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GHG Mitigation Strategies and Energy Options: A Case Study for India

Vijay INAMPUDI SARADHI

Bhabha Atomic Research Centre
Mumbai
India

Joint IAEA/ICTP Workshop on Alternative Response Actions to Climate Change and Energy Options

I.V. Saradhi

Bhabha Atomic Research Centre

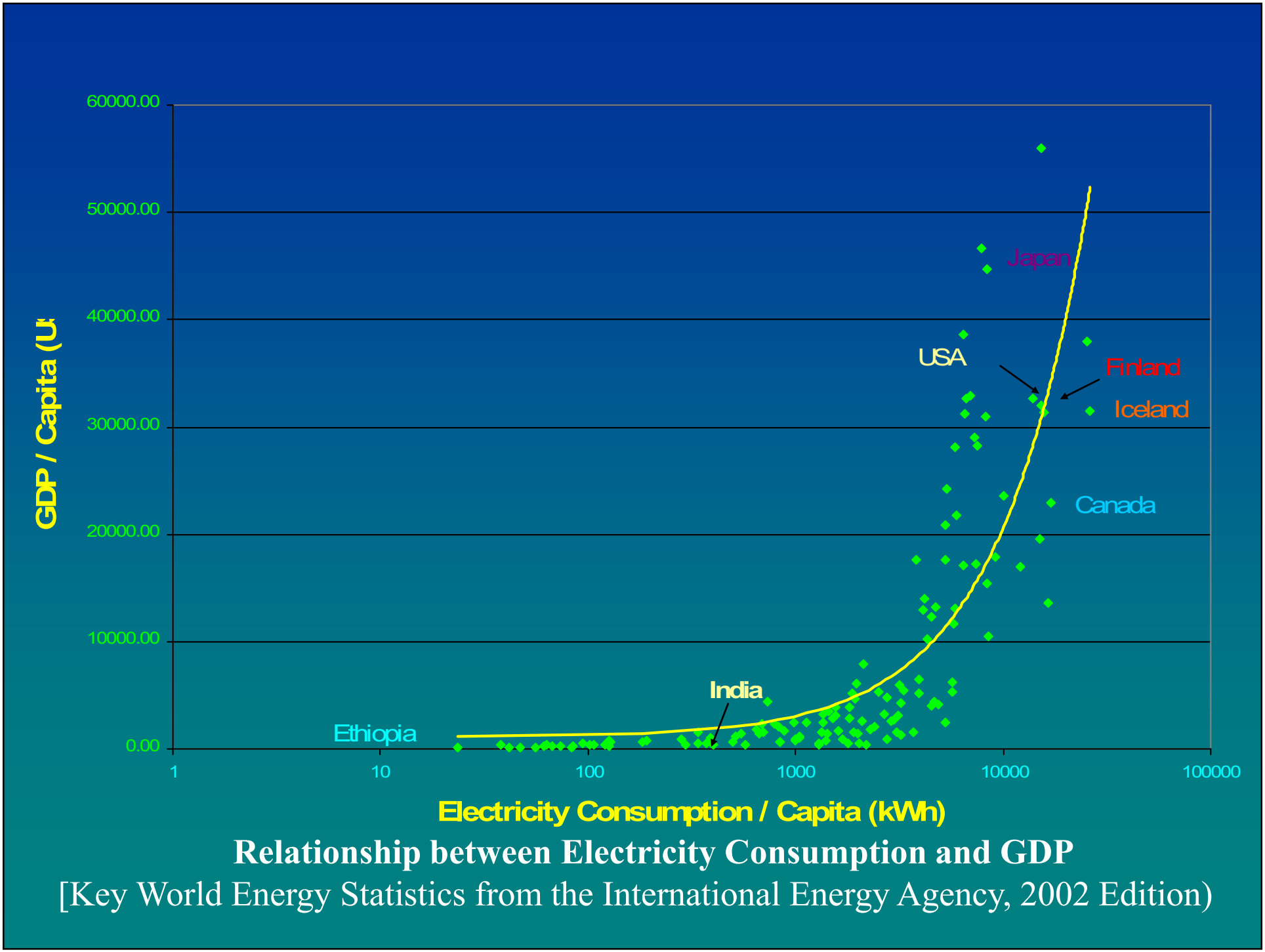
Mumbai, India

Indian Energy Scenario

- Policy initiatives of the Government of India during the past decade have resulted in a faster growth of GDP and forecasts by several agencies point towards continued growth of the India economy over next 30 to 40 years.

- High economic growth in India resulting in a rapid increase in energy consumption. The Government is restructuring the Indian energy markets to improve the economic performance and to bolster energy security and efficiency.

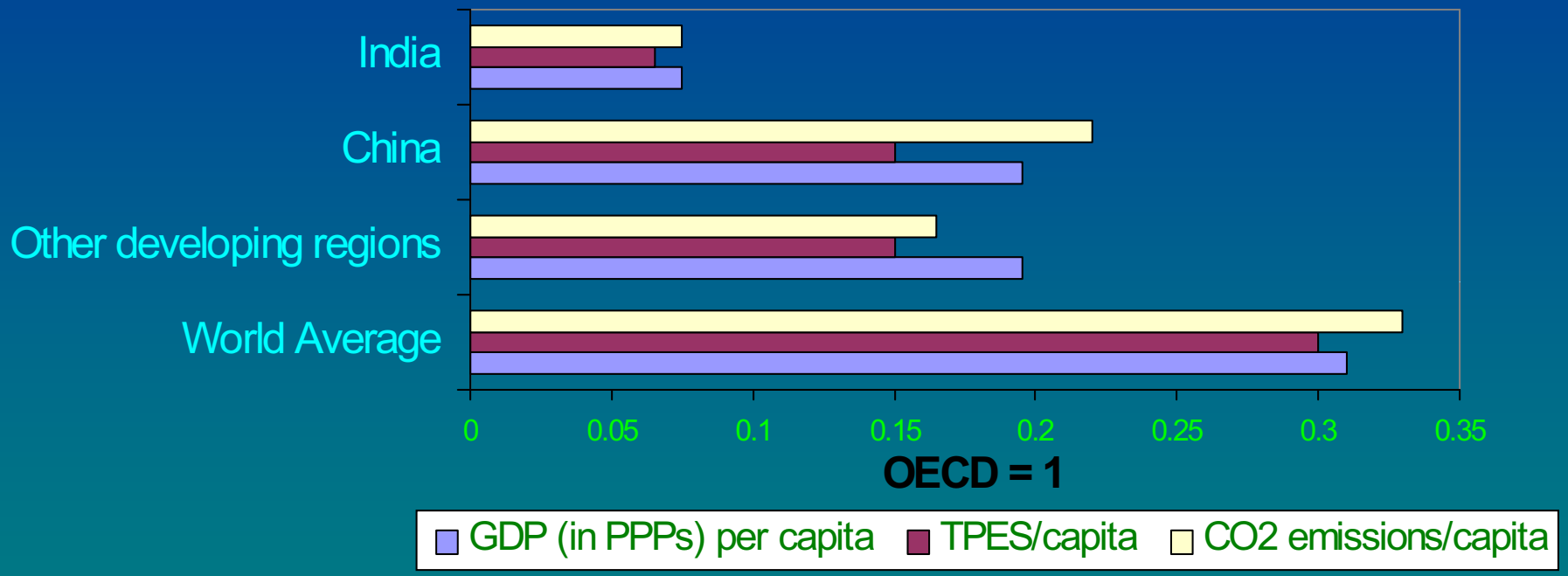
- It is a matter of concern that the annual per capita consumption of electricity in India, at about 750 kWh (including captive power generation) is among the lowest in the world.



Relationship between Electricity Consumption and GDP

[Key World Energy Statistics from the International Energy Agency, 2002 Edition)

