National Energy Map for India: Technology Vision 2030

Summary for policy-makers

The Energy and Resources Institute

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The Energy and Resources Institute
Darbari Seth Block
IHC Complex, Lodhi Road
New Delhi – 110 003, India

Tel. 2468 2100 or 2468 2111
Fax 2468 2144 or 2468 2145
India +91 • Delhi (0)11
E-mail teripress@teri.res.in
Web www.teriin.org

Office of the Principal Scientific Adviser,
Government of India
318, Vigyan Bhavan Annexe
Maulana Azad Road, New Delhi – 110 011
India

Tel. 2302 2112
Fax 2302 2113
India +91 • Delhi (0)11
Web www.psa.gov.in

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Preface

India has recorded impressive rates of economic growth in recent years, which provide the basis for more ambitious achievements in the future. However, a healthy rate of economic growth equalling or exceeding the current rate of 8% per annum would require major provision of infrastructure and enhanced supply of input such as energy. High economic growth would create much larger demand for energy and this would present the country with a variety of choices in terms of supply possibilities. Technology would be an important element of future energy strategy for the country, because related to a range of future demand and supply scenario would be issues of technological choices both on the supply and demand sides, which need to be understood at this stage, if they are to become an important part of India's energy solution in the future.

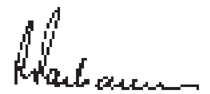
The Indian government aims to achieve an economic growth rate of over 8% in the next two decades in order to be able to meet its development objectives. However, rapid economic growth would also imply the need for structural changes in the economy as well as for induced shifts in the patterns of end-use demands. To meet the needs of the Indian populace in the most effective manner, it is important to map out the energy demand and supply dynamics in the country. This study estimates alternative trajectories of energy requirements and examines the likely fuel mix for the country under various resource and technological constraints over a 30-year time frame.

This study has been commissioned and supported by the office of the PSA (Principal Scientific Advisor) to the Government of India. The two-year study has drawn input from several organizations and sectoral experts across the country to gauge the likelihood of technological progress and availability of energy resources in the future.

The MARKAL model used in this study is a widely used integrated energy system optimization framework that enables policy-makers and researchers to examine the best technological options for each stage of energy processing, conversion, and use. This modelling framework was used to represent a detailed technological database for the Indian energy sector with regard to energy resources (indigenous extraction, imports, and conversion) as well as energy use across the five major end-use sectors (agricultural, commercial, residential, transport, and industrial).

The report discusses the data, assumptions, and methodological framework used to estimate useful energy requirements of the country based on demographic and economic drivers. Technological assessments of resources and energy conversion processes have been described in the report. Economic and technological scenarios have been developed within the integrated modelling framework to assess the best energy mix during the modelling time frame. Based on the scenario assessment, the report provides directions to various stakeholders associated with the Indian energy sector including policy-makers, technologists, and investors.

The report clearly points towards the country's increasing import dependence of all fossil fuels. It also indicates that coal would continue to play a key role in meeting the country's energy requirements. However, the indigenous availability of coal is expected to plateau in the next couple of decades with the current exploitation plans and technology. The need for energy efficiency in the end-use sectors and radical policy changes in the transport sector is also highlighted. The study points towards focussing efforts simultaneously on the demand and supply sides for the economy to attain the most efficient utilization of available resources.



(R K Pachauri)
Director-General, TERI

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Project team

Principal investigator	Leena Srivastava
Core team	Ritu Mathur, Pradeep K Dadhich, Atul Kumar, Sakshi Marwah, Pooja Goel
Sector experts in TERI	Amit Kumar, Shirish S Garud, Mahesh Vipradas, V V N Kishore, Pradeep Kumar, Alok Adholeya, Girish Sethi, N Vasudevan, Shashank Jain, Abhishek Nath, Upasna Gaur, Ananya Sengupta, Parimita Mohanty, K Rajeshwari, Ranjan K Bose, Sudip Mitra, R C Pal
Advisors	R K Pachauri, R K Batra, Y P Abbi, S K Chand, K Ramanathan, Preety M Bhandari
Project review monitoring committee	S P Sukhatme, S K Sikka, E A S Sarma, Y S R Prasad, R P Gupta, Chandan Roy, R K Saigal
Editorial and production team	Ambika Shankar, Archana Singh, Gopalakrishnan, Jaya Kapur, K P Eashwar, Richa Sharma, R K Joshi, R Ajith Kumar, Subrat K Sahu, T Radhakrishnan

Summary for policy-makers

Introduction

The GoI (Government of India) plans to achieve a GDP (gross domestic product) growth rate of 10% in the Eleventh Five Year Plan and maintain an average growth rate of about 8% in the next 15 years (Planning Commission 2002). Given the plans for rapid economic growth, it is evident that the country's requirements for energy and supporting infrastructure would increase rapidly as well. In order to enable policy-makers to undertake timely decisions, it is extremely important to estimate the magnitude of total energy requirements as well as examine the economic, environmental, and geopolitical implications of India's alternative energy pathways in the next few decades. While factors such as demographic profile, change in lifestyle, and consumer preferences dictate the level of useful energy demands, the availability and prices of resources and technologies influence the levels and patterns of final energy requirements in the future.

Realizing the importance of examining the role of various energy technology options for India's energy sector under alternative policy scenarios, the Office of the Principal Scientific Adviser to the GoI entrusted this study entitled 'National Energy Map: Technology Vision 2030' to TERI (The Energy and Resources Institute).

Approach

The key focus of this study was to examine the role that various technological options could play under alternative scenarios of economic growth and development, resource availabilities, and technological progress. For this purpose, it was important to choose an integrated energy-modelling framework that would facilitate the creation and analysis of various scenarios of energy demand and supply at the national level, as well as provide a detailed representation and analysis at the technological level for each category of resource as well as sectoral end-use demand.

After an extensive survey of existing models, the MARKAL (MARKet ALlocation) model was selected to examine the pathways for optimal energy supply to meet the end-use services in the five energy-consuming sectors (agriculture, commercial, residential, industrial, and transport) under various scenarios. MARKAL is a dynamic linear-programming representation of a generalized energy system. Exogenously estimated useful energy demands were provided to the model over a modelling time frame of 2001–31. Apart from indicating the minimized total system cost of the energy sector under various scenarios, the model results provide information regarding the level of uptake of total energy resources, their distribution across the consuming sectors, the choice of technological options at the resource supply, conversion and end-use levels, investment levels, an indication of capacity additions and retirements, emission level associated with resource supply, and end-use technological options adopted. The overall methodology is schematically described in Figure 1.

The availability and timeline of possible technological options (existing and futuristic) included in the model and their technological characterization were evolved on the basis of an extensive literature review. Additionally, it was important to draw on the knowledge base of experts from various energy consuming and supplying sectors to be able to provide input of adequate quality to the model. Therefore, several rounds of deliberations and focused interactions with sectoral experts, researchers, industry associations, R&D (research and development) institutions, government agencies, and policy-makers in each of the individual sectors were held via workshops to finalize the input data to the model.

Energy demands categorized by end use in each of the five major energy sectors were estimated using regression equations established using population and GDP as the key drivers to growth.

