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INDIA'S QUEST FOR ENERGY SECURITY

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INTRODUCTION

At one point in 2006, crude oil prices crossed US$70 per barrel (bbl) and appeared to be increasing. In spite of a subsequent fall in prices, several analysts warn that this is temporary and we may see $100/bbl in the not-too-distant future. Some say this is reminiscent of the 1970s when oil shocks sent panic waves through the world energy markets. There was then a flurry of activity in alternate energy technologies, such as solar power, wind energy and bio-fuels. However, these efforts petered out as oil prices fell, and it was back to business as usual. A similar concern about energy supply is now being witnessed. "Energy security" and "energy independence" are the two most talked about phrases at energy conferences and international summits, compounded by increasing concerns about global warming.

How concerned should we be? In other words, how is the present situation different from what prevailed in the 1970s? There appear to be a few key differences. First, the objective of achieving energy security is inter-woven with the threat of global warming, which was not seen as a serious issue in the 1970s. Second, there is a popular sentiment that global oil production is close to peaking (if it has not peaked already) and hence the rising trend in crude oil prices appears to be irreversible. Finally, China and India, which together account for roughly 40 percent of humanity, have soaring economies with an insatiable appetite for energy.

Concerns about energy supplies are certainly realistic, and even more so for emerging economies, which have to balance surging energy demand with price volatility and environmental concerns. Notwithstanding these concerns, and the talk about alternate fuels and the so-called "hydrogen economy", fossil fuels are likely to dominate the world energy mix for the foreseeable future, (EIA 2006) and price volatility and uncertainty of supply will continue for at least a few more decades. Alternate fuels have a history of over-expectations and under-achievement for various reasons such as cost, storage issues, safety, fuelling and infrastructure. (Romm 2006) What then should be the global strategy, especially for developing countries that have surging energy demands? What technological innovations are required so that the objectives of energy security and environmental compatibility are not mutually exclusive? Are "energy security" and "energy independence" achievable or are they just nice sounding and politically correct clichés?

INDIA: ECONOMY AND ENERGY REQUIREMENTS

For a country of its size and population, India, until recently, has been a relatively small player in the international energy market. This is a reflection of India's low to modest economic growth in the decades leading up to 1990. After years of protectionism, India initiated a process of fundamental restructuring of its economy in 1991. In a series of slow but steady steps, the tightly controlled economy was opened up, a process which continues within the constraints

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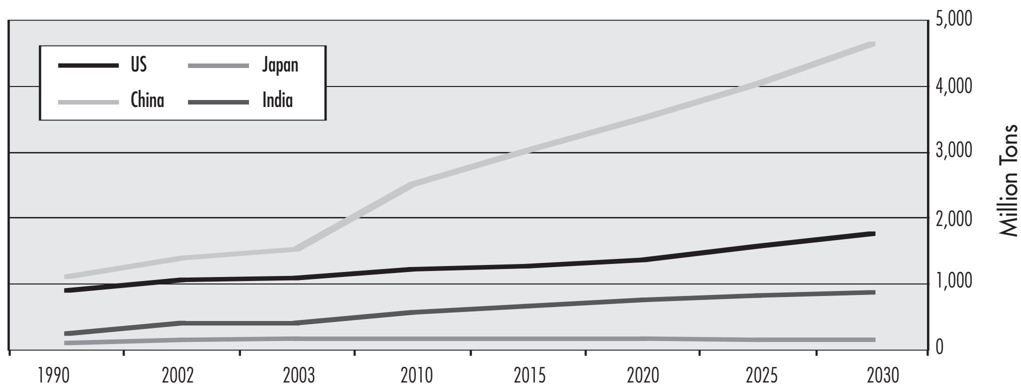
imposed by a democratic polity. In the last decade of the 20th Century, the Indian economy grew at a robust six to eight percent annually and this trend is expected to continue.