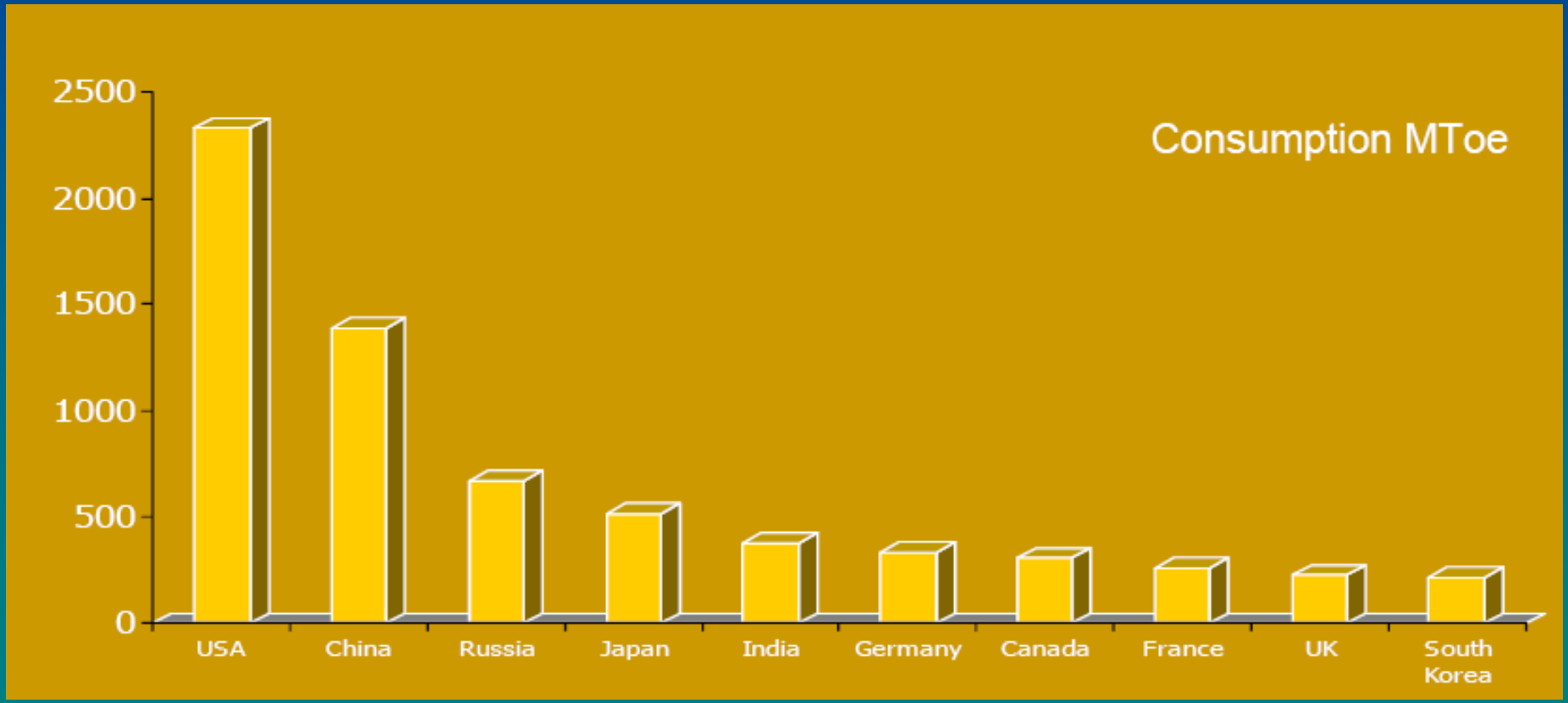
Comparitive Percapita Energy Indicators



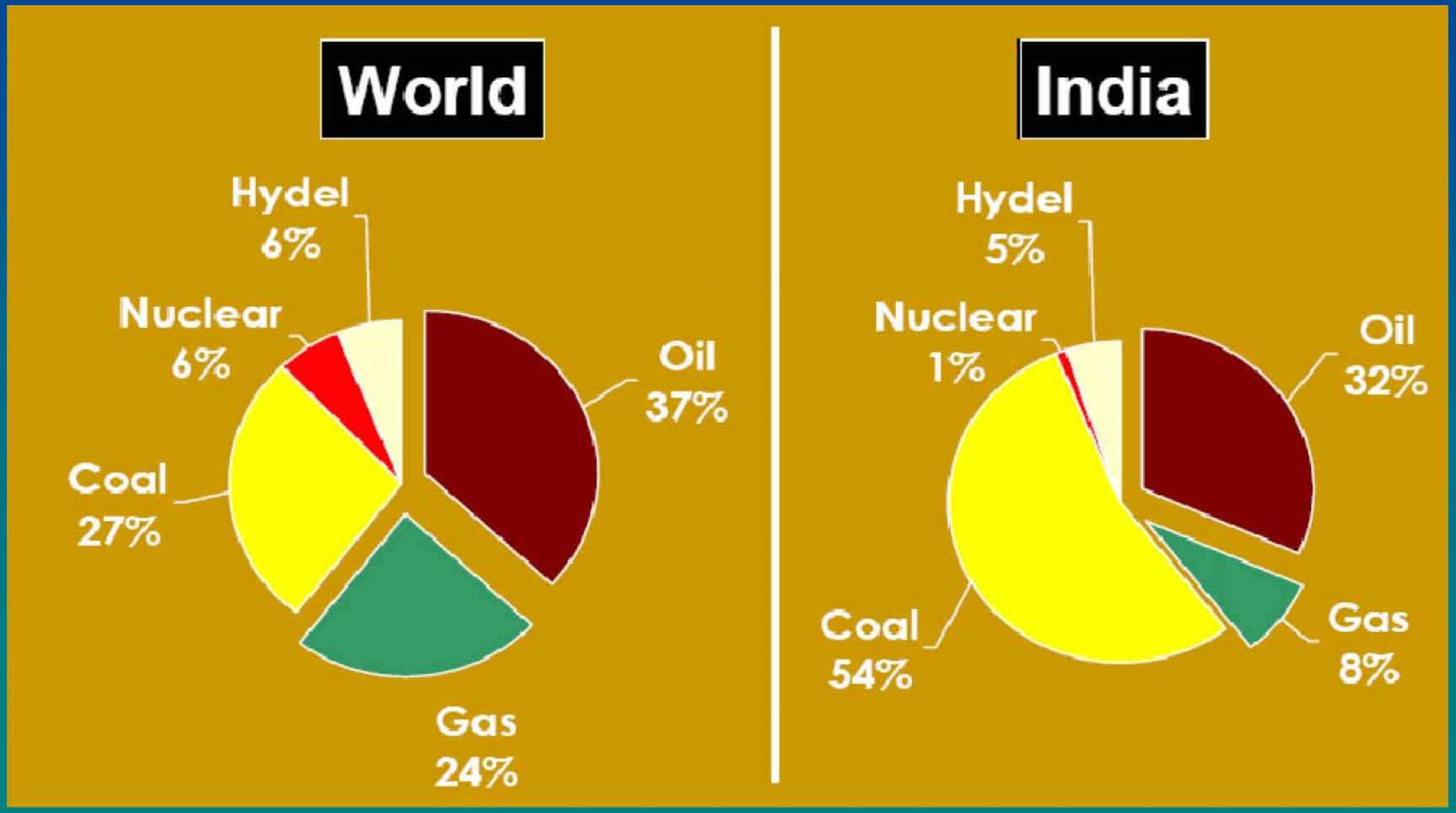
GDP – Gross Domestic Product ; TPES – Total Primary Energy Supply
OECD – Organisation of Economic Co-operation and Development
PPP - Purchasing Power Parity

Source : World Energy Outlook

India - 5th Largest Energy Consumer



Indian Energy Outlook



Indian Energy Sector- An Overview

	World	Asia Pacific	India
Energy Consumption (MTOE)	10224	3199	376
Energy Mix (%)			
Coal	27%	47%	54%
Oil	37%	34%	32%
Natural gas	24%	10%	8%
Nuclear	6%	4%	1%
Hydro	6%	5%	5%
Oil & Gas Imports (MTOE)	2467	836	98
Growth in Energy (last 10 yrs)			
Total Primary Energy	2.1%	4.2%	4.8%
Natural Gas	2.6%	6.0%	6.8%

India's Energy Resource Base

	Amount	Thermal Energy			Electricity Potential
		EJ	TWh	GW-Yr	GWe-Yr
Fossil					
Coal	38 BT	667	185,279	21,151	7,614
Hydrocarbon	12 BT	511	141,946	16,204	5,833
Non-Fossil					
Nuclear					
Uranium-Metal	61,000 T				
In PHWR		28.9	7,992	913	328
In Fast Breeders		3,699	1,207,616	117,308	42,231
Thorium-Metal	2,25,000 T				
In Breeders		13,622	3,783,886	431,950	155,502
Renewable					
Hydro	150 GWe	6.0	1,679	192	69
Non-Conventional Renewables	100 GWe	2.9	803	92	33

Production of Primary Energy Sources of Conventional Energy in India

Source	Unit	1970/71	1980/81	1990/91	2001/02	2002/03	2003/04
Coal and Lignite	MT	76.34	119.02	228.13	352.6	367.29	389.11
Crude oil	BCM	6.82	10.51	33.02	32.03	33.04	33.38
Natural Gas	BkWh	1.45	2.36	18.00	29.71	31.40	31.95
Nuclear Power	BkWh	2.42	3.00	6.14	19.48	19.39	17.78
Hydro Power	BkWh	25.25	46.54	71.66	73.7	64.1	75.33
Wind Power	BkWh	-	-	0.03	1.97	2.10	3.40