Energy scenarios

Seven alternative scenarios were set up against the BAU (business-as-usual) scenario to examine variations with regard to

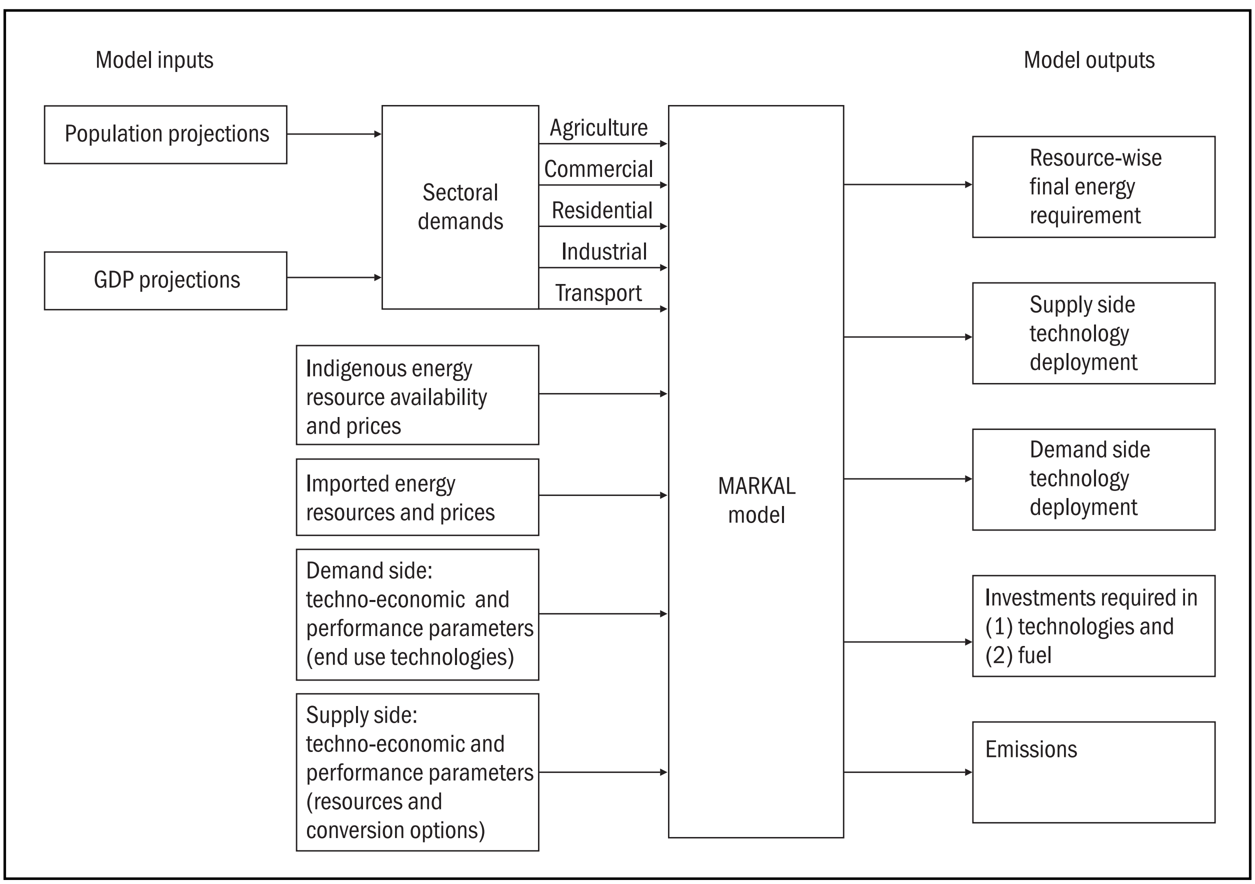

Figure 1 Schematic representation of methodological framework

economic growth and technological progress. Box 1 provides a brief description of these scenarios.

During the course of the study, it was felt that there was a strong need to focus attention on energy policy options in the transport sector on two accounts.

- Increasing trends of inefficiency in the sector due to the use of personal vehicles for passenger movement and enhanced road transportation for freight movement.
- Relatively low scope for supply-side alternatives to the use of gasoline and diesel, at least in the short term.

Accordingly, an additional set of policy scenarios was developed specifically for the transport sector in view of the country's high dependence on oil import and the concerns due to rising oil prices (Table 1).

Box 1 Description of scenarios

- LG (low growth) represents low GDP (gross domestic product) growth rate of 6.7%
- BAU (business-as-usual) represents energy development as per current government plans and policies, representing a GDP growth rate of 8%
- HG (high growth) represents a high GDP growth rate of 10%
- EFF (high efficiency) includes energy-efficiency measures spanning across all sectors
- REN (aggressive renewable energy) represents a high penetration of renewable energy forms
- NUC (high nuclear capacity) scenario considers an aggressive pursuit of nuclear-based power generation
- HYB (hybrid) scenario is a combination of the BAU, EFF, REN, and NUC scenarios
- HG-cum-HHYB (high-growth hybrid) represents a high growth rate of 10% in addition to the hybrid scenario

Table 1 Description of energy-efficiency scenarios for the transport sector

Scenario	*Description*
Enhanced share of public transport (PUB-PVT)	Share of public transport increased to 60% in 2036 as against 51% in the BAU scenario
Increased share of rail in passenger and freight movement vis-à-vis road (RAIL-ROAD)	▪ Railway freight share increased from 37% in 2001 to 50% in 2036 as against 17% in the BAU scenario ▪ Railway passenger share increased from 23% in 2001 to 35% in 2036 as against 23% in the BAU scenario ▪ Share of electric traction increased for rail passenger and freight to 80% by 2036 instead of 60% in the BAU scenario
Fuel efficiency improvements (FUEL EFF)	Fuel efficiency of all existing motorized transport modes increase by 50% from 2001 till 2036
Enhanced use of bio-diesel in transport sector (BIO-DSL)	Penetration of bio-diesel to 65 Mtoe by 2036
Transport sector hybrid (TPT-HYB)	Incorporates all the above-mentioned measures in addition to BAU

Mtoe – million tonnes of oil equivalent; BAU – business-as-usual

Key findings

The main findings of this study are discussed below.

Total commercial energy requirements

Table 2 presents the commercial energy requirements across various scenarios. In the BAU scenario, the total commercial energy consumption is estimated to increase by 7.5 times over the 30-year modelling period from a level of 285 Mtoe (million tonnes of oil equivalent) in 2001 to 2123 Mtoe in 2031. A comparison of energy requirements across the alternative economic growth scenarios indicates that if the economy grows at a slower pace of 6.7%, as characterized by the LG (low-growth) scenario, commercial energy requirement would increase to only about 1579 Mtoe by 2031 (5.9% GDP growth), while the energy requirements could be as high as 3351 Mtoe (8.6% GDP growth) by 2031 with a growth rate of 10% as represented by the HG (high-growth) scenario.

Although, the Indian government has plans for enhancing the exploitation of its hydro power, nuclear energy, and renewable energy resources, the analysis indicates that the impact of these supply-side alternatives is minor when compared with the total requirements of commercial energy by 2031, as indicated in the REN (aggressive renewable energy) and NUC (high nuclear capacity) scenarios. Although the contribution of hydro, nuclear, and renewable energy forms together increases by about six times during 2001–31, these sources can at most contribute to a mere 4.5% of the total commercial energy requirements over the modelling time frame. It is, therefore, evident that the pressure on the three conventional energy forms, that is coal, oil, and gas will continue to remain high at least in the next few decades.

The EFF (high-efficiency) scenario, however, indicates that there exists a significant scope for reducing energy (~ 581 Mtoe in 2031) if efficiency measures are deployed on both the demand as well as the supply side.

These reduction possibilities exist primarily in the power, industrial, and transport sectors, and can lead to energy displacement during the modelling period mainly in terms of coal (~ 337 Mtoe in 2031) and oil (~ 244 Mtoe in 2031).