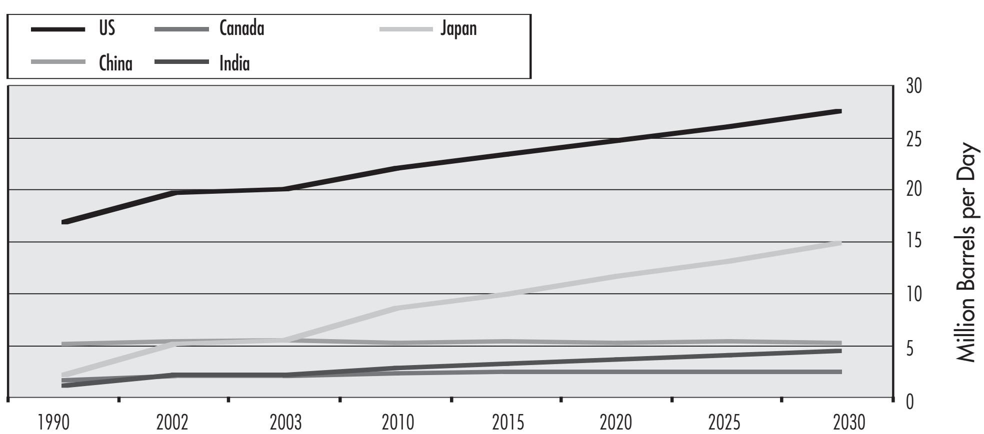
Consequently, India is facing a surging energy demand. Of course, India's energy requirements are dwarfed when compared with those of China. For instance, while India's present annual coal consumption of 431 million tons is expected to double to about 887 million tons by 2030, China's coal requirements will touch a mammoth 4,645 million tons (Figure 1). Similarly, by 2030, China is expected to consume about 15 million barrels of oil a day against India's 4.5 (Figure 2).

Figure 1: Coal Consumption of Selected Countries 1990-2030



Source: Energy Information Administration, US Department of Energy

Figure 2: Coal Consumption of Selected Countries 1990-2030



Source: Energy Information Administration, US Department of Energy

However, the crucial point is that China and India have the highest rates of growth of energy consumption. Oil consumption in China and India is expected to grow at 3.8 percent and 2.4 percent respectively on an annual basis, against a world average of 1.4 percent. (EIA 2006) India's growing CO_2 emissions will rank 3rd largest, after the United States and China.

The likely impact of India's rapid growth on world energy prices and greenhouse gas (GHG) emissions has caused concern in the energy world. US President Bush justified the landmark Indo-US agreement on nuclear power as being "… in our economic interests that India have a civilian nuclear power industry to help take the pressure off of the global demand for energy". (US 2006) French President Chirac declared that India needed nuclear power technology "… in order to drive and fuel India's economic development [and to prevent the country from becoming] an enormous polluting chimney". (*The Indian Express* 2006)

POWER TO THE PEOPLE

India's installed generation capacity of electricity, at 127,673 MW,[1] ranks 5th largest in the world. This performance is impressive, considering that in 1950 the generation capacity was just 1,500 MW. The net generation in 2004 was 630 billion units. (MOP 2005) The transmission and distribution grid has penetrated roughly 90 percent of India's 0.7 million villages, but less than half of rural homes are electrified.

Despite this impressive growth, India's power sector suffers from several problems, technical, economic, and political. (Tongia forthcoming) Per capita electricity consumption is 500 kWh,[2] well below the world average of 2,500 kWh and much less than that of China. There is an estimated shortfall in peak and average demand of 13 percent and 11 percent respectively. Power supply, especially in rural areas is highly erratic, with large fluctuations in voltage and frequency. Transmission and distribution losses (including power theft) are sometimes as high as 50 percent, averaging over 25 percent nationwide. The economic fundamentals of the power sector are shaky; agriculture power supply is virtually free, and is un-metered due to pressure from the farmers' lobbies. As a result, most utilities have a negative rate of return and the annual losses are hundreds of billions of rupees. This issue continues to plague the healthy development of the power sector and is a bottleneck in infrastructure growth.