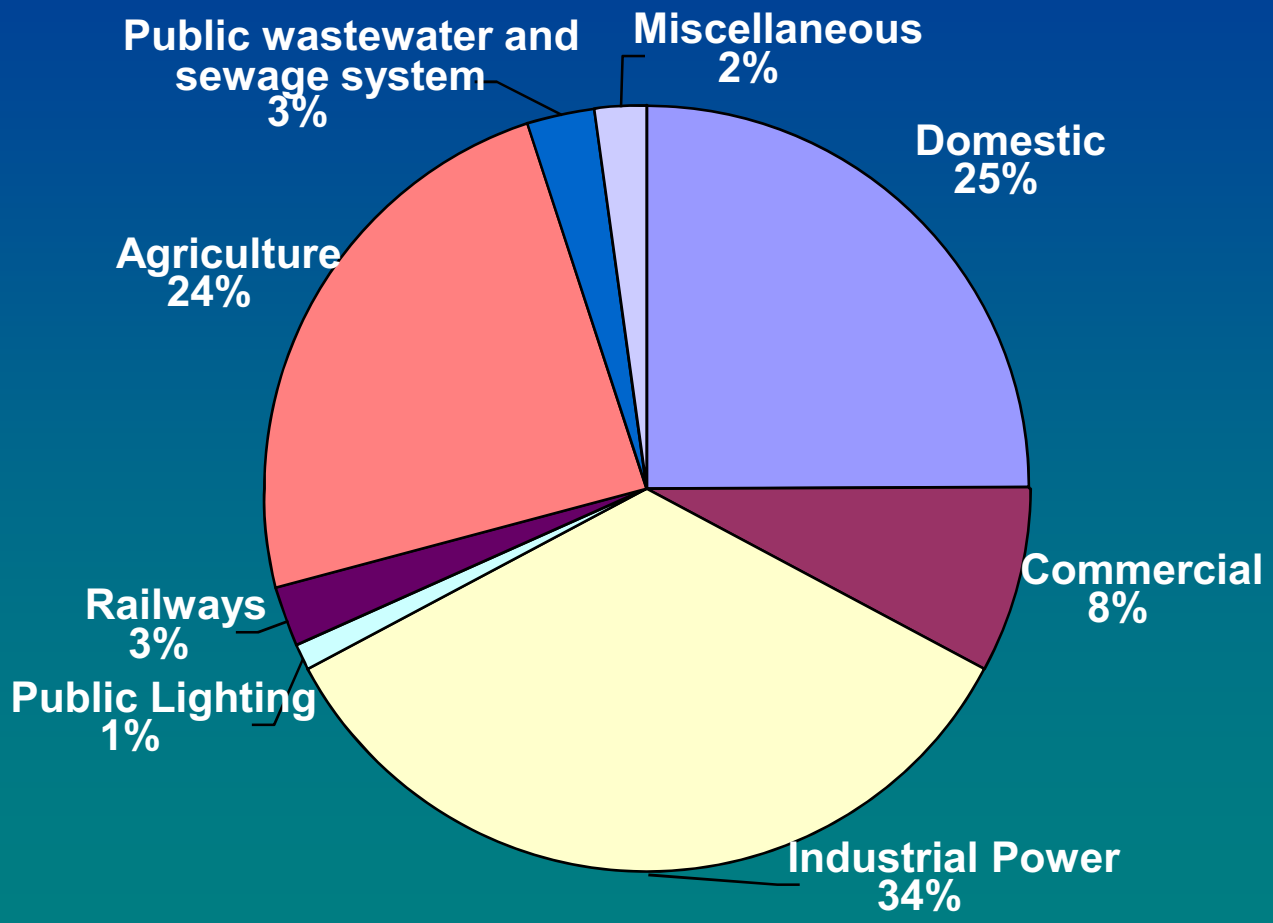
Source: TEDDY, 2006
MT – million tonnes; BCM-billion cubic metres; BkWh – billion kilowatt-hours

ELECTRICITY

INDIAN SCENARIO

- Present Per Capita Consumption ~ 750 kWh per annum
- Present Installed Capacity 152,148 Mwe
- Fossil Fuels 64.3%
- Hydel 24.2%
- Nuclear 2.8%
- Non-Hydrolectric Renewables 8.7%
- Captive Power Generation 19509 MWe Connected to Grid

End use of Power Generation



Fuel Supply: Options for Future

- Coal
  - Conventional
  - Gasification
- Natural Gas
- Hydro
- Nuclear
  - PHWR + FB + AHWR
- Wind
  - On-shore
  - Off-shore
- Biomass
- Solar
  - Photo voltaic

Coal

- **Reserves**
  - **Proven 91 billion Tons**
  - **Indicated 116 billion Tons**
  - **Inferred 37 billion Tons**
  - **TOTAL 245 billion Tons**
- **Concentrated in Eastern India**

Issues with coal:

Ash disposal
CO2 emissions

Indian Coal Quality:

High ash: 25% - 45%

Low sulfur < 0.5%

Low energy content

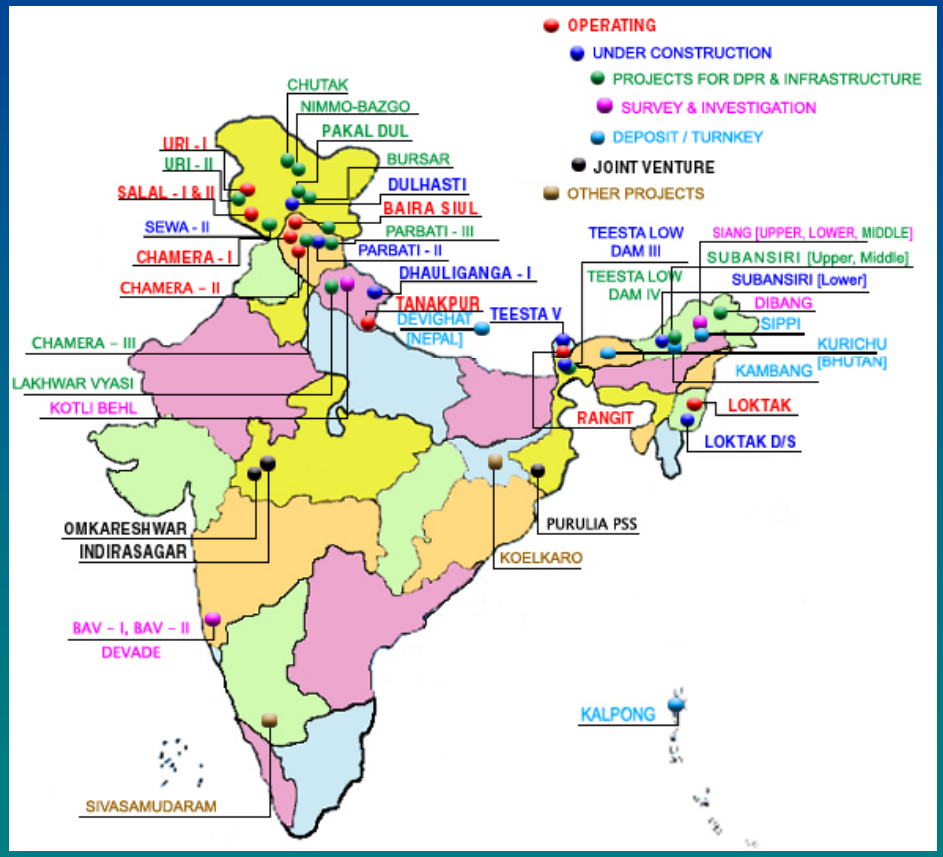
CO2 emissions about 1 kg per kWh

Options with Coal

- Coal's dominance will undoubtedly continue.
  - Availability
  - Cheap
- The question is: How much do we want to add with coal given the constraints of quality, transportation, carbon emissions and environmental issues.

Hydro-Electricity

- **Inferred potential > 120 GW**
- **Installed capacity 30 GW**
- **Most big projects are in North-Eastern states of Arunachal Pradesh, Sikkim, Uttaranchal and J&K**
- **Problems of rehabilitation and resettlement with large projects**
- **Environmental issues**
- **Water sharing agreements with neighbors**



National Hydro Power Corporation, Government of India

Regional Hydroelectric Potential

Region	Hydroelectricity Potential	Hydroelectricity to be developed	
	TWh	TWh	% of total
Northern	225	193	37
Western	31	21	4
Southern	62	31	6
Eastern	43	36	7
Norther-Eastern	239	237	46
Total	600	518	100 %

Source : Electricity in India, 2002

Nuclear Power

- In India to utilize the resources appropriately a three stage nuclear power programme has been chalked out by the Department of Atomic Energy.
- In the first stage, indigenously built Pressurized Heavy Water Reactor (PHWR) which used domestic uranium resource is developed and presently under operation at different locations.
- The second stage of the nuclear power programme involves building a chain of fast breeder reactors multiplying fissile material inventory along with the power production.
- The third stage consists of exploiting country's vast resources of thorium through the route of fast or thermal critical reactors or the accelerator driven sub-critical reactors (ADS).

NUCLEAR POWER PLANTS IN OPERATION AND UNDER CONSTRUCTION

Serial No.	Unit- Location	Type	Capacity (MWe)
UNDER OPERATION			
1	TAPS-1 TARAPUR, MAHARASTRA	BWR	160
2	TAPS-2 TARAPUR, MAHARASTRA	BWR	160
3	RAPS-1 RAWATBHATA, RAJASTHAN	PHWR	100
4	RAPS-2 RAWATBHATA, RAJASTHAN	PHWR	200
5	MAPS-1 KALPAKKAM, TAMILNADU	PHWR	220
6	MAPS-2 KALPAKKAM, TAMILNADU	PHWR	220
7	NAPS-1 NARORA, UTTAR PRADESH	PHWR	220
8	NAPS-2 NARORA, UTTAR PRADESH	PHWR	220
9	KAPS-1 KAKRAPAR, GUJARAT	PHWR	220
10	KAPS-2 KAKRAPAR, GUJARAT	PHWR	220
11	KAIGA-1 KAIGA,KARNATAKA	PHWR	220
12	KAIGA-2 KAIGA, KARNATAKA	PHWR	220
13	RAPS-3 RAWATBHATA, RAJASTHAN	PHWR	220
14	RAPS-4 RAWATBHATA, RAJASTHAN	PHWR	220

Contd….