The HYB (hybrid) scenario indicates that energy requirements by the year 2031 would be of the order of those in the LG scenario,

Table 2 Variation in commercial energy consumption across various scenarios (Mtoe)

Scenario	*2001/02*	*2006/07*	*2011/12*	*2016/17*	*2021/22*	*2026/27*	*2031/32*
BAU	285	391	527	749	1046	1497	2123
REN	285	391	524	740	1033	1479	2097
NUC	285	391	527	749	1030	1455	2061
EFF	285	379	479	623	838	1131	1542
HYB	285	379	478	619	823	1101	1503
LG	285	361	456	605	816	1134	1579
HG	285	435	638	962	1438	2186	3351
HHYB	285	405	544	760	1087	1576	2320

BAU – business-as-usual; REN – aggressive renewable energy; NUC – high nuclear capacity; EFF – high efficiency; HYB – hybrid; LG – low growth; HG – high growth; HHYB – high-growth hybrid; Mtoe – million tonnes of oil equivalent

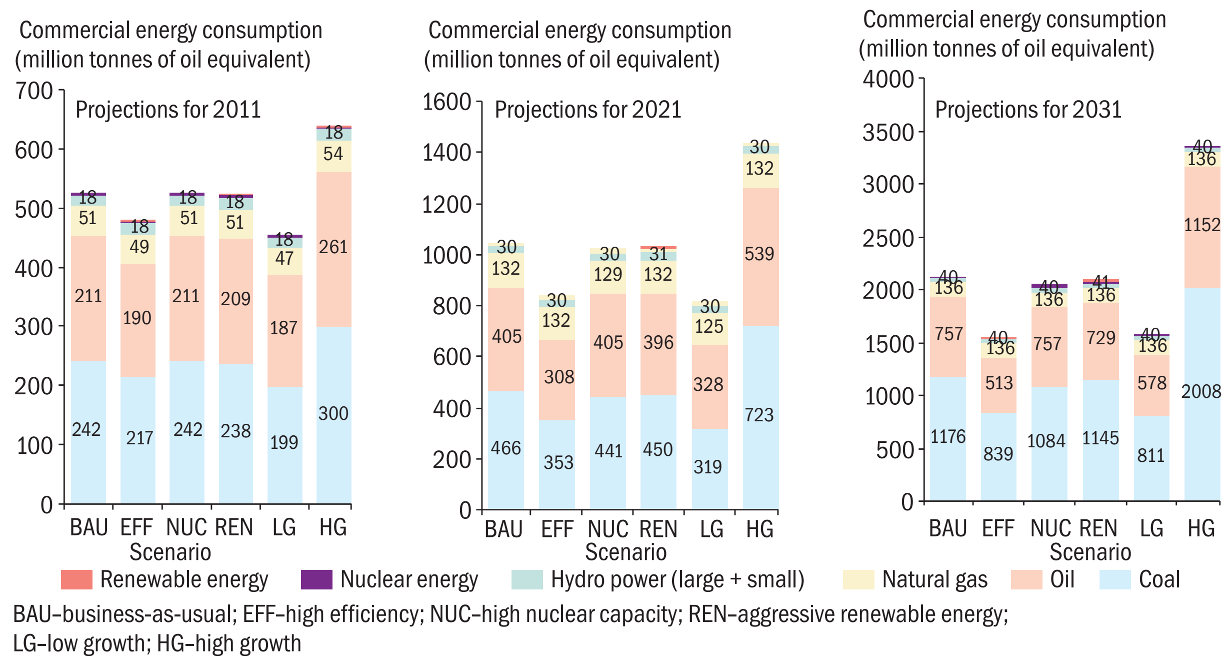

Figure 2 Fuel-wise commercial energy consumption in 2011, 2021, and 2031 in alternative energy scenarios

while those in the HHYB (high-growth hybrid) scenario would be in the range of requirements in the BAU scenario.

Gas is a preferred option for power generation as well as fertilizer production. However, while the domestic availability of natural gas is estimated to plateau at about 44 Mtoe by 2012, imports of gas are fraught with uncertainty. Accordingly, coal and oil are expected to remain the dominant fuels in the next couple of decades. In the BAU scenario, the share of coal in commercial energy ranges between 45% and 55% during the entire modelling time frame, while the share of oil ranges between 36% and 40% (Figure 2). However, the HYB scenario indicates the potential to reduce coal and oil requirements as compared to the BAU scenario during the modelling time frame with adequate and timely policy and technological intervention.

Identification of main demand- and supply-side interventions for India's energy sector

Based on the analysis of the model results, the key interventions can be delineated as follows.

- Enhancing end-use efficiencies (intervention 1, I-1).
- Adopting advanced coal- and gas-based power generating technologies (intervention 2, I-2).
- Enhancing the exploitation of renewable energy and nuclear energy resources (intervention 3, I-3).
- Enhancing efficiency in the transport sector by modal shifts (intervention 4, I-4).

Accordingly, Figure 3 shows the possibilities of reducing commercial energy requirements over the 30-year modelling time frame

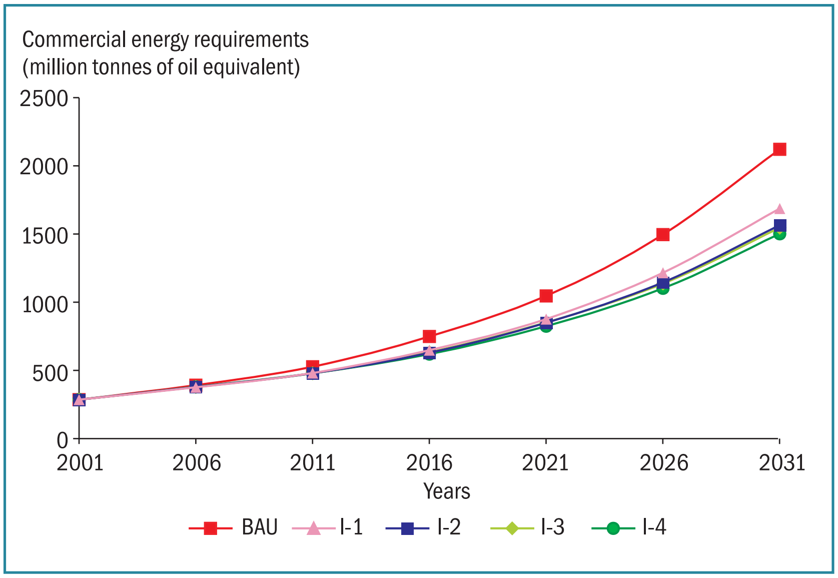

Figure 3 Scope for reducing commercial energy requirements

The potential savings due to end-use efficiency alone increase from about 28 Mtoe in 2011 to 106 Mtoe in 2021, and 294 Mtoe in 2031 across all the sectors.

The possibility of commercial energy saving due to advanced coal- and gas-based power generating technologies is represented by the area between I-1 and I-2 in Figure 3.

The model results indicate that in order of economic merit, the preferred power generation technologies are: (1) large hydro; (2) refinery-residue-based IGCC (integrated gasification combined cycle); (3) imported-coal-based IGCC; (4) high-efficiency CCGT (combined cycle gas turbine) (H-frame gas turbine); (5) indigenous-coal-based IGCC; (6) normal CCGT; (7) ultra-supercritical boiler; and (8) supercritical boiler.

against the above-mentioned set of interventions. It is observed that from a level of 2123 Mtoe in 2031 in the BAU scenario, commercial energy requirements can be reduced significantly to 1503 Mtoe in the I-4 scenario. Thus, a reduction of about 620 Mtoe (more than twice the total commercial energy requirements in 2001) can be achieved by undertaking an integrated approach of adopting demand-side as well as supply-side alternatives in the energy sector.

