level, the NPV is an investment guide: if the NPV is a positive number, then invest; if it is a negative number, then it is not worth investing. Government policy is fundamental to changing the outcome of NPV analyses, by offering incentives or penalties to promote or inhibit investment decisions.

Because the NPV is affected by scale of investment, it can be difficult to use to compare technologies such as solar and nuclear that operate in different orders of magnitude. A more "apples to apples" approach is LCOE, which pares down all costs to a dollar per kWh figure. The LCOE is used in discussions of grid parity. While it does take into account capital costs and amortization expenses, these are factored in as "overnight costs". In other words, the LCOE calculation treats all investments in new facilities as producing revenues from day 1.

Assumptions for NPV and LCOE Calculations[64]

The assumptions and key figures for the NPV and LCOE calculations were collected from a diverse set of resources and all date from within the past five years. Given the varied nature of the environment and the technologies, even within a specific sector such as Solar PV or Subcritical Pulverized Coal CFBC, figures and prices are approximate and vary. Hence in our analysis we are targeting results on orders of magnitude rather than precision. For example,

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[64] **Nuclear sources:** World Nuclear Association, www.world-nuclear.org ; Nuclear Energy Agency, http://www.nea.fr/html/ndd/reports/efc/EFC-complete.pdf

Coal sources: http://ibnlive.in.com/news/coal-prices-to-be-revised-by-coal-india/7704-7.html?from=search (April 2006) based on blending local 45% ash coal with 10% foreign coal to get 30% average ash level as reported in Fossil-Fired Power Generation, International Energy Agency (2007); Towards a Better Technology Policy for Coal-Based Power in India, Chikkatur, Anath P. and Ambui D. Sagar

Gas sources: *Sustainable Energy: Choosing Among Options*, by Tester, Drake, Driscoll, Golay, and Peters, MIT Press; IEA World Energy Outlook

Wind sources: Pew Center for Climate Change, India Brief; *Sustainable Energy* http://lightbucket.wordpress.com/2008/03/13/the-capacity-factor-of-wind-power/

Solar Sources: Indian Ministry of New and Renewable Energies; IEA World Energy Outlook 2007; *Sustainable Energy;* solarbuzz.com

Price of energy: IEA tariff report 2006

$0.06 per kWh is used as the energy tariff in India, which is a blended figure of tariffs charged to the industrial, agricultural and residential sectors. Changing this by a few cents up or down does not change the magnitude of scale of the NPV results.

Assumptions								
	Nuclear New	**Nuclear Fuel**	**Subcrit Pulveriz'd Coal CFBC**	**Avg Coal**	**Gas**	**Wind**	**Solar PV**	**Solar Thermal**
Discount rate	10%	10%	10%	10%	10%	4%	4%	4%
Capacity Factor	90%	90%	94%	70%	60%	22%	17%	20%
Capital Investment Cost U. S. $/kW	1560	0	822	680	400	1000	3000	3000
O&M Cost Fixed (U. S. $/kW)	59.17	59.17	24.81	24.81	10.34	26.41	10.08	49.48
O&M Cost Variable (U. S. $/kWh)	0.00043	0.00043	0.0031	0.0031	0.0041	0	0	0
Plant Life	40	20	40	40	40	25	25	25
Construction Time	6	0	3	3	2	2	1	2
Average Plant Size (MW)	500	1800	1135	1135	1135	100	100	100
Carbon Emissions (Mt CO2/TWh)	0	0	0.8	1	0.66	0	0	0
Policy Notes	No taxes; gov't owned	No taxes; gov't owned				Low int. loans; 10 year tax exempt.	Low int. loans; feed-in tariff 0.25 for 5 yrs	Feed-in tariff 0.22 for 5 yrs