For India to achieve its goal of power to all, there needs to be a significant improvement in all aspects: generation, transmission and distribution, and appropriate pricing policies. This is clearly a huge task and well beyond the scope of this analysis. Here we limit the focus to power generation. India's present generation capacity is 131,000 MW and is dominated by coal, followed by hydro and gas (Figure 3).

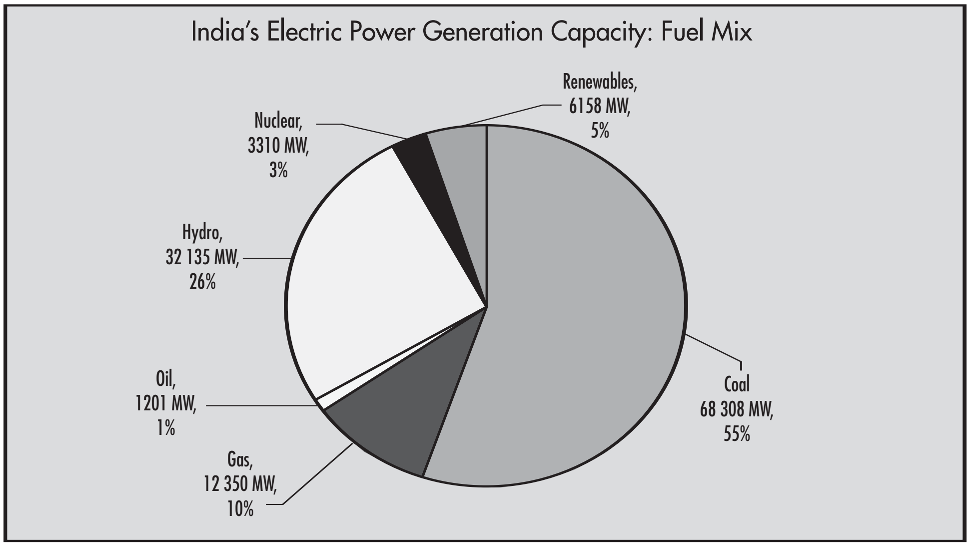
India will have to double its present capacity over the next decade, or the present problems of blackouts and brownouts will continue. This translates to adding 13,000 MW per year, or installing a new 1000 MW power plant every month. Such growth is certainly dramatic in the Indian context, although China was reported to have added almost 50,000 MW last year – or one power plant a week.

The question remains: from where will this additional capacity come, and what might be the fuel mix for generating this power? The generated electricity must be absorbed by the system, which includes the physical infrastructure (the grid), utilities (which are regulated and financially strapped), and consumers. Clearly, all these must be sustainable. Otherwise, the utilities' deficits will further increase, discouraging investments. It should also be environmentally friendly, to the extent possible.

1. MW (Megawatt) = 1000 kW (kilowatt)

2. kWh = kilo watt hour. More commonly known as a "unit" of electricity, it is the energy consumed by an appliance of 1 kW rating in one hour.

Figure 3



Source: Ministry of Power, Government of India

The Conventional Fuels: Coal, Hydro, Gas

India has large coal reserves and at the present rate of consumption, coal is expected to last for another 250 years. India's reliance on coal will, therefore, continue. However, coal is not without its share of problems. Coalmines are mainly concentrated in the Northeastern belt of the country and the coal has to be transported over large distances to the thermal power plants located across the country. Indian coal is characterized by high ash content, sometimes as high as 45 percent. This adds to the transportation costs and also causes problems of ash disposal in power plants.

Present coal production capacity in India is strained and has not kept pace with the increasing demand in coal generating stations. Consequently, coal stocks are reportedly at dangerously low levels in several power plants. Last year a decision was taken at the highest level to expedite coal imports of 14 million tons to bridge the shortfall. If coal's present share in installed generation capacity continues in the future, even a doubling of coal production capacity will not be sufficient to meet the expected coal demand a decade from now.

Most coal is transported by railways, often over more than 1,000 km, and there is an urgent need to augment the coal transportation network. In the United States, Europe and Russia coal is transported cheaply by barge. Unlike India, these countries have invested in building and maintaining a network of deep navigable waterways.