As indicated in Figure 3, the scope for energy reduction is the maximum from end-use efficiencies in the demand sectors as represented by the area between BAU and I-1. In 2031, each of the end-use sectors has a potential to reduce energy consumption between 15% and 25% of the energy use in the BAU scenario. However, given the relative weight of each sector in the total energy use, the industry and transport sectors have the highest potential for energy savings, amounting to 44% and 41% in 2011, respectively, 42% and 44% in 2021, respectively, and 41% and 47%, respectively, in 2031.

Although the government already has plans to exploit its hydro power potential, additional efforts should be directed towards replacing the sub-critical coal-based power generation technology with efficient options such as IGCC and H-frame CCGT, which can play a significant role in reducing the country's coal requirement. It is observed that about 122 Mtoe of coal consumption could be reduced by 2031 by moving to these more efficient power generation options (Figure 4).

Further, another 72 Mtoe of coal for power generation could be displaced by enhanced nuclear-energy and renewable-energy-based power generation, which is represented by the area between I-2 and the trajectory I-3 in Figure 4.

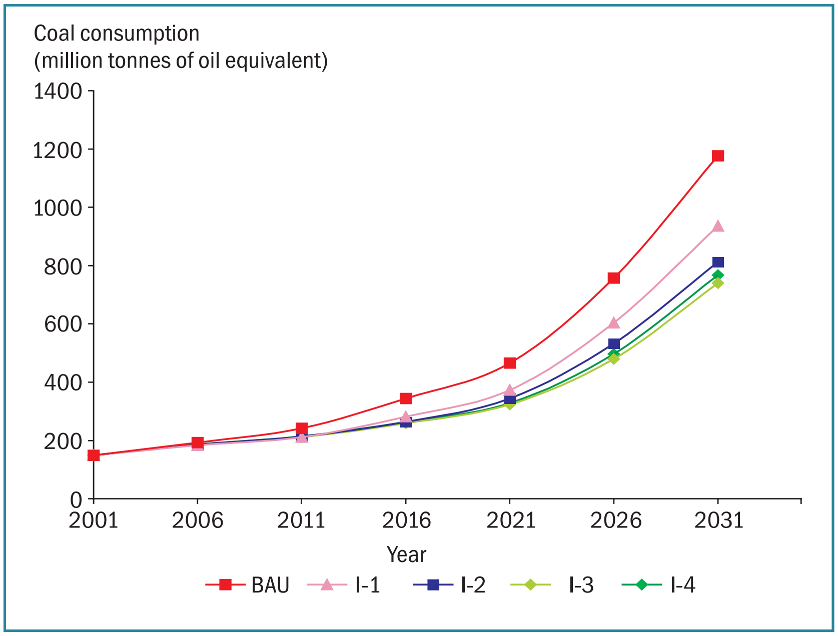

Figure 4 Coal consumption across various interventions and scenarios

With the likely growth in energy demands and it is clear that the maximum annual production potential of all the conventional energy forms will be fully exploited by 2016, and the country would need to increase its imports of coal, oil, and gas in the future.

Moreover, as indicated in Figure 5, in the BAU scenario, imports of all the conventional energy forms would increase significantly from the 2001 levels. Although the scope for reducing import dependency seems minor even in the HYB scenario, all efforts need to be focused towards this end, which have implications on energy security as well as foreign exchange outflows of the economy.

Although the requirement for total electricity reduces only due to end-use efficiencies in each of the consuming sectors, the primary commercial energy requirements are determined also by the choice of power generating technology. In the BAU scenario, power generation capacity increases to 795 GW (gigawatts) by 2031. The model results indicate that with the end-use efficiencies alone, power generating capacity could reduce by 128 GW in 2031 (which is of the order of total power generating capacity in 2001). IGCC and H-frame CCGT are almost equally preferred options for power generation and their introduction leads to the displacement of the coal sub-critical technology.

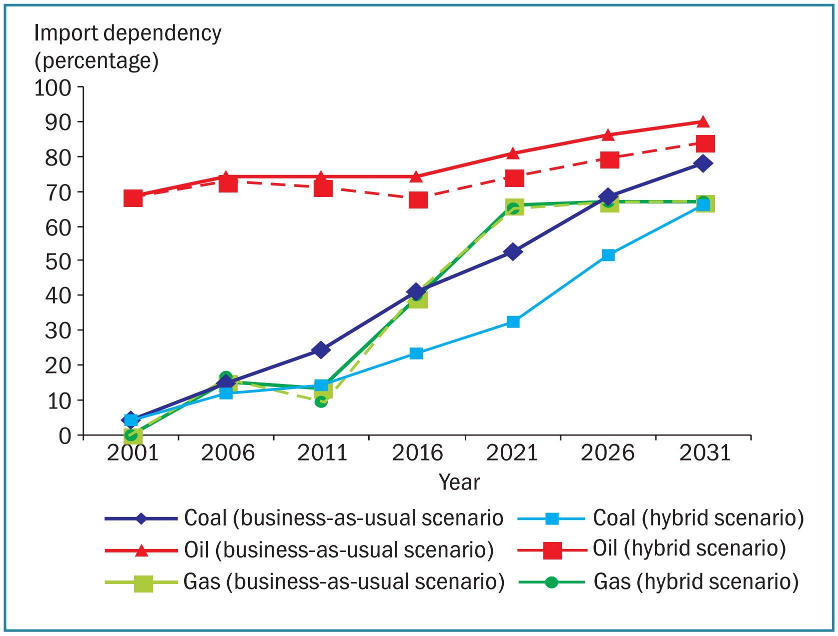

Figure 5 Fuel-wise import dependency

Transport sector options

The consumption patterns in the transport sector indicate that despite rising oil prices, demands for passenger and freight movement have been rather inelastic with regard to fuel prices.

In the BAU scenario, the total energy consumption in the transport sector is estimated to increase by about 14 times from 34 Mtoe in 2001 to 461 Mtoe in 2031 (Figure 6).

The analysis of the transport sector indicates that although much of the fuel reduction possibility in this sector can be related to autonomous efficiency improvements of the transportation modes, efforts should be made to enhance rail-based movement and the use of public transportation. This will go a long way in reducing the transport sector's dependence on oil. By targeting action on the demand as well as supply sides in the transport sector in the TPT-HYB scenario, a reduction of about 190 Mtoe of energy can be achieved in 2031 as compared to the BAU scenario.

