Comparison of Distributed Generation Options for India

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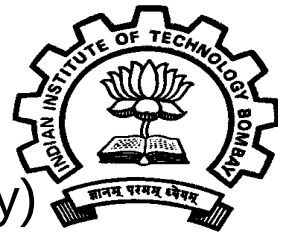
EPP



CEIC Seminar 16th June 2003 (* on leave from IIT Bombay)

Outline of Talk

- India- Energy Balance
- Power Sector Balance and Trends
- Distributed generation options
- Non-Renewable Comparison
- Renewable Options
- Issues

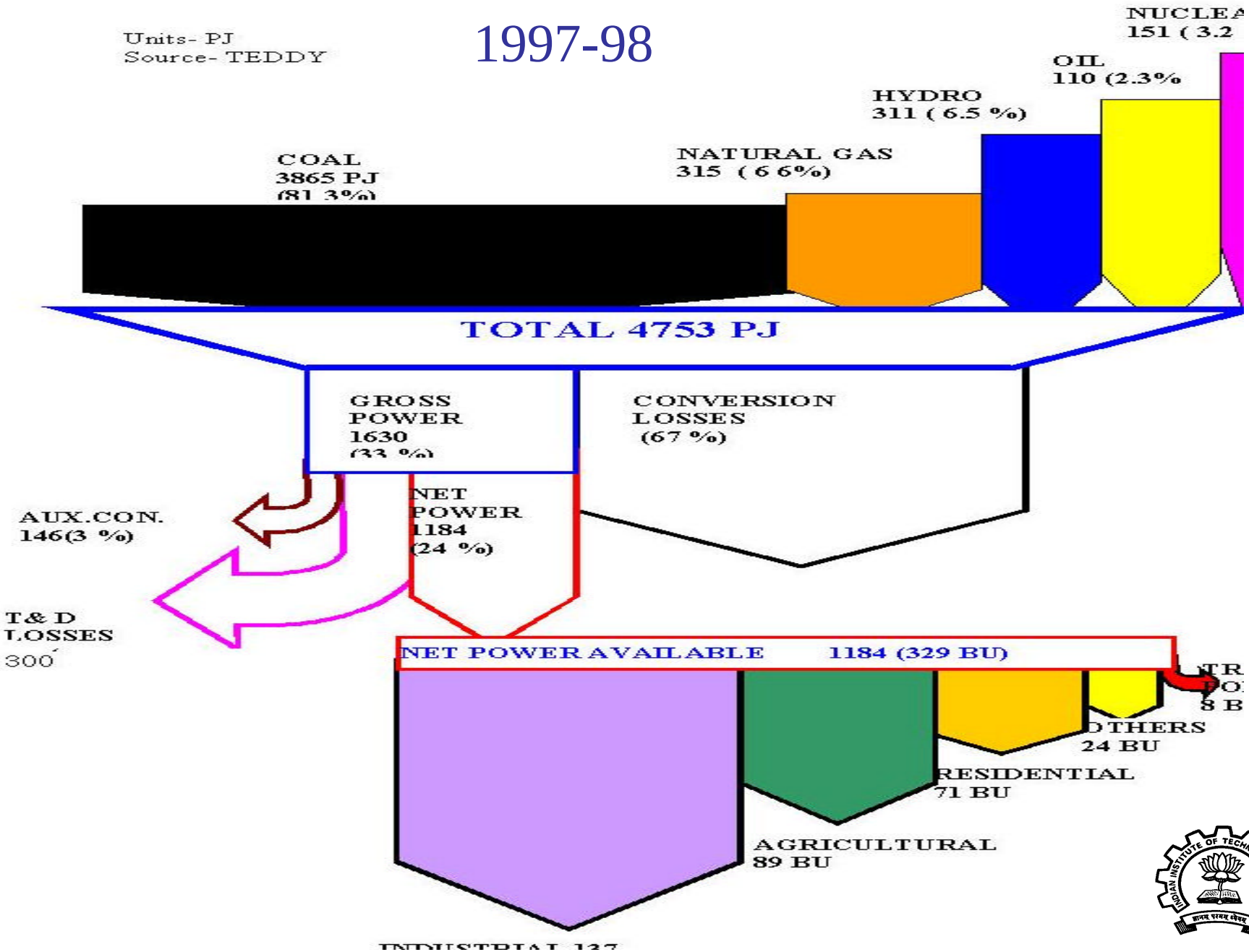
Energy Content

- Average Calorific Value of Indian Coal 4500kcal/kg (18.8 MJ/kg)
- Average Calorific Value of Oil 10000kcal/kg (41.8 MJ/kg)
- Natural Gas 9300 kcal/m^3 (38.9 MJ/m^3)
- Nuclear, Hydro – Work backwards from generation based on plant efficiencies
- Hydro 85%, Nuclear 25%

Power Generation

- Coal 205.5 Million Tonnes
- Oil 2.63 Million Tonnes
- Gas 8.11 Billion m^3
- Hydro 311 PJ
- Nuclear 151 PJ
- Coal 3865 PJ, Oil 110 PJ, N Gas 315 PJ
- Total Primary 4753 PJ