Even if India significantly augments coal production and transportation to meet the expected future demand, the reliance on coal may not be desirable from an environmental perspective. The emissions regulations for nitrogen oxide (NO_x), carbon monoxide (CO), particulates, etc. will have to be made stringent, failing which many Indian cities and rural areas will suffer from poor air quality. Then there is the question of CO_2. India is on track to become the world's 3rd largest emitter of CO_2 if the reliance on coal continues.

There is limited energy potential from natural gas or liquefied natural gas (LNG). There was some excitement as a result of discoveries of reserves in the Bay of Bengal and also with the possibility of imports from West Asia and Bangladesh. There is a strong economic case for importing natural gas from the Middle East. (Tongia 2005; Tongi and Arunachalam 1999) A pipeline would take four to five years before it would be fully operational, and could be timed to coincide with new gas-fired combined cycle power plants.

LNG hauled over oceans in large tankers is fast becoming an alternate and attractive method of gas transport. There has been a significant reduction in the cost of building such quayside infrastructure. It is likely that LNG transportation may become competitive with overland pipelines. However, as recent experience in the United States has shown, the cost of electric power depends critically on the gas price. Several natural gas power plants in the United States filed for bankruptcy because power sector natural gas prices exceeded $6/MMBTU.[3] Hence, any large-scale capacity addition will be subject to risks inherent in price volatility.

India built a few major hydroelectric power plants decades ago. These are completely paid for and the cost of power generation is low. However, over the years, the share of hydro-electricity in power generation has progressively fallen. Hydro-electricity is also concentrated in the northeastern part of India. Tapping these sources would critically depend on addressing major environmental issues, possible international agreements on water sharing, and the building of high voltage transmission lines to distant load centres. Large hydro projects also have the problem of land acquisition and the rehabilitation and resettlement of people, which causes considerable hardship and resentment among the local people.

Renewables

Are renewables the answer? History does not seem to suggest so. Renewables have under-performed in India, as they have elsewhere. India has done reasonably well in wind energy in the last decade and has the world's 5th largest wind-based capacity. However, wind speeds in most parts of India are lower than those in European countries and the United States. As a result of this, and also faulty site selection, wind still contributes an insignificant amount to the total electric power generation. Biomass has a similar story. Theoretically, biomass should play an important role, given that India is an agricultural country, but food requirements take precedence over energy needs, and land availability is a constraint. In addition, most solutions are of small or modest scale, and many of the projects thus far have relied on government grants/assured payments, or have been built for combined heat and power applications (cogeneration). For now, renewables have a modest role to play in providing electricity. However, there appear to be good prospects from wind energy (off-shore in particular) and maturing solar technologies; solar photovoltaic cells for distributed applications; and solar thermal for utility-scale power.

Revival of Nuclear?

It seems from the above that conventional fuels and renewables will not be able to secure India's desired electric power growth in the coming decades. So, is nuclear the answer? Again, past history does not suggest so; even after years of promise, it accounts for just three percent of generation capacity. However, it appears that past performance will not restrain India from embarking on unprecedented growth in nuclear power, partly because of the shortfall in other sources and partly because of climate concerns. (Bharadwaj *et al* 2006)

3. MMBTU= Million British Thermal Units; this is the measurement for natural gas.

Even to grow from three to ten percent, the nuclear power sector would need to increase dramatically. Nuclear power would need to surpass previous government projections, which were based on domestic uranium resources. The potential of nuclear power is limited by several constraints, including fissile material availability, site selection and design approval, and industrial infrastructure for reactor construction, financing and waste disposal.

The Indian nuclear power program has focused on Pressurized Heavy Water Reactors (PHWRs). Domestic uranium reserves, estimated at 50,000 to 70,000 tons, if used in PHWRs, can only sustain a capacity of about 10,000 MW for about forty years.[4] The fuel for PHWR is natural uranium oxide and this can be run in a "once-through" mode (the spent fuel is discarded) or reprocessed to extract plutonium for fuelling Fast Breeder Reactors (FBRs). A prototype 500 MW-FBR is under construction using plutonium reprocessed from the spent fuel from PHWRs.