Serial No.	Unit- Location	Type	Capacity (MWe)
UNDER OPERATION			
15	TAPS-4 TARAPUR, MAHARASTRA	PHWR	540
16	TAPS-3 TARAPUR, MAHARASTRA	PHWR	540
17	KAIGA-3 KAIGA, KARNATAKA	PHWR	220
		TOTAL	4070
UNDER CONSTRUCTION			
18	KAIGA-4 KAIGA, KARNATAKA	PHWR	220
19	KK-1 KUDANKULAM, TAMILNADU	PWR	1000
20	KK-2 KUDANKULAM, TAMILNADU	PWR	1000
21	RAPP-5, RAJASTHAN	PHWR	220
22	RAPP-6, RAJASTHAN	PHWR	220
		TOTAL	2660

BWR : BOILING WATER REACTOR
PHWR : PRESSURIZED HEAVY WATER REACTOR
PWR : PRESSURIZED WATER REACTOR

Case Study of Indian Electricity Sector

Details of the Study

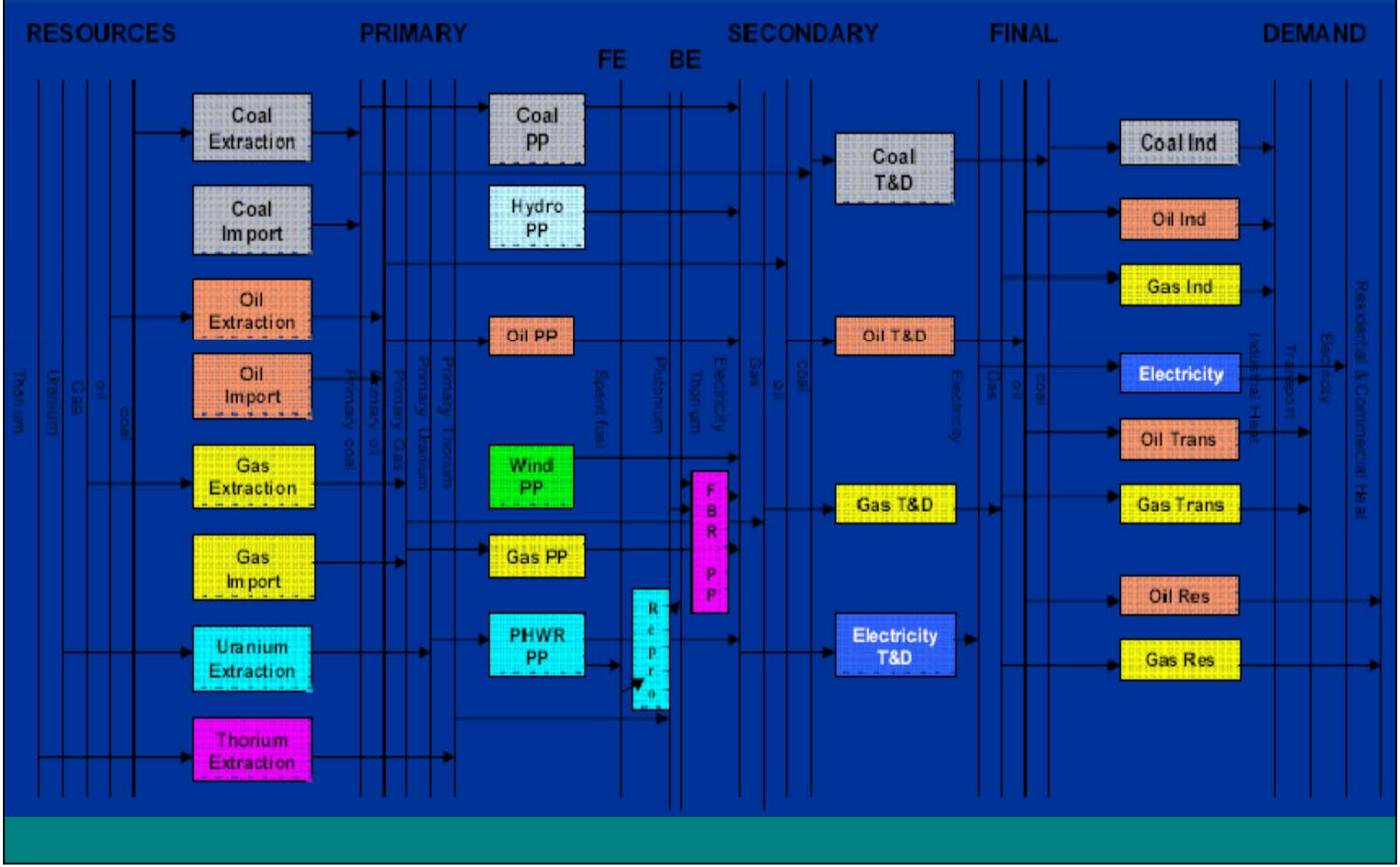
- Study Period: 30 years

Starting from 2005 to 2035

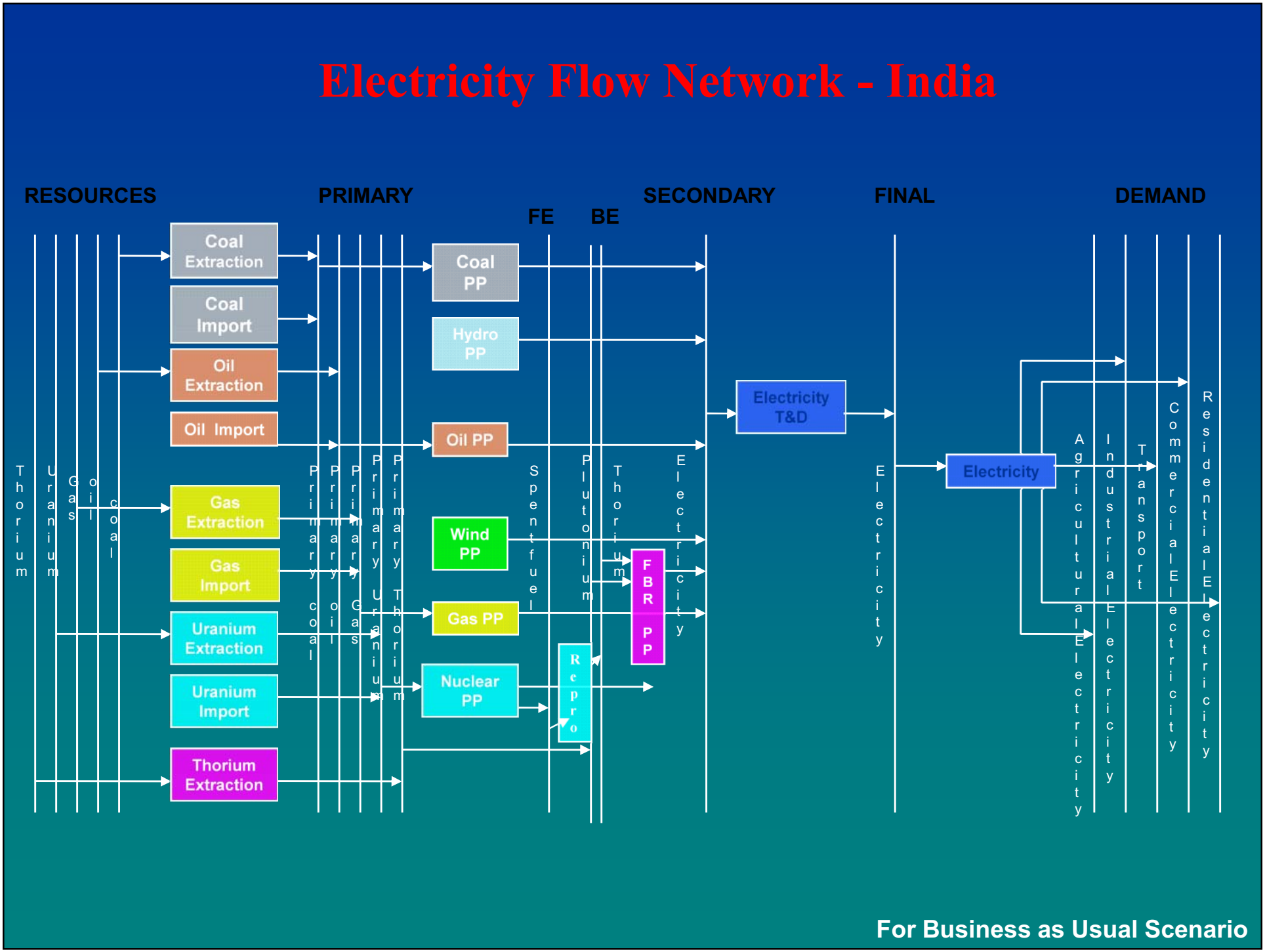
Base year – 2005

Three seasons (Summer, Winter and Rainy)

Energy Flow Network



Electricity Flow Network - India



Data Used in MESSAGE

	Plant Factor	Cost	Constr time	life time
Coal based TPP	0.7	Investment cost of 1017 $/kW fixed cost of 27.7 $/kWyr	5 years	40 years
Natural Gas based TPP	0.7	Investment cost of 700 $/kW ; fixed cost of 27.7 $/kWyr	2 years	40 years
Oil based TPP	0.7	Investment cost of 800 $/kW ; fixed cost of 27.7 $/kWyr	2 years	40 years
Hydroelectric PP	0.6	Investment cost of 1418 $/kW fixed cost of 40 $/kWyr	8 years	50 years
Nuclear PP	0.7	Investment cost of 2000 $/kW; fixed cost of 20 $/kWyr	6 years	40 years
Wind based PP	0.4	Investment cost of 500 $/kW ; fixed cost of 40 $/kWyr	2 years	40 years

Scenarios Developed

- business-as-usual scenario
- scenario of low growth rate
- high growth rate scenario
- scenario with high nuclear intervention
- scenario with aggressive renewables energy
- Hybrid Scenario
- CO_2 limit scenario

Business-as-Usual Scenario

- This scenario is characterized by most likely path of development in the absence of any major intervention.
- This scenario incorporates existing government plans and policies.
- In this scenario 8 % growth rate of GDP is considered over entire modeling framework.
- In this scenario deployment of clean technologies and penetration of technologies are assumed as per the existing trends and proposed projects for nuclear and renewables.
- The nuclear energy based power generation capacity is assumed to the extent of 20 GW and renewables upto 45 GW.

Scenario of Low Growth Rate

- The scenario assumes a low growth of GDP at the rate of 6 % per annum.
- All other assumptions with respect to technologies and other parameters are similar to those is business-as-usual scenario.