Resource Prices	
Price of mixed 30% ash imported/ domestic coal feed for subcr'l CFBC ($/ton)	$43.66
Tons of coal needed per hour for 1135MW plant	674
$ of imported/ domestic coal mix per kWh	$0.0276
Price to wash 1 ton of coal	$24.53
Tons of coal needed per hour for 1135MW plant	674
$ of washed coal mix per kWh	$0.0431
Price of Gas ($/million btu)	$4
Price of Uranium dioxide ($/ton)	$169,000
kWh/ton uranium dioxide	13,699,200
$/ton of uranium dioxide	$169,000.00
$ of uranium dioxide per kWh	$0.0123
Price of energy (U. S. $/kWh)	0.06
Tax Rate	30%

NPV Results

NPV			
Nuclear New	**Additional Nuclear Fuel**	**Sub Coal CFBC**	**Regular Coal**
$283,233,201	$4,799,898,123	$2,065,452,029	$1,381,197,278
Gas	**Wind**	**Solar PV**	**Solar Thermal**
$340,910,755	$12,564,344	($105,273,850)	($145,894,679)

The results indicate that it is an extremely good investment decision to:

- Purchase uranium from the U.S. or elsewhere to utilize the 1,800 MW of unused capacity in India's existing nuclear fleet;
- Build and operate a coal plant, with the subcritical pulverized coal CFBC at nearly double the NPV of an average Subcritical coal plant in India

The results also indicate that it is a relatively good investment decision to:

- Build and operate a new nuclear power plant – this investment is penalized by the upfront capital costs and time-to-build;
- Build and operate a gas plant – however this is heavily dependent on gas prices. In the model these are set at $4/million btus, but with India's low gas resources, this number is likely to increase;

Finally, the results indicate that without more incentives, a reduction in capital costs or an increase in efficiency, it is not a good investment decision to:

Build and operate wind, solar PV or solar thermal generation facilities. Wind is borderline positive and has been successfully installed across India; however, it suffers from low capacity factors compared to the rest of the world. Solar PV and Thermal may be viable when capital costs decrease, for example when thin film PV hits $1/W

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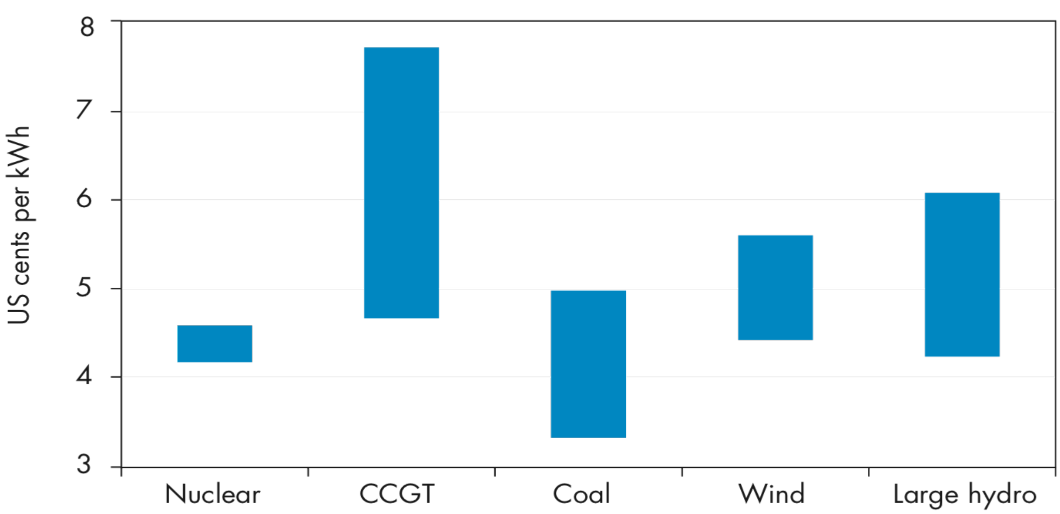
LCOE Results

LCOE				
	Nuclear New	Additional Nuclear Fuel	Sub Coal CFBC	Regular Coal
	$0.0405	NA	$0.0437	$0.0449
	Gas	Wind	Solar PV	Solar Thermal
	$0.0575	$0.0469	$0.1357	$0.1379

The LCOE results show that nuclear, coal and wind are all cost competitive, in the 4-5 cent per kWh range. The LCOE of gas is highly dependent on gas prices and is as expected higher than coal and nuclear. Solar PV and thermal are higher but not out of the ballpark: with lowering capital costs, the solar LCOE may come down further quickly. Our results are not dissimilar to those published in the IEA's World Energy Outlook, and the results indicate that the U. S.-India nuclear agreement will prove productive to the Indian energy sector immediately, through sale of additional uranium. In the long run, with both an exceedingly high NPV and low LCOE, coal will remain the leader.