India has large thorium (a metal with a range of uses) reserves. However, as thorium is not a fissile material, it must first be converted to Uranium-233 before being used as a fuel. This technology is not yet commercialized and may be a few decades away.

A rapid growth of nuclear power is feasible only with imported uranium. The recent agreement between India and the United States on civilian nuclear power reactors provides an opportunity to build a large number of Light Water Reactors (LWR) in addition to fuelling a number of Indian technology PHWRs. India could potentially add up to 32,000 MW by 2020, which would undoubtedly be one of the largest engineering and logistical challenges the country has faced. (Bharadwaj *et al* 2006) While it is difficult to predict India's overall capacity in 2020 and beyond, nuclear power seems set to play a growing role in the generation mix.

FUELLING TRANSPORT

India has limited petroleum reserves. Consequently, the gap between domestic crude production and imports is ever widening. While domestic production of crude in the last fifteen years has stagnated at around 11 million tons per annum, crude imports reached 90 million tons in 2003-2004. Unlike developed countries, India is a diesel-based economy. Diesel consumption is about five times the consumption of gasoline and it is the fuel for trucks, agricultural machinery, water pump sets, and stand-by generators. So, India will have to find fuel substitutes for gasoline and diesel and prime mover technologies, which can utilize these fuels.

Hydrogen

The energy community is deeply divided over hydrogen. The enthusiasts are convinced that hydrogen, along with fuel cells, holds the answer to the world's energy problems in an environmentally sustainable manner. However, there are plenty of dissenters who argue the opposite, and with good reason. Transportation fuel cells cost at least 100 times the cost of conventional internal combustion engine. (Wald 2004) Moreover, fuel cell powered cars at best offer marginal efficiency improvement over the diesel-hybrid option. (Oppenheim and Schock 2004) As things stand, it is unlikely that hydrogen fuel cell vehicles will achieve five percent of global market share by 2030. (Romm 2006) Some studies indicate that widespread use of hydrogen for transportation might actually increase green house gas emissions, since many pathways for

4. The peak PHWR capacity depends on the rate at which plants can be built. If more are built quickly, a higher peak can be reached, but sustained for shorter period of time, such that with the end of life of the last unit, the last domestic uranium is used. See Tongia and Arunachalam 1998: 549-558 for more details.

hydrogen production, such as grid electrolysis, are energy intensive. (Romm 2006) Although research in hydrogen generation, storage and transportation technologies is going to continue, short of any major breakthrough, these technologies are unlikely to capture the market.

Bio-Fuels

Bio-fuels are attracting a lot of headlines. US President Bush called for efforts to boost research and development spending on cellulosic ethanol technologies and Indian President Kalam emphasized bio-diesel from oilseeds, such as jatropha. Bio-fuels clearly have several advantages in that they are renewable, almost carbon neutral, and the conversion technologies are reasonably well developed. However, it is important to understand the realistic potential and associated costs. Specifically, increasing bio-fuels production runs the risk of reduction in food crops and diverting large tracts of land for growing bio-fuels.

Ethanol

Ethanol is a promising substitute for petrol. Most gasoline engines can operate on a gasoline-ethanol blend of up to ten percent with minor or zero modifications. The energy content of ethanol is about a third lower than that of gasoline and blending ethanol therefore would lead to a decrease in the engine mileage per unit volume of fuel. However, unlike petrol and diesel, ethanol contains oxygen, resulting in improved combustion and lower emissions. Already ethanol is blended as an additive to boost the octane number in some states in the United States, especially since the previous additive, Methyl tert-butyl ether, is being phased out due to concerns about ground water pollution.

Brazil is the world's largest ethanol producer, manufacturing 36 percent of global production. About 50 percent of Brazil's sugarcane harvest is used for making ethanol from sugarcane juice. The cost of production is about $1/gallon, which is competitive even at half of today's oil prices.