High Growth Rate Scenario

- The scenario assumes a high growth of GDP at the rate of 10 % per annum.
- All other assumptions with respect to technologies and other parameters are similar to those is business-as-usual scenario.

Scenario with High Nuclear Intervention

- In this study nuclear based power generation is expected to increase to 6.8 GW by 2012 and further to 14 GW by 2017, 55 GW by 2027 and 63 GW by 2032.
- The high nuclear energy based power generation has been assumed in view of the latest developments in the nuclear sector due to enhanced international cooperation and Government of India's initiative in this direction.
- This scenario considers aggressive pursuit of nuclear energy based power generation driven by the assumption that the country is able to import fuel.
- This scenario assumes a projected GDP growth rate of 8 % similar to business-as-usual scenario.

Scenario with Aggressive Renewables

- In this scenario, high penetration of renewable energy is considered. The lower bound of installed capacities considered by 2035 for 45 GW, 10 GW, 8 GW and 8 GW for wind, small hydro, solar and biomass respectively.
- The maximum capacities considered in the study are the expected potentials of these technologies.
- This scenario also assumes a projected GDP growth rate of 8 % similar to business-as-usual scenario.

Hybrid Scenario

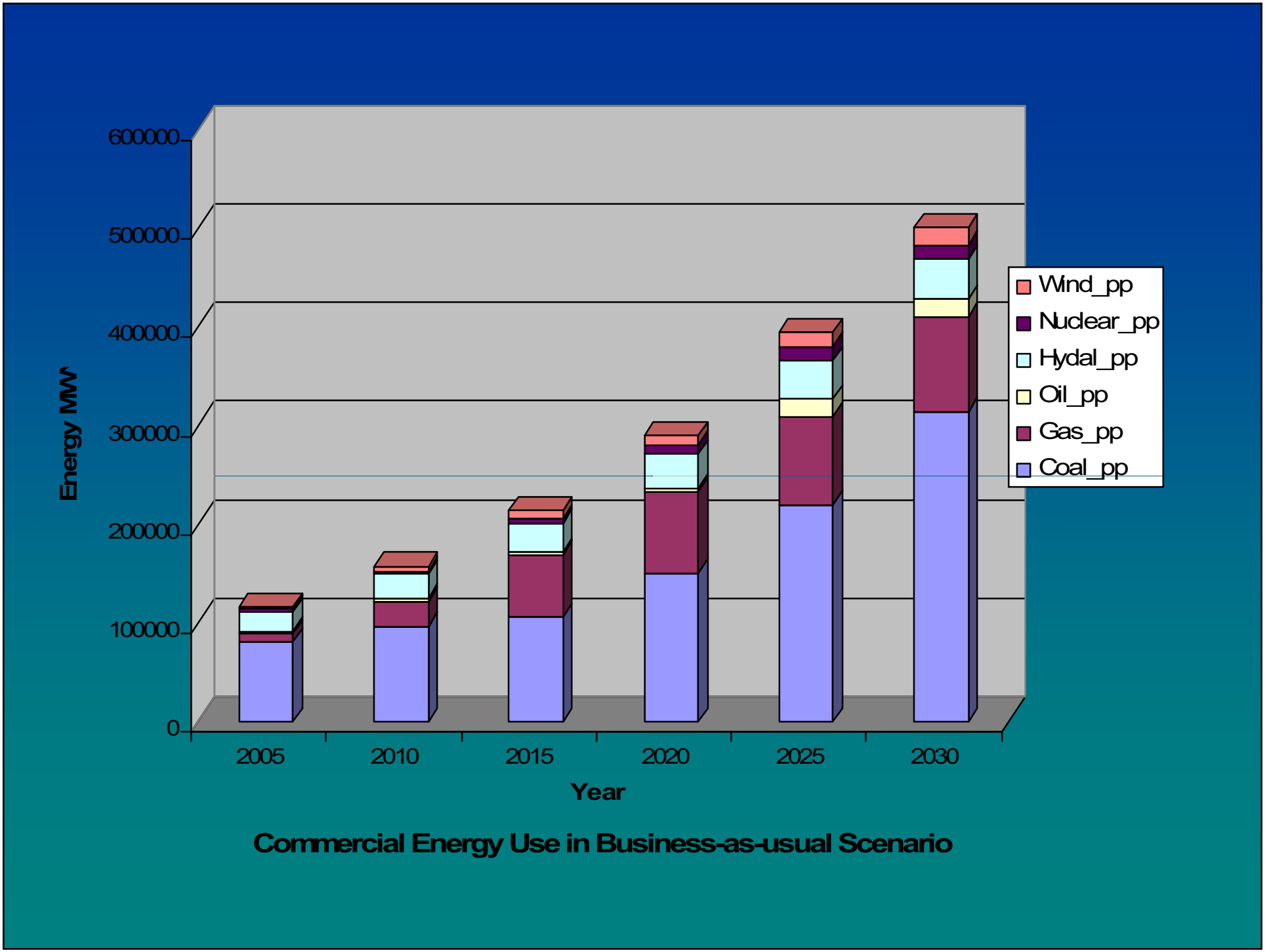
- In this scenario both high nuclear and aggressive renewables scenario are merged together
- Both nuclear and renewables are expected to be utilized to the maximum capacities
- This scenario also assumes a projected GDP growth rate of 8 % similar to business-as-usual scenario.

CO_2 limit scenario

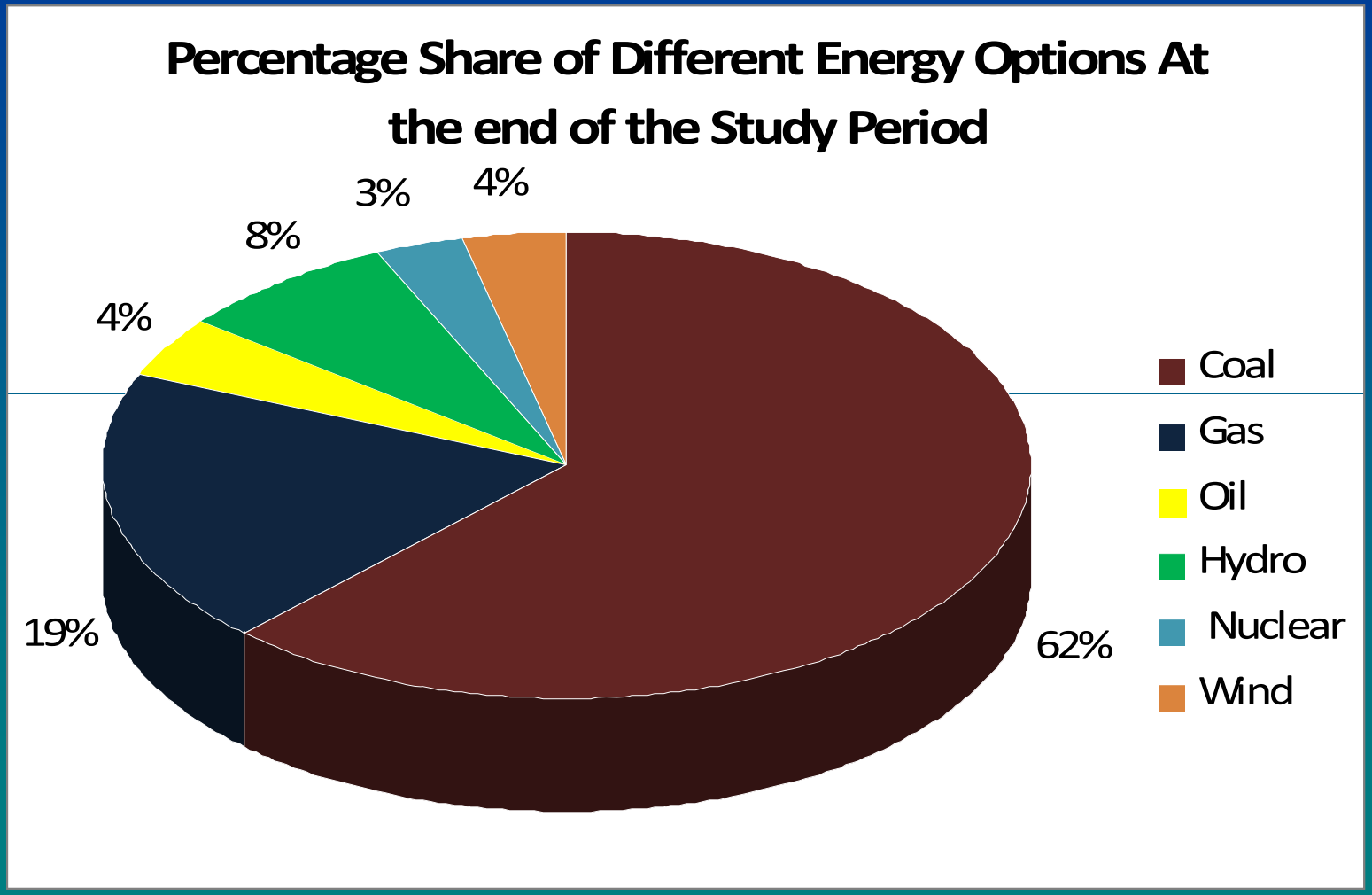
- In this scenario the maximum amount of limitation that is possible under BAU, High nuclear and Aggressive Renewable scenarios is considered.