Figure 17.13: **Electricity Generating Costs in India**



Source: IEA analysis.

What the NPV and LCOE analysis do not take into account are the potential costs of carbon emissions. If India commits in the next global agreement to a cap and trade emissions policy, and depending on the world price of carbon emissions, this could quickly tip the economic scales from coal generation to nuclear and renewables.

<u>VIII. Conclusion</u>

Both Congress and the President partially justified the U. S.-India nuclear agreement by stating that it would help the environment and global warming. Our research shows that there is virtually no evidence that either the Congress or the chief executive attempted to amass any quantitative support for this position. In fact, the environmental testimony we did find presented evidence of the efficacy of non-nuclear alternative methods of reducing India's growing GHG output. While it is uncontrovertibly true that a new zero emission generating source like a nuclear plant will increase India's energy supply without increasing its carbon footprint, there is no evidence that the Congress weighed this alternative against support for other zero emission sources such as solar or wind, or efficiency improvements that would make more electricity available with the same level of emissions (through improvement of the grid or coal washery), or even if India needed or could use U. S. technology to expand its existing idiosyncratic thorium based future nuclear fleet.[65]

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[65] Perhaps this is not surprising. Congress and the President were clearly primarily concerned with nuclear safety and non-proliferation considerations. Years of testimony and research on these points were evidenced in the record. Once they decided to go forward with the treaty on the basis of national security, they were no longer uncertain as to whether to pass the bill, and there would be little incentive to do research on any other aspect of the bill. In his article Bureaucratic Decision Costs and Endogenous Agency Expertise, Matthew Stephenson observes that when ex ante value of regulation is high, the value of information is lower.(Journal of Law, Economics and Organization, Vol 23 No. 2 (2007) at 3). In other words, when a decision maker (like Congress in this case) is no longer uncertain as

We then identified and examined some points that Congress might have pursued if it had been pursuing the bill primarily for the stated environmental reasons. We examined some of the Indian nuclear, coal, transmission and renewables options available to address carbon emissions. We posit that congress should have examined the net present value of the capital investment for different technologies that could be deployed to reduce projected emissions. This would have given Congress the ability to compare not only "overnight" costs of implementing different strategies but also to use discounting to reflect the time to build the different types of facilities needed to pursue each strategy. More sophisticated NPV analysis would also allow for discounting to reflect the uncertainties of relying on not-yet-commercial technologies. Such an analysis would be useful in weighing the "bang for the buck" of U. S. investment in the Indian nuclear sector vs. transmission or clean(er) coal or renewables. As a result, the record could have revealed not only what strategies could be deployed, but also which strategies should be deployed first.

Exportation of U. S. nuclear fuel to India will relieve the current shortage that has limited the output from existing nuclear plants. The result would be an immediate increase in output to meet growing demand with no additional emissions and without new capital expenditures. Our broader examination found three "conservation" measures could have similar immediate and significant impact on India's electricity supply without increasing the amount of fossil fuel used. In this way, they are zero emission options.

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to whether to take a regulatory action, it will not invest in gathering more information (educating itself) on the effects of the outcome. The logic is simple: If the new information would be counter to the decision to regulate, it isn't useful and if the new information would support it, it isn't necessary. Once the decision was made to support the treaty solely on the grounds that it supported national security reasons, additional information on environmental effects were not likely to change any minds, so investigation of these effects would be limited.

