Potential Power Sector Scenarios for India-Technological Approach

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India's Energy Resource Base

	Amount	Thermal Energy			Electricity Potential
		EJ	TWh	GWYr	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-Met	61,000 -T				
In PHWR		28.9	7,992	913	328
In Fast breeders		3,699	1,027,616	117,308	42,231
Thorium-Met	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.Conv.Ren.	100 -GWe	2.9	803	92	33

India's other Energy Resources

- Coal Bed Methane – 1000 bn CM
- Gas Hydrates – very large resource based expected to commercialized by 2012
- Deep sea Natural gas
- Coal and lignite reserves greater than 600 m deep

GHG Sources (As per India's Initial National Communication) Base Year 1994

GHG Sources (Gg/year)	**CO2**	**CH4**	**N2O**
Energy & Transformation	353518	0	4.9
Biomass for Energy	0	1636	2.0
Fugitive Fuel Emissions			
Oil & Natural Gas	0	601	0
Coal Mining	0	650	0
All Energy	**679470**	**2896**	**11.4**

Regional Distribution of Primary Commercial Energy Resources

Region	Coal (bt)	Lignite (bt)	Crude Oil (mt)	Natural Gas (BCM)	Hydro Power (TWH)
Northern	1.06	2.51	0.03	0.0	225.00
Western	56.90	1.87	519.47	516.42	31.40
Southern	15.46	30.38	45.84	80.94	61.80
Eastern	146.67	0	2.19	0.29	42.50
North-Eastern	0.89	0	166.17	152.00	239.30
Total	220.98	34.76	733.70	749.65	600.00

bt : Billion Tonnes BCM : Billion Cubic meters TWH : Trillion Watt Hours mt : Million Tonnes

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Renewable Energy Sources Potential

Source/Technology	Units	Potential/Availability	Potential Exploited
Biogas Plants	Million	12	3.22
Biomass-based power	MW	19,500	384
Efficient wood stoves	Million	120	33.86
Solar Energy	MW/Sq. Km	20	1.74
Small Hydro	MW	15,000	1,398
Wind Energy	MW	45,000	1,367
Energy Recovery from Wastes	MW	1,700	16.2

Trends in Commercial Energy Production

	Units	Production					
		1960-61	1970-71	1980-81	1990-91	2001-02*	2006-07**
Coal	mt	55.67	72.95	114.01	211.73	325.65	405.00
Lignite	mt	0.05	3.39	4.80	14.07	24.30	55.96
Crude Oil	mt	0.45	6.82	10.51	33.02	32.03	33.97
Natural Gas	BCM	-	1.44	2.35	1.79	29.69	37.62
Hydro Power	Bkwh	7.84	25.25	46.54	71.66	82.80	103.49
Nuclear Power	Bkwh	-	2.42	3.00	6.14	16.92	19.30
Wind Power	Bkwh	-	-	-	0.03	1.70	4.00

* Anticipated, ** Projections for the terminal year of the Tenth Plan

Trends in Supply of Primary Commercial Energy

(MTOE)

	Supply					
	1953-54	1960-61	1970-71	1980-81	1990-91	2001-02*
Coal	23.62	35.64	36.48	56.96	94.68	133.89
Lignite	-	0.01	0.81	1.23	3.34	6.52
Crude Oil	0.19	0.46	7.01	10.79	33.92	32.03
Natural gas	-	-	0.60	1.41	11.73	26.72
Hydro Power	0.24	0.67	2.17	4.00	6.16	6.37
Nuclear Power	-	-	0.63	0.78	1.60	5.15
Wind Power	-	-	-	-	-	0.14
Total	24.05	36.78	47.67	75.19	151.43	210.82
Net Imports	2.20	6.04	12.66	24.63	31.69	87.85
Commercial Energy Supply	26.25	42.82	60.33	99.82	183.12	298.67
Primary Non-Commercial Energy Supply	64.13	74.38	86.72	108.48	122.07	139.02
Total Primary Energy Supply	90.38	117.20	147.05	208.30	305.19	437.69