The United States is the world's second largest ethanol producer. However, the present retail price of $2.5 – $3/gallon (Axis Petroleum 2006) makes it almost as expensive as gasoline. Consequently, there are questions in the United States about the desirability of the corn-ethanol program. Some have argued that it takes more energy to make one gallon of ethanol than the energy contained in it. (Paztek 2006; Pimentel 2003) However, these calculations are refuted by other workers. (Farrell *et al* 2006; Shapouri *et al* 2002) Some agricultural economists are concerned about a large-scale diversion of corn for fuel. They argue that agricultural land use should follow the hierarchy of food first, then feed for livestock and last, fuel. (Barrioneuvo 2006)

Can ethanol help India achieve energy security? While ethanol production in India has shown steady growth, it is modest compared to the United States and Brazil. Present ethanol production in India is just enough to sustain a five percent gasoline blend. This is because India's sugarcane production is just enough to meet the domestic sugar demand and leaves little room for diverting sugarcane juice for ethanol, as is done in Brazil. Any imbalance between domestic production and the demand for sugar would lead to a spiralling of prices and other antisocial activities, such as hoarding. If sugarcane is to be the primary material for ethanol production, what options are there to ensure that the production of ethanol does not affect the production of sugar?

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5. Fertigation is the application of nutrients through irrigation systems.

6. Personal communication with R.K. Sivanappan, 2006.

Increasing sugarcane yield: Drip Irrigation and Fertigation[5] Using advanced agro-technologies, such as drip irrigation and fertigation, can more than double the sugarcane yield to about 150 tons/hectare (ha). A few farmers have even reported a yield of 350 tons/ha.[6] Drip irrigation and fertigation technologies, if deployed on 25 percent of the present area under sugarcane (about one million ha), can increase the total sugarcane production to 370 million tons. This could increase the ethanol production to 2,920 million litres, enough for 10 to 15 percent petrol blend. (Bharadwaj *et al* 2006)

Cellulosic Ethanol: A Challenge and Opportunity Cellulosic biomass is composed of cellulose, hemi cellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes and oils) and ash. Cellulose ethanol presents a major opportunity, since biomass feedstock is abundant and relatively inexpensive; India generates over 400 million tons of agro-forest residues, such as wood chips, rice and wheat straw, sugarcane tops and leaves, and bagasse.

However, the conversion technology is still under development[7] and costs are high. If this technology becomes commercialized, then bagasse holds promise as a feedstock for ethanol production. Our calculations[8] show that using 50 percent of bagasse could more than double the present ethanol production and meet 25 percent of India's demand for gasoline (Bharadwaj *et al* 2006).

Bio-diesel

The production of ethanol, described above, ultimately relies on any sugar, if not cellulose, but the conversion process is energy intensive, requiring distillation to separate the ethanol from water. In contrast, if one already has oil available from an oil-bearing fruit, such as jatropha, the conversion to bio-diesel is simpler, based on catalytic trans-esterification of the oil. The outputs from this conversion are bio-diesel and modest quantities of glycerine and oil cake. Jatropha is especially attractive because of its relatively low input requirements (water, fertilizer, pesticides etc) and high oil yields.

Bio-diesel's properties are similar to those of fossil diesel and are low in sulphur. Experiments with bio-diesel have resulted in lower emissions of CO and particulate matter, but reportedly higher NO_X emissions. Engines can operate totally on bio-diesel (B100), or with varying blends of bio-diesel and conventional diesel. In either case, the engine performance is reported to be satisfactory. Jatropha has consequently caught the imagination of Indian scientists and policy makers. Large-scale jatropha cultivation on about 11 million ha of land could substitute 20 percent of fossil diesel by 2011-2012.

However, large-scale cultivation on 11 million ha would rank jatropha 3rd in cropped areas after rice and wheat. This is a mammoth undertaking requiring careful planning with appropriate institutional arrangements to support crop growing, harvesting, fruit collection and transportation to processing plants. Indiscriminate expansion without providing adequate support in the above areas could be counter-productive. There are also discrepancies between promise and performance: against an expected yield of at least eight to 12 tons/ha, several plantations have harvested only one to two tons/ha. (Rao 2006)

7. There are three main conversion technologies for converting biomass to liquid fuels: Enzymatic hydrolysis, acid hydrolysis and gasification followed by FT synthesis (see "Other Options" section).