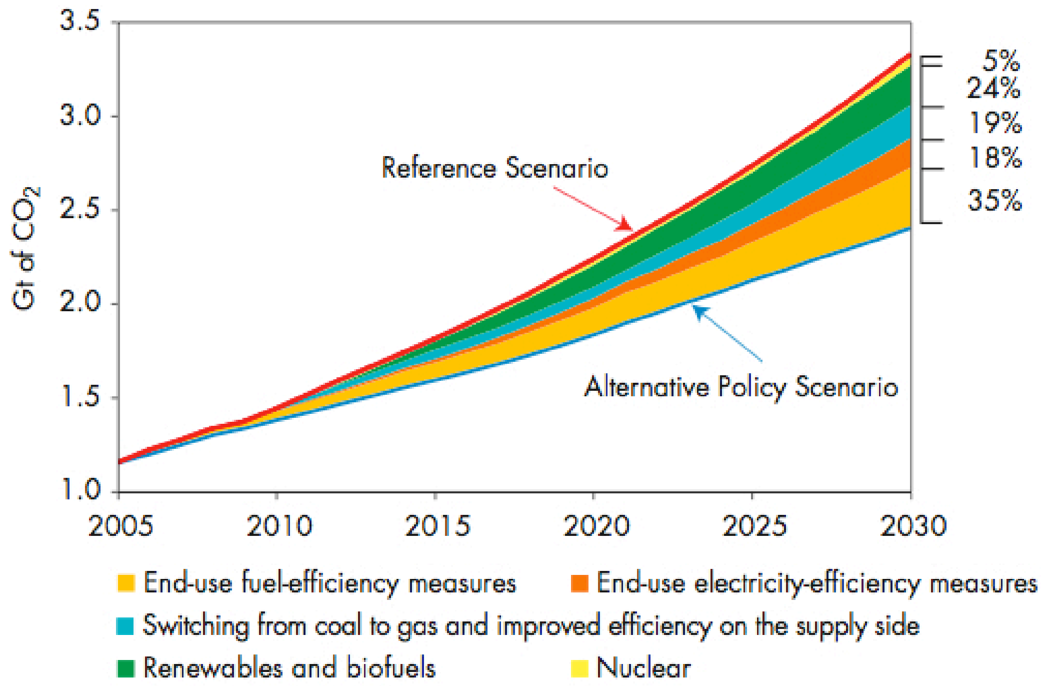

Figure 18.4: **India's CO_2 Emissions in the Alternative Policy Scenario Compared with the Reference Scenario**

Investment in coal washeries would increase the thermal efficiency of the entire generating fleet reducing the carbon output from those facilities by up to 2 percent.[66] Improving the transmission system would guarantee that more of the electricity already being produced would make it to consumers, increasing usable energy without increasing carbon. Investment in new agricultural pumps could decrease total energy use in India by up to 2 percent, lowering emissions while freeing up electricity supply to other demands. Whatever technology is pursued for the *next* increment of power, environmental concerns dictate that investments in washeries and transmission and pumps should be made to lower the carbon impact of the sizable existing coal fleet.

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[66] Two percent of the out put of the entire Indian coal fleet would be more than 1400MW. Think of this option as shutting down seven 200MW coal plants and replacing them with 2 free mid-sized nuclear plants! Chart taken from World Energy Outlook.

Finally, it is clear that the U. S. used the bill to garner important policy concessions from India. It created a politically acceptable means of gaining the Indian government's voluntary compliance with nuclear safeguards. If the bill been primarily for environmental purposes, the U. S. might have gained similar policy concessions in support of lower carbon emissions. Failing to focus on this potential, Congress missed a great opportunity. Even our brief examination of the energy sector of India shows that lack of market discipline on energy prices creates incentives to pollute. Subsidized agricultural electricity rates and government controlled coal prices that hide the real heating value of coal, are disincentives to investments that would reduce electricity demand through efficiency improvements and lower emissions/supply ratio through use of more efficiently combusted coal. With the right price signals, investment should be attracted to replace inefficient pumps or build coal washeries. That investment could come from many sources (including U. S. aid), but only the government of India itself can take the initial step of adopting policies supporting more market oriented pricing in the energy sector.