*Provisional

Share of Net Energy Imports in Primary Commercial Energy Supply

(%)

Year	Coal	POL*	Electricity	Total
1980-81	0.25	25.45	-	25.70
1990-91	2.22	15.56	0.07	17.85
2001-02	4.12	25.25	0.04	29.41

* Petroleum oil and lubricants

Physical Performance

Programme	Eighth Plan Actual	Ninth Plan Target	1997 -98 Actual	1998 -99 Actual	1999 -2000 Actual	2000 -01 Actual	2001 -02 Actual	Likely achievement 1997-02	% of target
Demand / Consumption (mt)	79.16#	104.8 (2001-02)	84.29	90.56	97.09	100.08	100.43	...	...
Reserve Accretion (MTOE)*		865.00	62.8	163.6	176.8	165.8	244.0	813.0	94.0
Crude oil (mt)	154.28	180.82	33.86	32.70	31.93	32.47	32.03	162.99	90.1
Gas production (BCM)	101.71	144.53	26.40	27.43	28.52	28.88	29.69	140.92	97.5
Refining Capacity (mt)	61.55#	113.95@	62.24	95.60	112.54	112.54	116.07	116.07	101.9

figure for the terminal year (1996-97) @Target in the terminal year of the Ninth Plan

* Including private/joint venture contribution of 175 MTOE for five years

Table 7.3.1
Estimated Energy Demand

Primary Fuel	Unit	Demand (in Original Units)		Demand (MTOE)	
		2006-07	2011-12	2006-07	2011-12
Coal	mt	460.50	620.00	190.00	254.93
Lignite	mt	57.79	81.54	15.51	22.05
Oil	mt	134.50	172.47	144.58	185.40
Natural gas	BCM	47.45	64.00	42.70	57.60
Hydro Power	BKwh	148.08	215.66	12.73	18.54
Nuclear Power	BKwh	23.15	54.74	6.04	14.16
Wind Power	BKwh	4.00	11.62	0.35	1.00
Total Commercial Energy				411.91	553.68
Non-Commercial Energy				151.30	170.25
Total Energy Demand				563.21	723.93

mt : Million Tonnes; BCM : Billion Cubic Meter; Bkwh : Billion kilo watt hour

Power Generation

Technologies Cost and Availability in India

Current Fossil resource availability for Power

- Coal - 91.6 billion tonnes (recoverable coal)

  Source 2004 MOC

  - Current Consumption in Power Sector is 189.36 million tonnes

- Natural Gas availability 920 billion Cubic meters (recoverable gas)

  Source 2003 GAIL study

Generation Technologies

(Coal based)

	Capital cost (Rs. Cr/MW)	Net Generation Efficiency (%)	International Capital costs (Rs Cr/MW)	International cost of generation (Rs/Kwh)	Net Generation Efficiency (%)
Sub-critical steam cycle	4.2	35%			
Super-critical steam cycle (240 ata, 5400C/5650C)	4.4	36%			46% (on LHV, cooling water temp 10°C
Ultra-super-critical steam cycle (300 ata, 6000C/6000C)	4.8	39-40%	4.79-5.60	1.74-2.08	
IGCC	7.5-8.0	40%	5.17-6.91	1.83-2.34	43.6%(with F turbine)
R&M	1.5	5 to 8 (improvement)			

Generation Technologies
(Gas based)

	Capital cost (Rs. Cr/MW)	Net Generation Efficiency (%)	International Capital costs (Rs Cr/MW)	International cost of generation (Rs/Kwh)
Combined Cycle (Tech-E)	3.0	53.0%		
Combined Cycle (Tech-FA)	3.3	57.1%	1.93-2.37	1.034
Combined Cycle (Tech-H)	3.6	60%	2.33	1.44

Technology Assessment

(Coal based)