Results

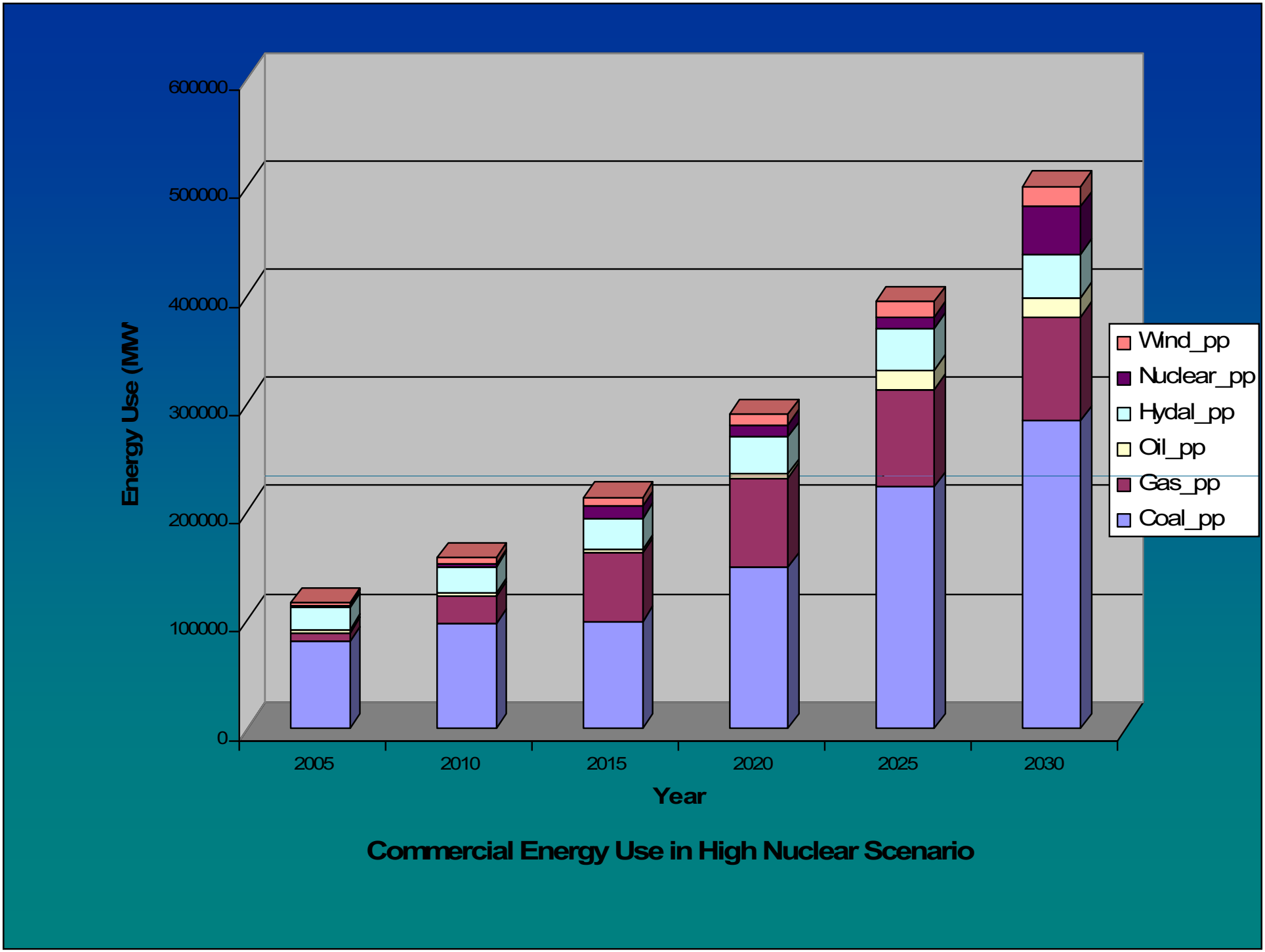
- Coal remains the dominant fuel during the entire study period; but, with limited domestic production capacity, the import dependence of coal found to be more than 70 % by 2035.
- The contribution from nuclear is becoming increasingly significant towards the end of the study period without any special intervention.
- The contribution of hydro power steadily decreased during the study period.
- The contribution of wind power technology also significantly increased during the study period in this scenario up to maximum potential of 45 GW as it is available at competitive price.
- The contributions from oil is forcibly limited in the study as the same will be utilized in other commercial energy sectors like transport industry.


600000
500000
400000
300000
200000
100000
0
Energy MW
2005
2010
2015
2020
2025
2030
Year
Wind_pp
Nuclear_pp
Hydal_pp
Oil_pp
Gas_pp
Coal_pp
Commercial Energy Use in Business-as-usual Scenario

- At the end of the study period the percentage share of coal, gas, oil, hydro, nuclear and wind are 62, 19, 4, 8, 3 and 4 respectively.
- The model indicates that hydro power is also utilized, which reaches the maximum potential of 84 GW.
- However, the percentage share of hydro power in the total power generation capacity is reduced to 8 %


Percentage Share of Different Energy Options At the end of the Study Period
3%
4%
8%
4%
19%
62%
Coal
Gas
Oil
Hydro
Nuclear
Wind

- In the business-as-usual scenario the electricity consumption increased by 6.2 times over the study period.
- In low growth scenario and high growth scenario the electricity consumption increased by 4.4 and 9 times respectively.
- The total electricity generation capacity at the end of the study period across various scenarios found to be about 650 GW, 420 GW and 850 GW for business-as-usual, low growth and high growth respectively.
- The thermal power capacity for the business-as-usual scenario is about 500 GW at the end of study period.


600000
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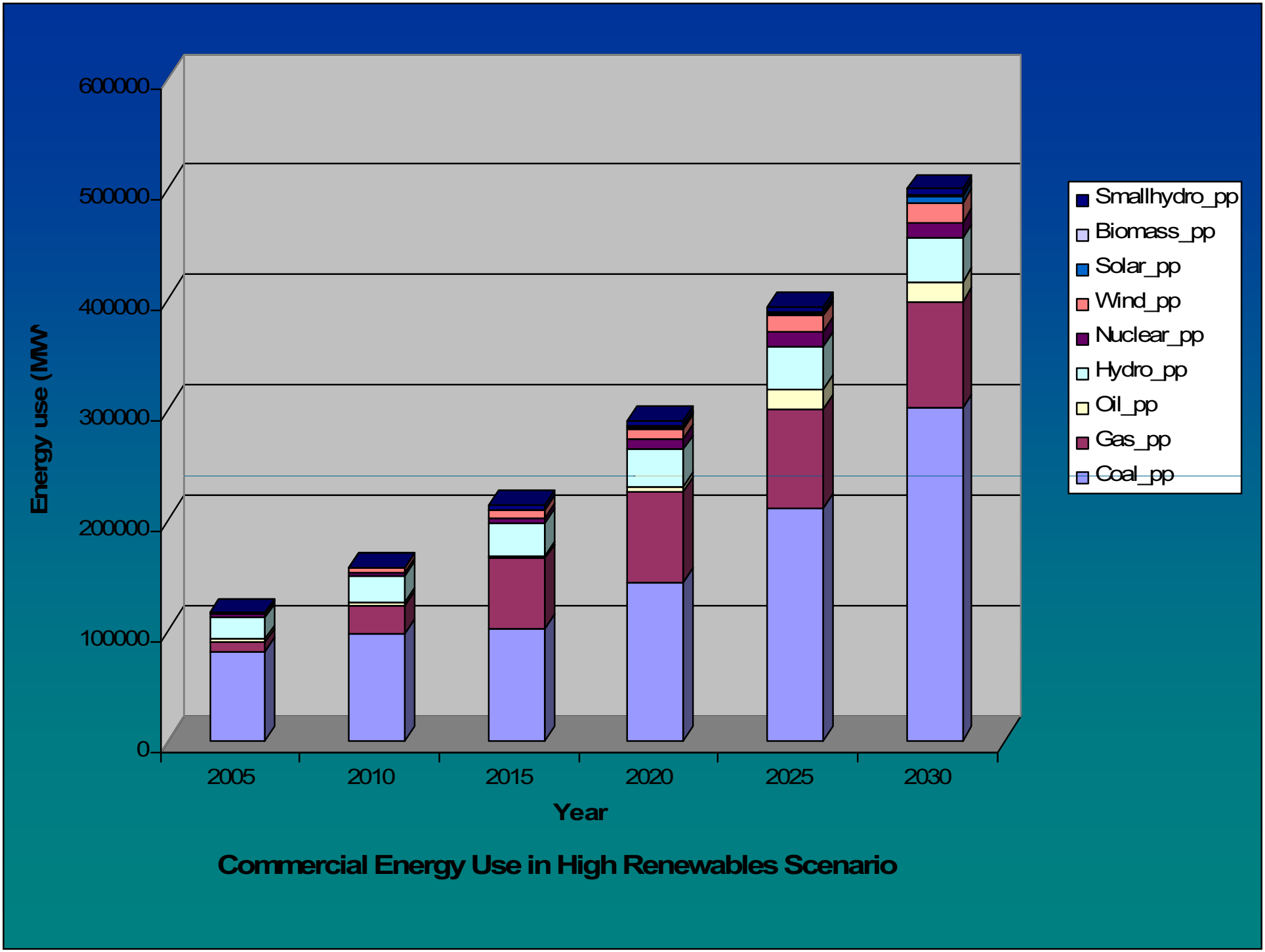
0
Energy Use (MW
2005
2010
2015
2020
2025
2030
Year
Wind_pp
Nuclear_pp
Hydal_pp
Oil_pp
Gas_pp
Coal_pp
Commercial Energy Use in High Nuclear Scenario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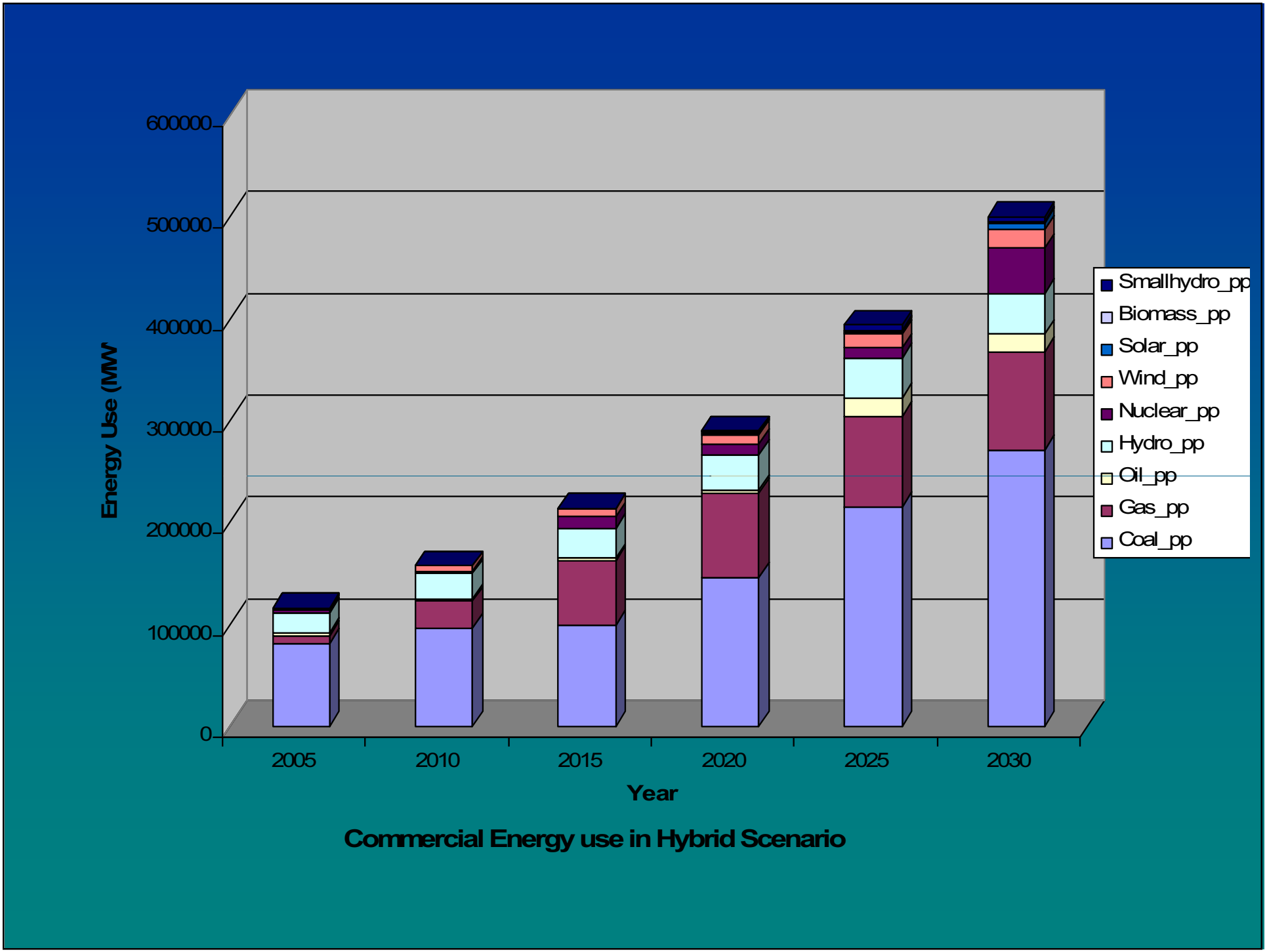
Energy use (MW
2005
2010
2015
2020
2025
2030
Year
Smallhydro_pp
Biomass_pp
Solar_pp
Wind_pp
Nuclear_pp
Hydro_pp
Oil_pp
Gas_pp
Coal_pp
Commercial Energy Use in High Renewables Scenario