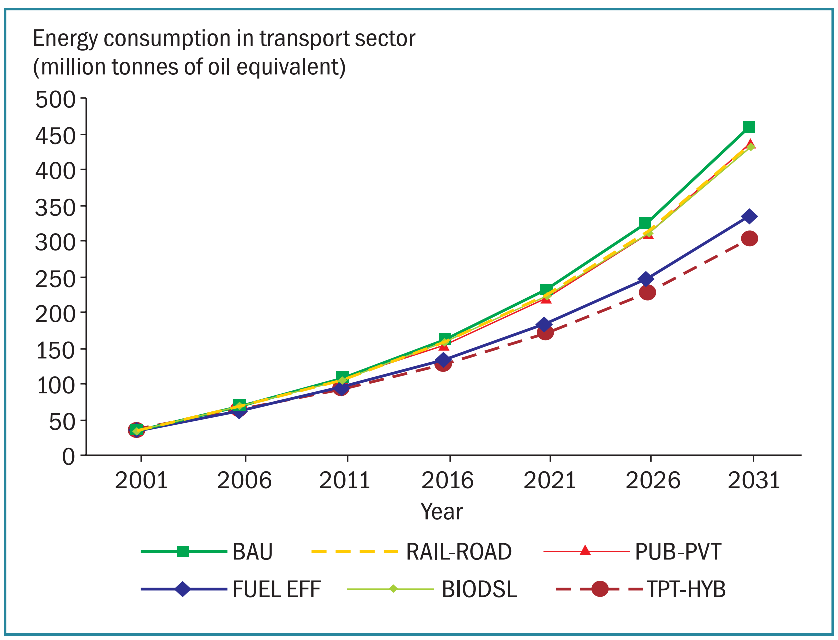

Figure 6 Comparison of energy consumption in the transport sector across various scenarios

The Sankey diagram shown in Figure 7 depicts the Indian energy balance for 2001 in the BAU scenario, which amounts to 11 917 PJ (petajoules). It is observed that the highest losses occur during the generation of coal-based power and account for about 2924 PJ representing 25% of the total energy supply. The second-largest energy loss occurs in the transmission and distribution of electricity, amounting to 590 PJ (5% of the total energy supply to the economy), which is higher than any of the electricity consuming sectors. Fuel and oil losses account for about 316 PJ, followed by conversion losses related to gas-based power generation (amounting to 219 PJ).

Figure 8 depicts the energy flows in the Indian economy in the BAU scenario in 2031 amounting to 88 879 PJ. Conversion losses related to coal-based power generation are still the highest, constituting about 21% of the total energy supply. Power transmission and distribution losses continue to be significant (amounting to 2864 PJ or 3% of the energy supplied), followed by conversion losses in gas-based power generation, and fuel and oil losses representing 2037 PJ (1.7% of the energy supply) and 2089 PJ (1.8% of the energy supply), respectively.

The Sankey diagram shown in Figure 9 represents the energy flow in the Indian economy under the EFF scenario in the year 2031. Total energy requirements are 27% lower than in the BAU scenario amounting to 64 574 PJ. Conversion losses related to coal-based power generation constitute only 14% (8798 PJ) of the total energy supply, while losses in the transmission and dis-

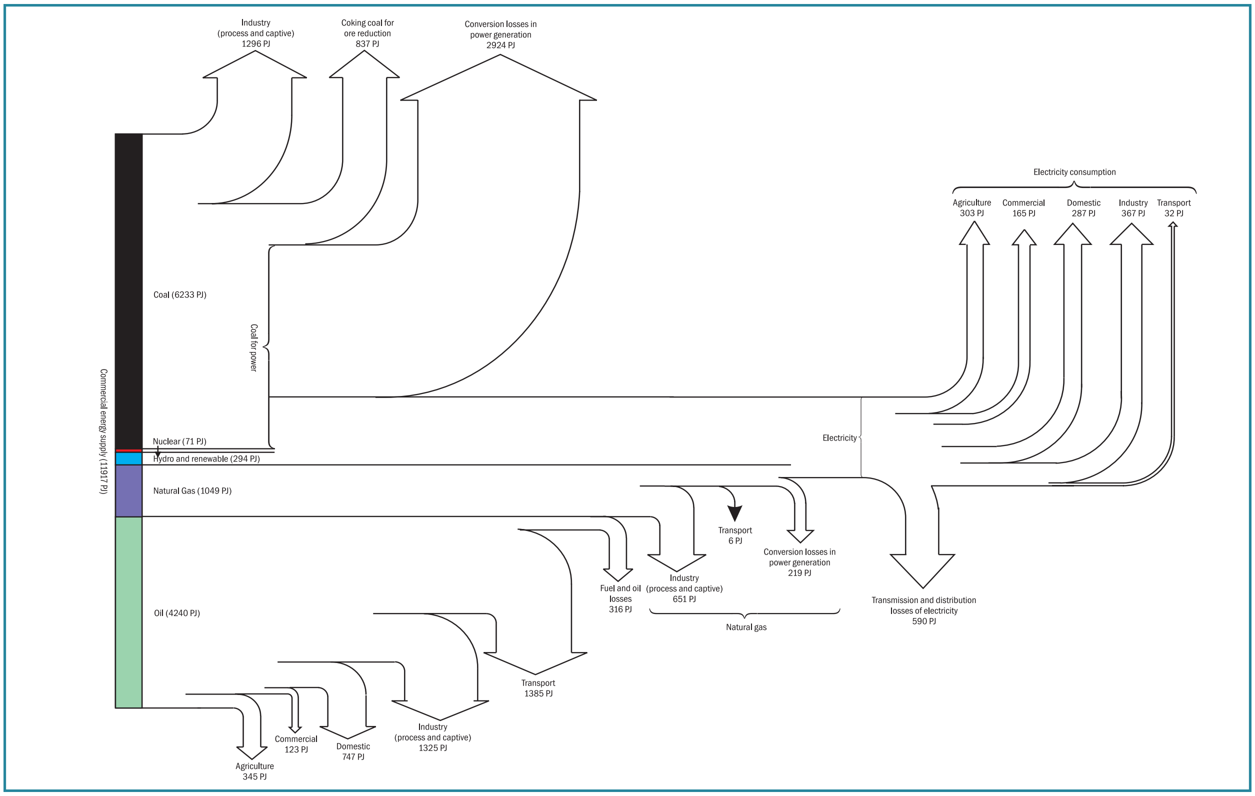

Figure 7 Sankey diagram for the business-as-usual scenario (2001)