Year	2002-07	2007-12	2012-17	2017-22	2022-27	2027-32
Coal Based Generation	o Sub-critical steam cycle (sub-CSC) o R&M	o Sub-CSC o R&M o Super-CSC (Ist plant) o IGCC demo	o Sub-CSC o R&M o Super-CSC o IGCC demo. (Ist plant)	o Sub-CSC o R&M o Super-CSC o IGCC (Ist plant) o Ultra super-CSC (Ist plant)	o Sub-CSC o R&M o Super-CSC o IGCC o Ultra-super CSC	o Sub-CSC o R&M o Super-CSC o IGCC o Ultra super-CSC

Technology Assessment

(Gas based)

Year	2002-07	2007-12	2012-17	2017-22	2022-27	2027-32
Gas Based Generation	o CCPP with GTs of Tech. B Tech. E Tech. FA	o CCPP with GTs of Tech. B Tech. E Tech. FA Tech. H (Ist plant)	o CCPP with GTs of Tech. B Tech. E Tech. FA Tech. H (Ist plant)	o CCPP with GTs of Tech. B Tech. E Tech. FA Tech. H (Ist plant)	o CCPP with GTs of Tech. B Tech. E Tech. FA Tech. H o FC demo	o CCPP with GTs of Tech. B Tech. E Tech. FA Tech. H o FC (Ist plant)

Technology E - 35.7% open cycle efficiency at ISO conditions
Technology F - 37.7% open cycle efficiency
Technology G - 39.5% open cycle efficiency
Technology H -> 40% open cycle efficiency

Growth in Hydro capacity

Period	Capacity existing at start	Capacity added in the period	Total capacity at end of period	Average yearly growth (approx.)
Capacity perlaining to stations with IC 15 MW & above				
excludes any upgrating done later				
1947-1960 (13 yrs)	426	1188	1614	91
1961-1970 (10 yrs)	1614	4948	6562	495
1971-1980 (")	6562	5426	11988	543
1981-1990 (")	11988	6078	18066	608
1991-2000 (")	18066	6039	24105	604
2001-2003 (2.5yrs)	24105	2265	26370	906
Capacity including uprating as in June 2003		26615		
Hydro capacity of stations below 15 MW IC		760		
Total Hydro capacity		27375 MW	485	

Hydro Power

Major focus:

- Application of new technologies in planning and investigation; designing and construction and use of corrosion resistant runners and other water borne components

Objectives:

- Minimize gestation period of projects
- Minimize construction risks and duration
- Increase life of projects

Nuclear generation technologies
(Three Stage Power Program)

Stage-I PHWRs	Stage-II FBRs	Stage-III Thorium Based Reactors
o 12 - Operating o 6 - Under construction o Several others planned o Scaling to 700 MWe o Gestation period being reduced o Power Potential ~ 10000 MWe <u>LWRs</u> o 2 BWRs Operating o 2 VVERs under construction	o 40 MWth FBTR- Operating since 1985, Technology Objectives realized o 500 MWe PFBR-Under Construction o Power Potential ~ 530000 MWe	o 30 kWth KAMINI-Operating o 300 MWe AHWR- Under Development oPotential is Very Large Availability of ADS can enable early introduction of Thorium on a large scale

New starts in the X Plan

Units	Projected Financial Sanction
2 x 1000 MWe LWRs	2004-05
2 x 700 MWe PHWRs	December 2005
300 MWe AHWR	2004-05

In addition, it is also necessary to launch pre-project activities for additional 2 x 1000 MWe LWRs and 2 x 700 MWe PHWRs to enable project approval and commencement of construction in early XI Plan.

Nuclear generation technologies

- FBR technology calls for special focus, necessary indigenous capability has already been developed
- Thorium based technology has maximum potential

Long-term Socio Economic projections by TERI

Source: National Energy Map for India-Technology Vision 2030

Assumptions of the model

$Ln(A_t/A_{t-1})$ = (Long Run Labour Augmenting TFPG for the US)-β ln[(Per Capita GDP(Ind))/(Per Capita GDP(US))]

Where

A_t = Labour Augmenting TFP level at time t

A_{t-1}= Labour Augmenting TFP level at time t-1

β = Conditional convergence rate for India

Steady state TFPG = 1.3%

β = 1.2%

Assumptions...