- The total power generation capacity remained almost constant in the business-as-usual scenario, high nuclear scenario and aggressive renewables scenarios.
- There exists variation in the technology deployment for power generation across various scenarios.
- In high nuclear scenario the percentage share of electricity consumption from nuclear increased to 9 % compared to that of 3 % in the business-as-usual scenario.
- In aggressive renewable scenario the percentage share of electricity consumption from renewables increased to 6.2 % compared to that of 3.5 % in the business-as-usual scenario.


600000
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100000
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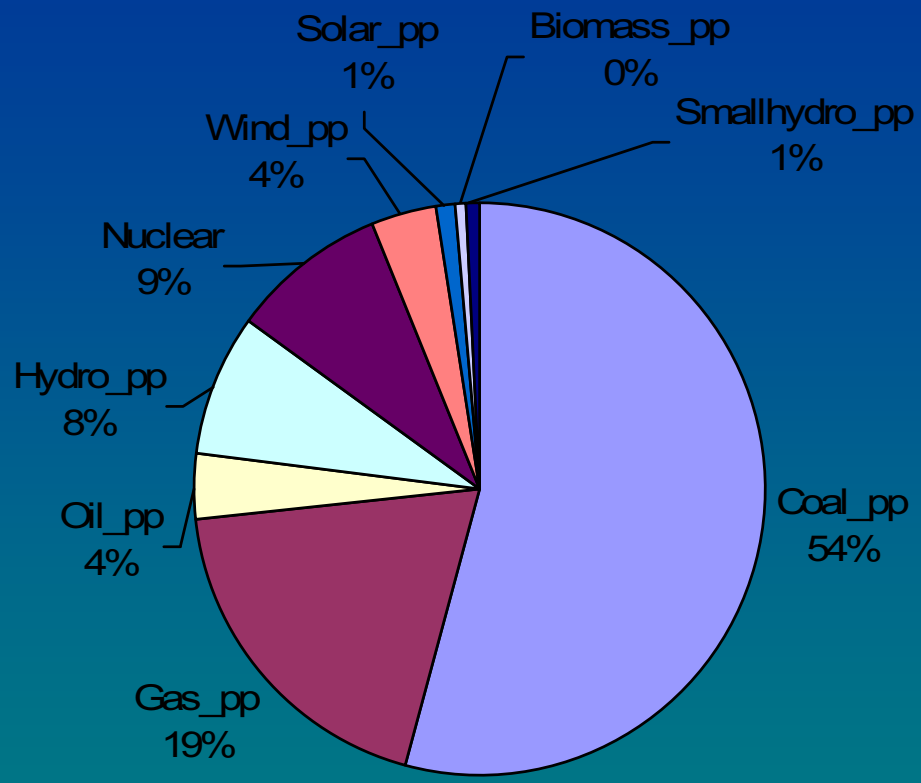
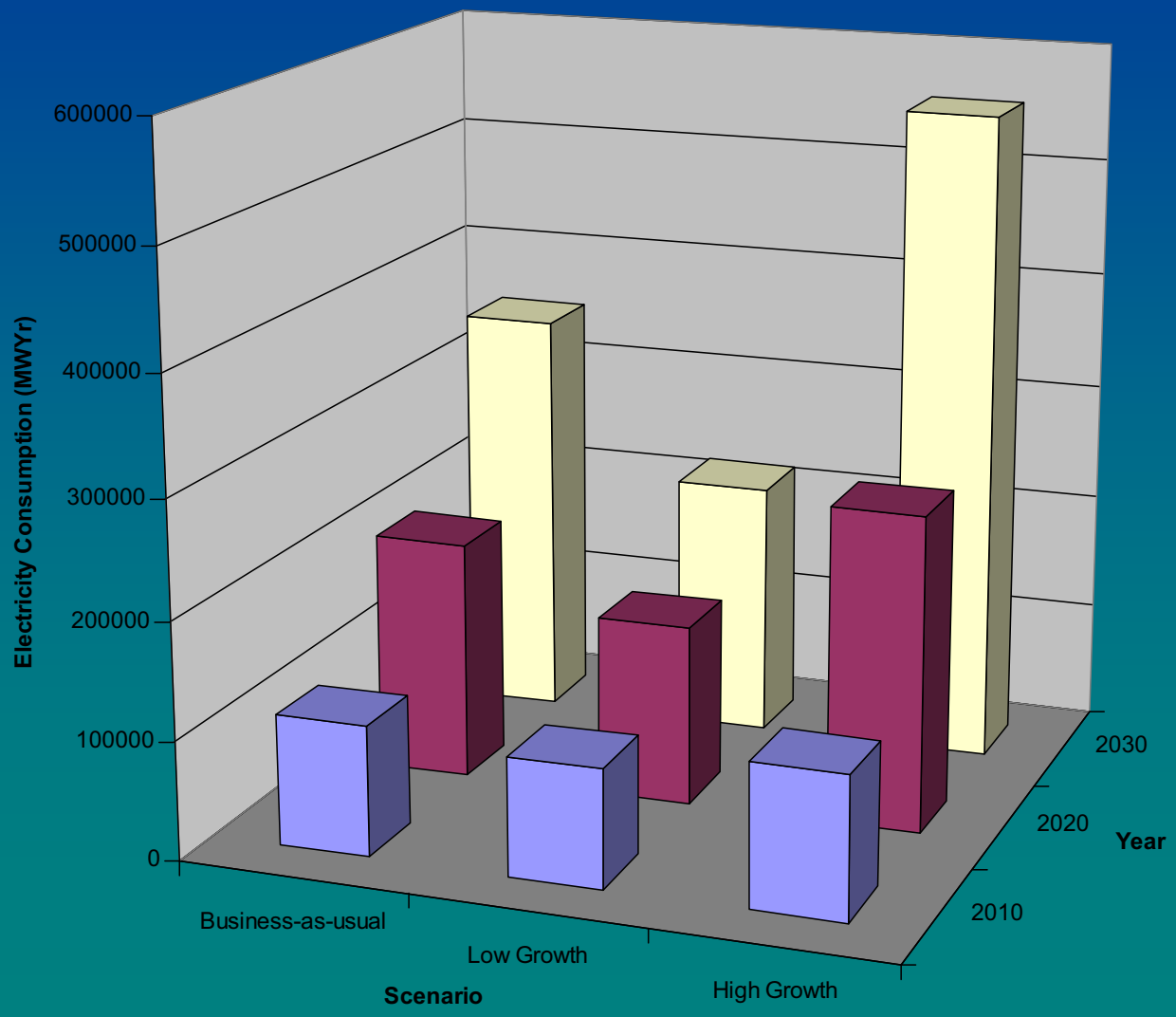
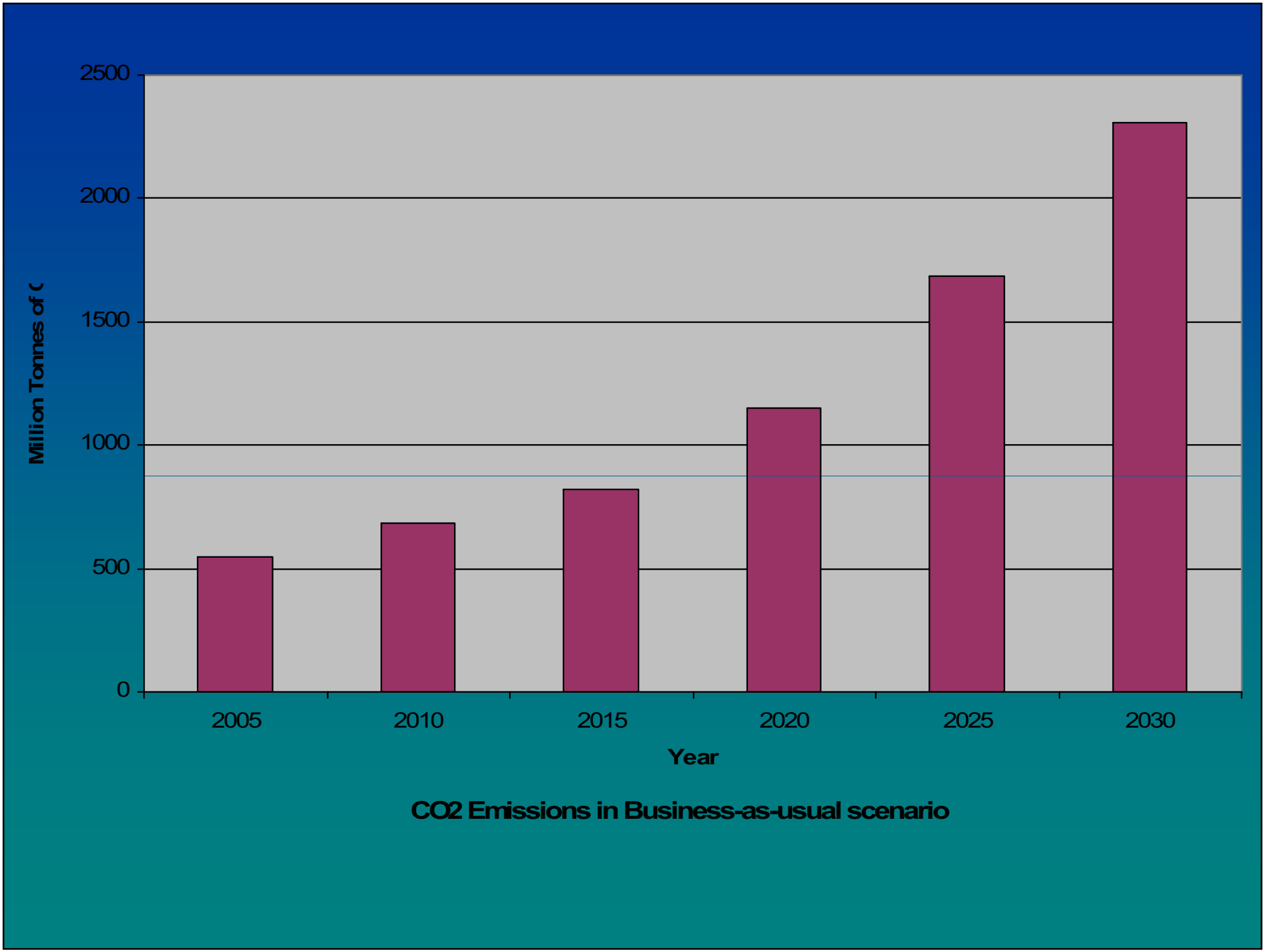
Energy Use (MW
2005
2010
2015
2020
2025
2030
Year
Smallhydro_pp
Biomass_pp
Solar_pp
Wind_pp
Nuclear_pp
Hydro_pp
Oil_pp
Gas_pp
Coal_pp
Commercial Energy use in Hybrid Scenario