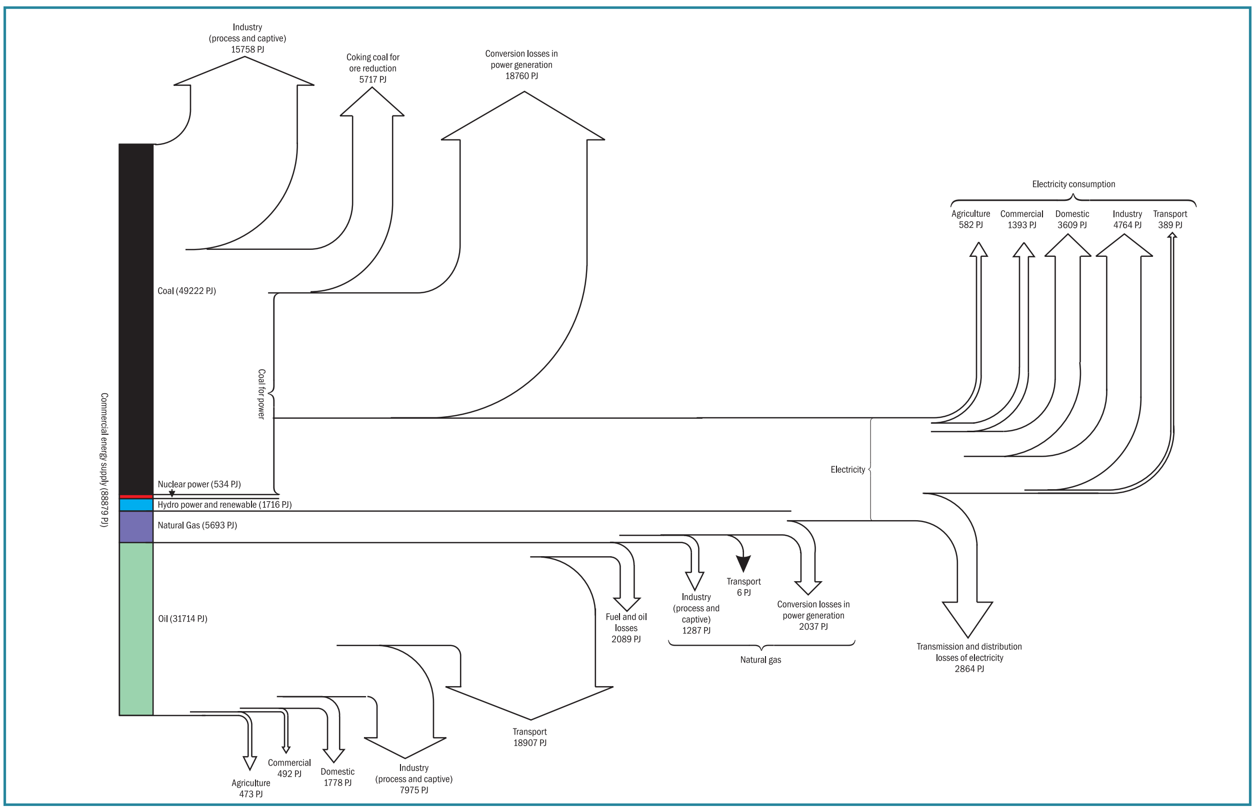

Figure 8 Sankey diagram for the business-as-usual scenario (2031)

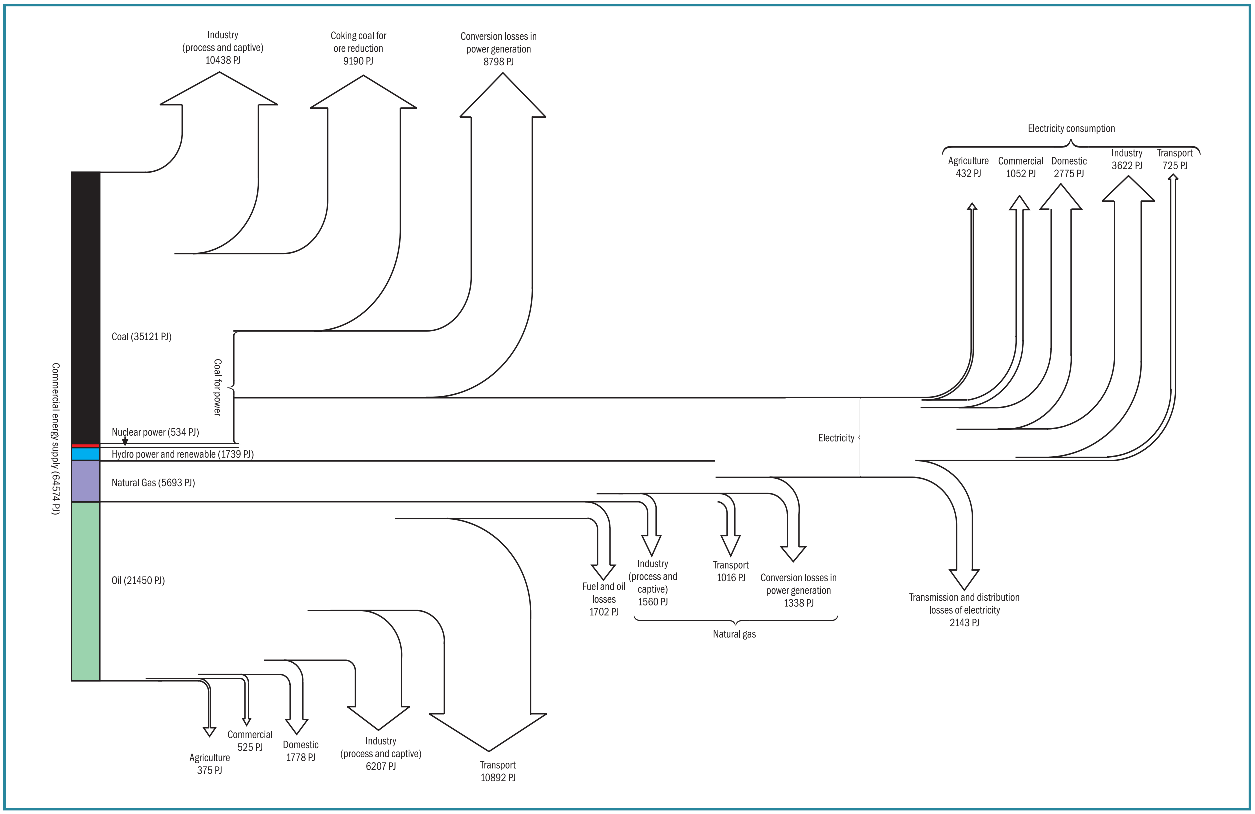

Figure 9 Sankey diagram for the high-efficiency scenario (2031)

tribution of power account for 3% (2143 PJ) of the total energy supply. The fuel and oil losses in the refining and gas-based power generation are 2.6% (1702 PJ) and 2% (1338 PJ), respectively, of the total energy supply.

Need for an integrated energy planning approach

Figure 10 depicts the trends in energy intensity in each of the alternative scenarios developed in this study against the BAU scenario. It is observed that even in the BAU scenario, energy intensity exhibits a declining trend, from 0.022 kgoe (kilogram of oil equivalent)/rupee of GDP in 2001 to 0.017 kgoe/rupee of GDP in 2031 (a decrease of 23%). This implies that even with a GDP growth rate of 8%, and government plans and policies materializing as planned, the Indian economy is already expected to be progressing along an energy-efficient path.

The second observation is that much of the scope for further reduction in energy intensity exists due to the adoption of efficiency measures rather than the supply-side options such as the enhanced pursuit of nuclear-energy- and renewable-energy-based power generation technologies. In the EFF scenario, energy intensity could decrease from 0.022 kgoe/rupee of GDP in 2001 to 0.012 kgoe/rupee of GDP in 2031.

An analysis of the two integrated energy policy scenarios, that is, the HYB (representing an integrated policy approach at 8% GDP growth) and the HHYB (representing an integrated policy approach at 10% GDP growth) suggest that supply-side options alone would not be able to reduce energy intensity significantly. It is, therefore, necessary to simultaneously adopt measures on

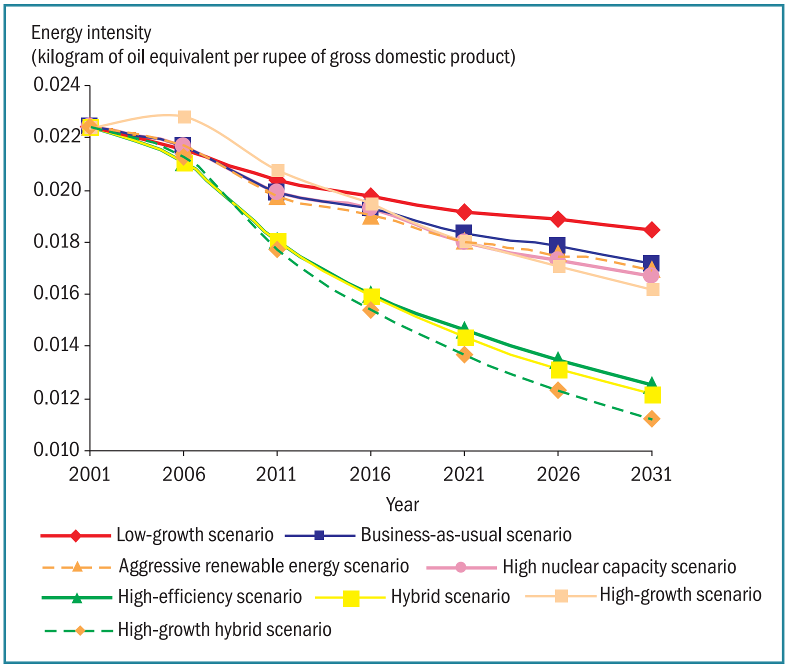

Figure 10 Trends in energy intensity from 2001 to 2031

the demand and supply sides. Moreover, it is best for the economy to pursue a high economic growth (10% GDP) while targeting exploitation of alternative energy forms as well as efficient technology options from the demand as well as supply side. With this approach, the economy would not only be able to meet its developmental goals but also ensure rapid economic growth, making sure that this growth is achieved with the lowest possible energy intensity (reaching 0.011 kgoe/rupee of GDP by 2031 in the HHYB scenario).