Demographics

- Population Projections based on UN Population projections for India (CAGR of 1%)

- Rate of growth of Labour Force is 1.6% per annum

Based on figures given in World Bank report on World Development Indicators

Comparison of GDP Growth Rates (%)

(Investment Share Increasing)

	Base	Scenario 1	Scenario2	Scenario3
2006	5.66	5.52	5.43	5.92
2011	6.18	6.01	5.6	6.49
2016	6.61	6.41	5.9	6.96
2021	6.95	6.73	6.05	7.33
2026	7.21	6.97	6.15	7.6
2031	7.4	7.14	6.2	7.78
2036	7.52	7.25	6.21	7.89

Comparison of Per Capita GDP Growth Rates

(Investment Share Increasing)

	Base	Scenario 1	Scenario2	Scenario3
2006	4.24	4.1	4.01	4.5
2011	4.91	4.74	4.43	5.22
2016	5.52	5.32	4.81	5.87
2021	6.05	5.82	5.15	6.42
2026	6.49	6.24	5.43	6.87
2031	6.2	6.57	5.64	7.21
2036	7.07	6.81	5.77	7.44

Comparison of US and Indian per capita GDP (1993-94 prices)

Year	US Per Capita GDP(RS)	Indian Per Capita GDP(Rs)
2006	1070738.57	1507.38
2011	1155769.21	1886.11
2016	1232466.64	2431.44
2021	1313569.53	3217.91
2026	1415797.38	4355.68
2031	1546713.79	6004.61
2036	1706239.13	8391.45

Conclusions

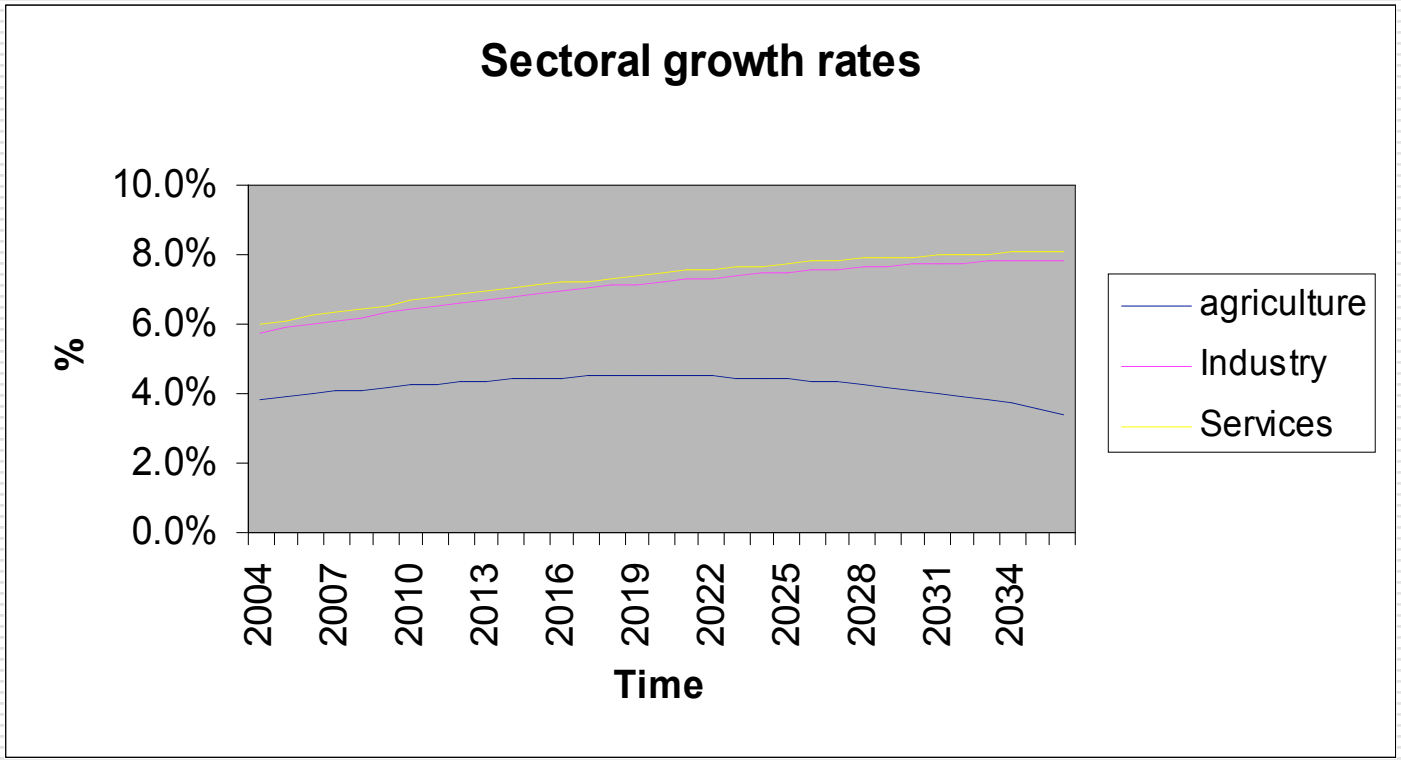
- Base Case: Growth Rates range from 5.5% to 7.5% per annum (average of 6.7% for the 30 year period)
- GDP initially grows at an increasing rate and then at a decreasing rate due to diminishing returns to capital
- Capital stock shows a similar trend as GDP