Percentage share of power generation in Hybrid scenario

Comparison of Electricity Consumption Across Various Scenarios




2500
2000
1500
1000
500
0
Million Tonnes of C
2005
2010
2015
2020
2025
2030
Year
CO2 Emissions in Business-as-usual scenario

Lowest possible limit on Carbondioxide emissions for different scenarios (Year - 2030)

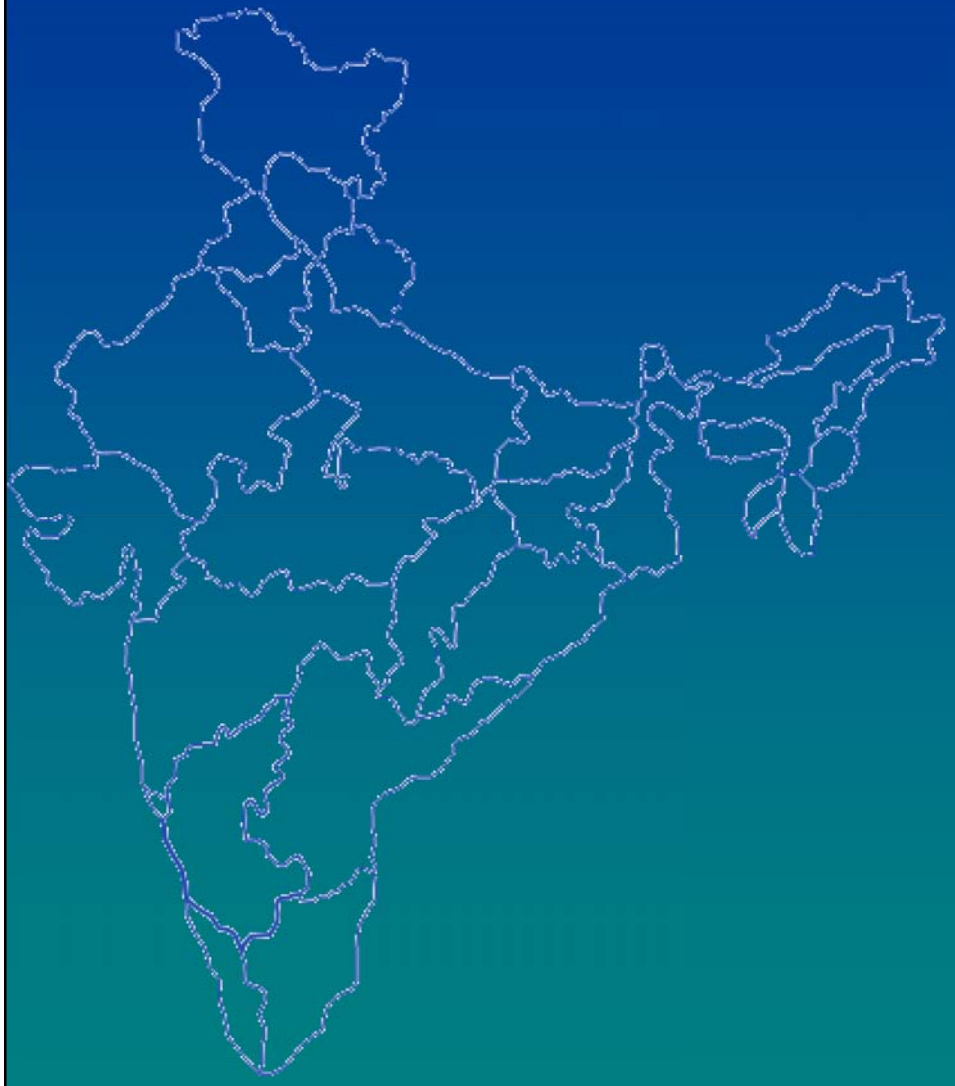
S.No.	Scenario	CO2 emissions (million tonnes)
1	Business-as-usual	2100
2	High Nuclear	1900
3	High renewables	2000
4	Hybrid	1800

Summary

- India needs electric power now, more than ever, for human development and growth. It must generate power from all energy sources
- Coal remains the dominant fuel for production of electricity during the study period. However, the import dependency of coal increases.
- Introduction of high nuclear capacity replaces coal to some extent and also contributes to 10 % reduction in CO_2 emissions.
- Introduction of renewables also replaces coal to some extent and contributes to 4 % reduction in CO_2 emissions.

Future Study

- High efficiency scenario can be developed
- Introducing clean coal technologies like IGCC can also be studied
- Detailed cost analysis need to be carried out



Thank You