Recommendations

The results of the modelling exercise indicate that from the viewpoint of energy security and the need to reduce its dependence on imports of all the conventional energy fuels, the country needs to undertake all possible options on the demand and supply side simultaneously to reduce its total energy requirements as well as diversify its fuel resource mix. Towards this end, the economy would need to pursue an integrated approach to energy planning. The key elements that should constitute such an integrated planning exercise are suggested in the following sections along with a graded classification scale to help delineate the immediate priority areas from the other options.

Provide a thrust to exploration and production of coal

The study clearly indicates that coal would continue to be the mainstay, accounting for about 45%–55% of India's commercial energy mix throughout the modelling time frame in each of the scenarios.

By 2031, imports of coal in the BAU scenario are expected to be about 1176 Mtoe. Even at the current price of 60 dollars/tonne for imported coal, this would translate to a foreign exchange outflow of about 400 thousand crore rupees.

With coal demand expected to increase in the Asian market, prices of coal may also increase rapidly, exerting greater pressure on the economy. Therefore, it is extremely important to reduce the import dependency of coal by gearing up the exploration and production activity in this sector with a view to increase the extractable coal reserves. For this, a multi-pronged approach consisting of following elements would need to be adopted.

- Bringing about technological up-gradation of mining technologies.
- Opening up of the coal sector to private investors. A policy similar to the new exploration policy of the Ministry of Petroleum and Natural Gas, GoI, may be

adopted after modifications to suit the coal sector requirements.

- Strengthening the CMPDIL (Central Mine Planning and Design Institute Ltd) to undertake greater R&D (research and development) efforts, and scale up its efforts to improve coal extraction technology and methods, especially beyond 300-m (metre) depth.
- Undertaking joint ventures for extraction of coal from deep coal seams with a view to upgrade technology and improve productivity
- Adopting advanced exploration and production technologies to identify and produce coal from seams beyond 300 m.

Involving private sector in exploration and production of hydrocarbons

Although the initiatives taken by the DGH (Directorate-General of Hydrocarbons) are already producing results in the exploration and production area, recent findings by the Reliance and other joint venture operations indicate possibilities of much greater findings in the oil and gas sector. NELP-V (New Exploration and Licensing Policy-V) is a step in the right direction but it is important to continue pursuing exploratory efforts for tapping indigenous oil and gas.

Steps towards energy security in hydrocarbons

India's high dependence on oil import reflected in various scenarios indicates the economy's vulnerability to oil supply disruptions (emanating from external factors such as wars and political instability) and adverse impacts of sudden oil price shocks.

Since the transport sector accounts for most of the oil consumption, it is also the most crucial sector in terms of requiring action for improving efficiency and enhancing possibilities of conservation and substitution through the use of alternative fuels and technologies. Enhancing the share of public transport and rail-based movement; introduction of alternative fuels such as CNG (compressed natural gas), bio-diesel, and ethanol; and autonomous efficiency improvements in vehicles could reduce the import dependency of petroleum products from about 74%, 81%, and 90% in the BAU scenario to 72%, 76%, and 85% in the HYB scenario for 2011, 2021, and 2031, respectively.

Reduce coal requirements

It is observed that coal would continue to account for 50% of the energy mix, with about 70% being used by the power sector. The model results indicate that maximum reduction in the energy requirements can be achieved in the power sector on the supply side.

Since coal-based power generation will continue to play a critical role in the next 30–50 years, it becomes essential to adopt well-proven technologies like supercritical and ultra-supercritical boilers in the immediate future, that is, in the Eleventh Five Year Plan instead of using sub-critical technology. The Benson boiler was first designed in 1924 (Siemens Power Generation 1995), and since then, these boilers are being designed and operated at higher steam properties (for example, pressures of 300 bars and temperatures greater than 600 °C). It is strongly recommended that India adopt this technology immediately. Experience worldwide has shown that Benson boilers become cost-effective if the unit size is about 1000 MW (megawatts) or more.

Also, it is important to accelerate the transition to other efficient coal-based power generation technologies such as the IGCC technology. For this purpose, demonstration plants using IGCC should be set up to address the issue of technology barrier. Faster learning can be achieved by outright purchase of technology. A continued effort is required in this direction to achieve sustained adoption of the emerging technologies. For example, in case of the indigenous development of supercritical boilers, the phased manner of technology development was adopted.

With increased refining capacity, refinery residue such as vacuum residue and petroleum coke will be available on a large scale. It is recommended that refinery-residue-based IGCC power generation plants also be set up. International experience in this technology is already available. Handling refining residue is comparatively easier than handling high-ash coal for gasification for the production of 'syn' gas and its use in gas turbines for power generation. The government should adopt this technology as soon as possible.

Further, adoption of aero-derivative advanced gas turbines like H-frame for power generation should be aggressively promoted. In future, it is possible that natural gas reserves will increase, especially due to the efforts of the GoI in deep-sea exploration as also due to the viability of extracting natural gas from gas hydrates. Therefore, aggressive adoption of advanced gas turbine will also help in enhancing the efficiencies of IGCC plants. It will also be helpful if the GoI can adopt a research programme on advanced gas turbine in national research institutions or laboratories like National Aeronautics Ltd and Hindustan Aeronautics Ltd.

Apart from the power sector, the possibility for reducing coal exists in steel reheating furnaces, ceramic industry, brick units, and in adoption of blended cements and improved technology in coal-based captive power generation units. Appropriate pricing of energy would play a crucial role in this regard.

Reduce consumption of petroleum products

Since the transport sector accounts for nearly 70% of the total petroleum consumption, the following measures are recommended to reduce the consumption of petroleum products and thereby their import dependency.

- Enhancing the share of public transportation, promoting MRTS (Mass Rapid Transit System), ensuring better connectivity of trains to urban areas of the cities, introducing high capacity buses, and so on.
- Electrifying the railway tracks to the maximum extent possible.
- Increasing the share of rail in freight movement by enhancing container movement and providing door-to-door delivery systems.
- Introducing Bharat-III norms across the country for road-based personal vehicles
- Introducing cleaner fuels such as low-sulphur diesel, ethanol blending, and bio-diesel.

In the industry sector, given the inefficient diesel consumption by the DG sets for captive power generation, phasing out the use of diesel in industry as well as in the agriculture sector is recommended. Provision of reliable power supply is imperative to achieve this.

Use of naphtha for fertilizers production and power generation should be avoided to make it available for the petrochemicals sector. Natural gas should, therefore, be made available in adequate quantities for off-take by the fertilizer industry and power plants.