Sectoral Shares in GDP

%	Agriculture	Industry	Services
2006	21.9	27.3	50.8
2011	20.1	27.7	52.2
2016	18.3	28.1	53.6
2021	16.4	28.5	55.1
2026	14.4	29.0	56.6
2031	12.5	29.4	58.1
2036	10.4	29.9	59.7

Report on the India Vision 2020, Planning Commission

Sectoral Growth rates



Calculated using the expected sectoral shares given in the ***Report on the India Vision 2020, Planning Commission***

Demographics

- Population Projections based on Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat

Population = *f(FR, MR, NIM)*

FR = Fertility rate, MR= Mortality rate, NIM= Net international migration

Population projections: TERI Study

Year	Population (bn)	Urban	Rural
2001	1.032	0.288	0.745
2006	1.112	0.323	0.789
2011	1.188	0.364	0.824
2016	1.259	0.412	0.847
2021	1.323	0.467	0.856
2026	1.379	0.530	0.848
2031	1.424	0.589	0.835
2036	1.461	0.604	0.857

Population Projections (GOI)

Year	Average growth. rate* (%/yr)	Population **(B)
1991	1.99	0.843
2001	1.50	1.027
2011	1.02	1.19
2021	0.70	1.32
2031	0.40	1.41
2041	0.20	1.47
2051	0.00	1.50

* Growth rate figures are applicable for the next decade. The figure for 1991 is calculated, the rest are projected.

** The figures for 1991 & 2001 are from Census of India 2001, the rest are projected.

A Survey of various Studies

	Investigator	Period of Projection	Primary Commercial Energy Growth Rate (%/y)	Electrical Energy Growth Rate (%/y)
1	SCE-India	2002-2012	4.3	
2	TERI-India	1997-2019	4.5	5.7
		2020- 2047	3.7	3.9
3	IEO-USA[10]	1997- 2020	4.5	4.5
4	EAGJ-Japan	1990- 2025	3.9	....
		2026- 2050	2.6	....
		2051-2100	1.8	....
5	IEEJ-Japan	1999-2020	5.2	5.4
6	RS&RAE-UK	until 2026	....	4.0
		until 2050	....	3.0
		2051-2100	....	2.0
7	CEA-India	1997- 2012	....	6.5
8	Present Study	2002- 2022	4.6	6.3
		2022-2032	4.5	4.9
		2032-2042	4.5	4.5
		2042- 2052	3.9	3.9

TERI's Study DISHA Projected fuel-mix installed capacity and generation in Base Case