8. These calculations are based on conservative yield estimates of 260 litres ethanol per dry ton of bagasse. The theoretical yield is expected to be about 420 litres.

Crop switching by farmers is not an unknown phenomenon. Malaysia, faced with the large availability of synthetic rubber, transferred millions of acres from rubber to palm oil plantations. Considering that rubber was not in the food chain this transfer was entirely dependent on economic viability. However, in India a large amount of acreage is devoted to crops such as rice, wheat and sugarcane, which are part of the food chain, and therefore India may have to exercise caution in crop switching. When the government is considering imports of food grain to keep prices down, switching to jatropha on a large-scale is fraught with danger.

Other Options

There are several other options for replacing oil, such as methanol, natural gas and coal-based liquids. Coal liquefaction to produce chemicals is an established technology dating back over seventy years. One such technology, Fischer Tropsch (FT) synthesis, was commercialized by the South African company, SASOL. South Africa meets roughly 40 percent of its diesel requirements by this process. The same technology is used to convert natural gas to liquid fuels. The process involves coal gasification to produce a combustible gas, which is cleaned and then chemically treated to generate a range of hydrocarbon products, such as light hydrocarbons, naphtha, diesel, and wax. Coal gasification can also be followed by combustion in a gas turbine to generate electricity. China is presently taking up two projects to produce about 80,000 barrels per day. Each of these projects is expected to cost about $5- to $7-billion and consume 15 million tons of coal per annum. In theory, India could fulfill 20 percent of its diesel requirements through four such large projects. However, as discussed earlier, coal production and supply is already strained and it is probable India will have to import coal for large-scale diesel production. FT synthesis is an energy intensive process and involves significant CO2 emissions; hence while it solves the problem of oil substitution, it worsens climate problems.

Energy conservation and similar initiatives, such as minimizing transmission and distribution losses are promising options and can reduce demand to some degree. The challenge is the creation of an appropriate regulatory framework (such as the vehicle Corporate Average Fuel Economy (CAFE) standards in the United States) or allowing market-based mechanisms to operate.

Hybrid vehicle technologies as deployed today also have the potential to reduce fuel consumption by 50 percent, e.g., popular vehicles manufactured by Toyota and Honda. The next step, many believe, is a plug-in hybrid, which would recharge overnight and allow a full day's typical driving off batteries. Naturally, costs have to decrease, but this is expected to be a matter of time. However, one challenge is that there must be sufficient "off-peak" electrical power available for such systems.

CONCLUSION

There are no easy answers to India's quest for energy security with environmental sustainability. The electric power sector appears to be more manageable, given India's thrust in nuclear power. The coming decades might see large additions in nuclear power generation capacity without significantly increasing the CO_2 emissions. The Indo-US nuclear agreement provides an opportunity to import LWRs and gives India time to commercialize the FBR and thorium-based reactors. At the same time, it will help to reduce India's dependence on coal to some extent.

The situation in the transport fuel sector is not so clear. Hydrogen technology is still decades away. India should increase its ethanol production without compromising sugar production. Drip irrigation and fertigation technologies can increase the sugarcane yield and consequently increase ethanol production to some extent at a reasonable cost. Ethanol from cellulosic feedstock, such as bagasse and rice husk, hold promise, and India should focus research efforts on commercializing these technologies. The two main alternatives for diesel substitution are bio-diesel and coal-based diesel. Bio-diesel, while renewable and carbon neutral, has large land requirements. Coal-based diesel, on the other hand, is energy intensive and results in CO_2 emissions. There is no clear winner. India may have to take a mixed approach, developing alternate fuels and also prime mover technologies, such as hybrids. In any case, achieving full gasoline or diesel replacement, or energy independence appears to be a distant proposition. In addition to introducing various innovations, both in technology and in policy, India should work to stabilize global energy supplies at favourable terms.

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