Natural gas to be the preferred fuel for the country

The study clearly indicates that natural gas is a preferred option for power generation as well as for the production of nitrogenous fertilizer. The availability of natural gas, therefore, needs to be facilitated by removing infrastructural constraints. Besides its high end-use efficiency, it is a cleaner fuel and relatively much easier to handle than coal. It is, therefore, important to enhance natural gas exploration and production from deep sea. Additionally, efforts should be made to source gas from within the Asian region (including Turkmenistan, Bangladesh, Iran, and Myanmar).

Make renewable energy resources competitive, and target their use in remote areas and for decentralized power generation

Renewable-energy-based power generation is not a preferred option due to the high upfront costs and low capacity utilization of these technologies. However, renewable energy resources play a crucial role to play in providing decentralized power to remote areas. Apart from continuing to provide support to renewable energy schemes, efforts should also be directed towards large-scale deployment of related technologies in order to further bring down their costs. Decentralized power generation, especially in remote locations where the grid cannot be extended, should necessarily be based on renewable energy forms to provide these regions with access to clean and reliable energy.

Hydro power

Despite its low capacity utilization factor, hydro power is a cheap option as indicated by the model. Accordingly, investments in hydro power should be accelerated to tap this perennial source of power.

Nuclear power

Since additional nuclear-based capacity displaces coal, it is important to enhance the penetration of this option to the extent possible. Efforts should be directed to step up nuclear capacity to about 70 GW during the modelling time frame, from 2001 to 2031. However, if the modelling time frame is extended beyond 2030, positive impacts of nuclear energy in the form of advanced thorium-based reactors can be realized, with an estimated potential of about 530 GW.

Recommendations for the industry sector

- Ban import of second-hand machinery, for example, in sponge iron plants and paper mills
- Use cleaner fuels
- Facilitate shift towards cogeneration, tapping waste heat for process heat
- Provide support to large-, medium-, and small-scale industry
- Sub-sectoral technology options that will result in large-scale energy savings include the following.
    - Introduce blast furnace with top recovery turbine in integrated steel plants, BOF (basic oxygen furnace) for steel making, and continuous casting for finished steel
    - Adopt and improvise COREX process for integrated steel plants
    - New cement plants to adopt six-stage preheating, and use blending materials like slag and fly ash
    - Move towards larger integrated paper mills with continuous digesters, black liquor boilers, and cogeneration
    - Adopt efficient pre-baked electrodes in aluminium manufacturing process

Recommendations for the residential and commercial sector

- Lighting is the major electricity-consuming end-use in the residential sector. The replacement of light bulbs with tube lights and CFLs (compact fluorescent lamps) can bring about huge energy savings. Towards this end, the cost of CFLs needs to be reduced by promoting their large-scale manufacturing.

- Even with a conservative estimate of efficiency improvement possibilities, there exists tremendous scope for savings in the residential and commercial space conditioning. For this, it is necessary to make available efficient motors as against local makes, provide incentives to buy from government certified outlets, and create awareness among consumers.
- Tradition fuels need to be replaced with cleaner fuels. Although traditional fuels such as dung, firewood, and crop residue are freely available, the low efficiencies, highly polluting nature, and other social and environmental impacts associated with their use do not make them a sustainable option in the long term. Although government initiatives would ensure that majority of the population is provided with access to modern fuels (city gas and liquefied petroleum gas), some of the rural poor are expected to continue supplementing their energy needs with freely available traditional fuels. For the population that has not shifted to cleaner options, programmes for improved cookstoves, and so on should be continued.

Rationalize agricultural power tariffs

Power tariffs for the agricultural sector should be at least at a level where the cost of generation can be recovered.

Enhance efforts to tap alternative indigenous energy sources

In order to minimize the levels of import dependency in the future, it is imperative to focus on increasing the supply of indigenous energy resources. Hence, India should plan to enhance efforts in R&D in the exploration and production of energy resources; especially in the area of deep-sea natural gas exploration, extraction of coal from seams that are over 300-m deep, in-situ coal gasification, and gas hydrates.

Transmission and distribution loss

It is also possible to reduce technical transmission and distribution losses to the level of 8%–12% as against 16%–19% in the country. The technologies for these would be to adopt very high-voltage AC transmission and HVDC (high-voltage DC transmission). The distribution losses can be reduced by adopting energy-efficient transformers that use high-grade steel in the transformer core to reduce hysterical losses.

Tables 3 and 4 show the pathways that are apparent to achieve these goals over the next 30 years.

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Table 3 Suggested technology deployment pathway for power generation

Technology	2006	2011	2016	2021	2026	2031	Impact on energy system	Recommendation
Hydro power	Technology is mature and available indigenously						Low	Immediate implementation may be carried out
Supercritical boilers	Technology is mature and available indigenously						Medium	Immediate implementation instead of sub-critical boilers
Ultra-supercritical boilers	Technology is mature and available internationally						Medium-high	Strongly recommended to implement immediately
Advanced aero-derivates gas turbines—H-frame	Technology is mature and available internationally						Medium-high	Strongly recommended to implement immediately
IGCC based on refinery residue	Technology is mature and available internationally						Medium	Strongly recommended to implement immediately
IGCC based on imported coal	Technology sourcing demonstration project		Technology learning and cost reduction		Commercialization of technology		Very high	Plan for commercial-scale demonstration project
IGCC based on indigenous coal	R&D and demonstration project		Technology learning and cost reduction		Commercialization of technology		Very high	Plan for commercial-scale demonstration project
Nuclear fast breeder reactor	R&D and demonstration project based on indigenous technology		Technology learning and cost reduction		Commercialization of technology		Very high	Strongly recommended to progress as per the plans of GoI
Nuclear-thorium-based rectors	R&D and pilot plant studies based on indigenous technology development		Technology scale-up from pilot plant to demonstration plant		R&D and demonstration project based on indigenous technology		Very high	Strongly recommended to progress as per the plans of GoI

IGCC–integrated gasification combined cycle; R&D – research and development; GoI – Government of India

Table 4 Suggested technology deployment pathway for end-use sectors

	2006	2011	2016	2021	2026	2031	Impact on energy system	Recommendation
Industry								
Industrial cogeneration	Technology is mature and available indigenously						Low	Strongly recommended to implement immediately
Waste recovery	Technology is mature and available indigenously						Low	Strongly recommended to implement immediately
Residential								
CFL	Technology is mature and available indigenously						Medium-high	Strongly recommended to implement immediately
LED	Technology is mature and available indigenously						Medium-high	Strongly recommended to implement immediately
Refrigerators (energy efficient)	Technology is mature and available indigenously						Medium-high	Strongly recommended to implement immediately
Air conditioners (energy efficient)	Technology is mature and available indigenously						Medium-high	Strongly recommended to implement immediately
Transport								
Integrated transport system	Technology is mature and available indigenously, needs to be integrated in urban planning						Medium-high	Strongly recommended to implement immediately
Efficiency improvements in automobiles	Technology is mature and available internationally						Medium-high	Strongly recommended to implement immediately

Impact on energy system	
Low	This means that the technology has an impact of less than 5% on the energy system, if implemented on a wide scale.
Medium	This means that the technology has an impact of 5%–10% on the energy system.
Medium-high	This means that the technology has an impact of 5%–15% on the energy system.
High	This means that the technology has an impact of 10%–15% on the energy system.
Very high	This means that the technology has an impact greater than 15% on the energy system.

CFL – compact fluorescent lamp; LED – light emitting diode