Year	**Capacity GW**	**Thermal**	**Hydro**	**Nuclear**	**RETs**	**Hydro Imports**
1997	90	71.3	24.4	2.5	1.3	0.4
2019	277	70.8	14.2	4.4	6.0	4.7
2047	798	73.2	14.2	4.4	6.0	2.3
	Gen.TWH					
1997	426	79.0	17.5	2.4	0.8	0.3
2019	1446	81.3	8.1	4.4	3.0	3.2
2047	4219	83.1	8.0	4.4	3.0	1.5

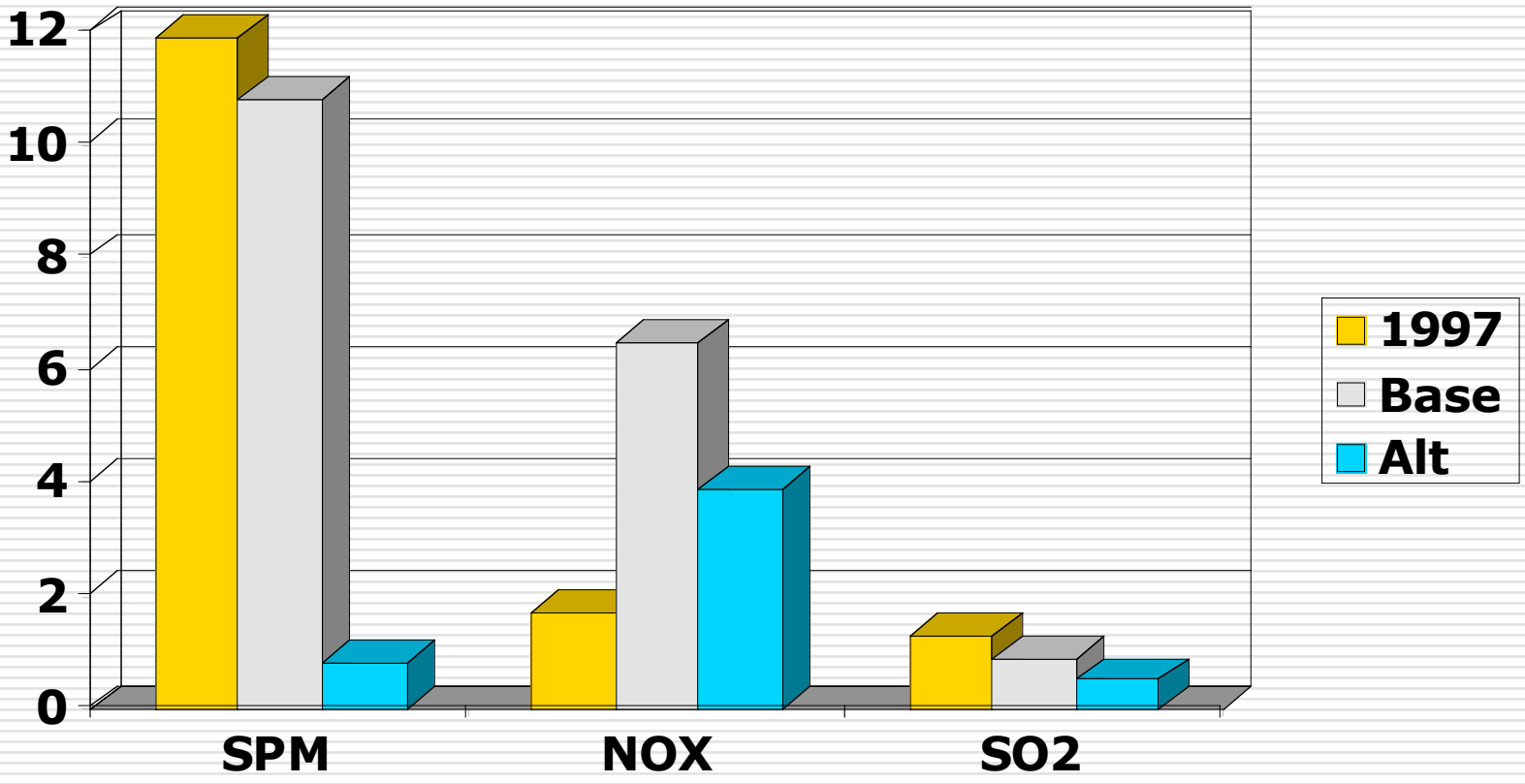
Demand forecast for fossil fuels in Base case- DISHA study

	1997	2019	2047
Coal Domestic mt	230	368	441
Coal Imported mt	9	140	794
Oil mt	3	14	41
Gas BCM	8	26	77

Sectoral power demand (TWH) DISHA study

Year	Scenario	Ind.	Transpt.	Agri.	Comm.	Resi.	Total
1997	BC	137	8	89	47	48	330
2019	BC	535	27	195	243	156	157
	Alt	482	42	175	219	155	1073
2047	BC	1703	115	346	915	508	3586
	Alt	1362	168	277	732	446	2985
CGAR	BC %	5.2	5.5	2.7	6.1	4.8	4.9
Alternative	Alt %	4.7	6.3	2.3	5.6	4.6	4.5

Emissions (mt) of pollutants: DISHA study



Projected Energy Based on Atomic Energy Commission (GOI)

Year	Popula -tion	Coal + Lignite	Hydro carbon	Hydro	Nuclear	Non-Conv-Renew	Prim. En.	Electricity			Elec/ Primary
	Billion	EJ	EJ	EJ	EJ	EJ	EJ	EJ (ET)	TWh-e	Per Cap kWh-e	%
2002	1.04	6.40	6.02	0.79	0.23	0.03	13.46	7.65	638	614	57
2022	1.33	11	13	5	2.1	1.6	33	22	2154	1620	66
2032	1.42	19	19	6	4.4	2.0	51	35	3485	2454	68
2042	1.47	31	30	6	9.8	2.4	80	54	5438	3699	68
2052	1.50	47	41	6	19.4	2.7	117	75	7957	5305	64

Projected Growth by Fuel MIX – Atomic Energy (GOI)

Year	Coal		Hydro-carbon		Hydro		Non-conv Ren		Nuclear		Total
	GWe	%	GWe	%	GWe	%	GWe	%	GWe	%	GWe
2002	71.92	51.84	32.81	23.65	27.78	20.02	3.5	2.52	2.72	1.96	138.73
2022	156	37	57	14	115	28	56	13	29	7	417
2032	266	41	101	15	150	23	68	11	63	10	648
2042	436	46	155	16	150	16	82	9	131	14	954
2052	615	46	204	15	150	11	100	7	275	20	1344

Projected Cumulative Nuclear Power Installed Capacity

	PHWR, AHWR and FBR based on Pu from PHWR			LWR and FBR based on Pu from LWR			Sub Total		Grand Total
Year	Thermal (GWe)	Fast (GWe)		Thermal (GWe)	Fast (GWe)		Oxide (GWe)	Metal (GWe)	(GWe)
	Oxide	Oxide	Metal	Oxide	Oxide	Metal			
2002	2.40	0.00	0.00	0.32	0.00	0.00	2.72	0.00	2.72
2022	9.96	2.50	6.00	8.00	0.00	3.00	20.46	9.00	29.46
2032	9.40	2.50	33.00	8.00	0.00	10.00	19.90	43.00	62.90
2042	7.86	2.50	87.00	8.00	0.00	26.00	18.36	113.00	131.36
2052	4.06	2.50	199.00	8.00	0.00	61.00	14.56	260.00	274.56

Other Scenario's for Power sector development

- Greater Regional Cooperation
  - Iranian, Russian, Bangla Desh, Burma Natural Gas pipeline possibility
  - Hydro power from Nepal, Bhutan, etc
- Greater penetration of advanced power generating technologies
  - Ultra supercritical boilers, IGCC, H-frame GTs
  - CO2 sequestration with pre-combustion caputre

Thank you