ENERGY BALANCE IN POWER SECTOR- INDIA



END USE ELECTRICAL ENERGY CONSUMPTION -INDIA

1997-98

Units- Billion kWH
Source- TEDDY

NET POWER AVAILABLE 329

TRANSPORT 8
(2.5 %)

OTHERS24
(7 %)

RESIDENTIAL 71
(21.5 %)

LIGHTING	28 (40 %)
FAN	21 (30 %)
REFRIGERATION	7 (10 %)
AIR CONDITIONING	3 (5%)
OTHERS	12 (15 %)

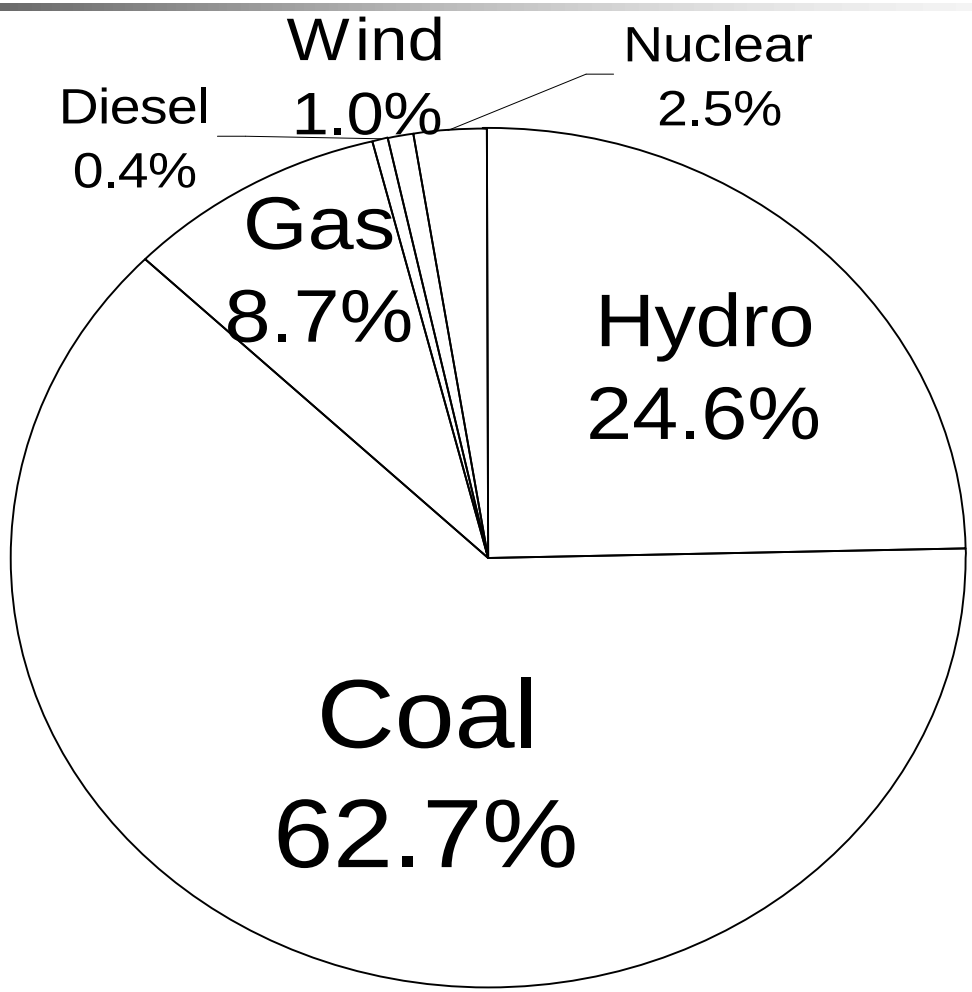
AGRICULTURE89
(27 %)

MOTORS & PUMPS

INDUSTRIAL 137 (42%)

MOTORS & PUMPS- 71 (52 %), MELTING-22 (16%)
HEATING-15 (11 %) , AIR COMPRESSOR-12 (9%)
AC &REFRIGERATION -7 (5 %), LIGHTING-5 (4%)
OTHERS 5 (4%)

Share of Power Installed Capacity (1998) in India



India - Fossil Fuel reserves

Fuel	Reserves	Prodn	R/P ratio
Coal (Million Tonnes)	60000	296	~200+
Oil (Million Tonnes)	660	33.86	19 (9)
N.Gas Billion m3	692	26.4	26
Nuclear	Nat U		~50

Data Source TEDDY

Electricity Sector in India

- Low per capita electricity consumption (~400 kWh/capita/year)
- Energy and Peak power scarcity
- Large number of villages un- electrified
- Significant proportion of households without access to electricity
- Electricity use linked with quality of life

Electricity

- 104 GW Installed Capacity 2002(less than 4% of World Capacity)

  Average 0.1 kW of installed capacity/capita
- World installed capacity 0.53 kW/capita
- Low electricity consumption – India-

  about 340 kWh/capita/year

  Nepal, Bangladesh & Bhutan –

  lower than 100 kWh/capita/year
- World average electricity consumption-

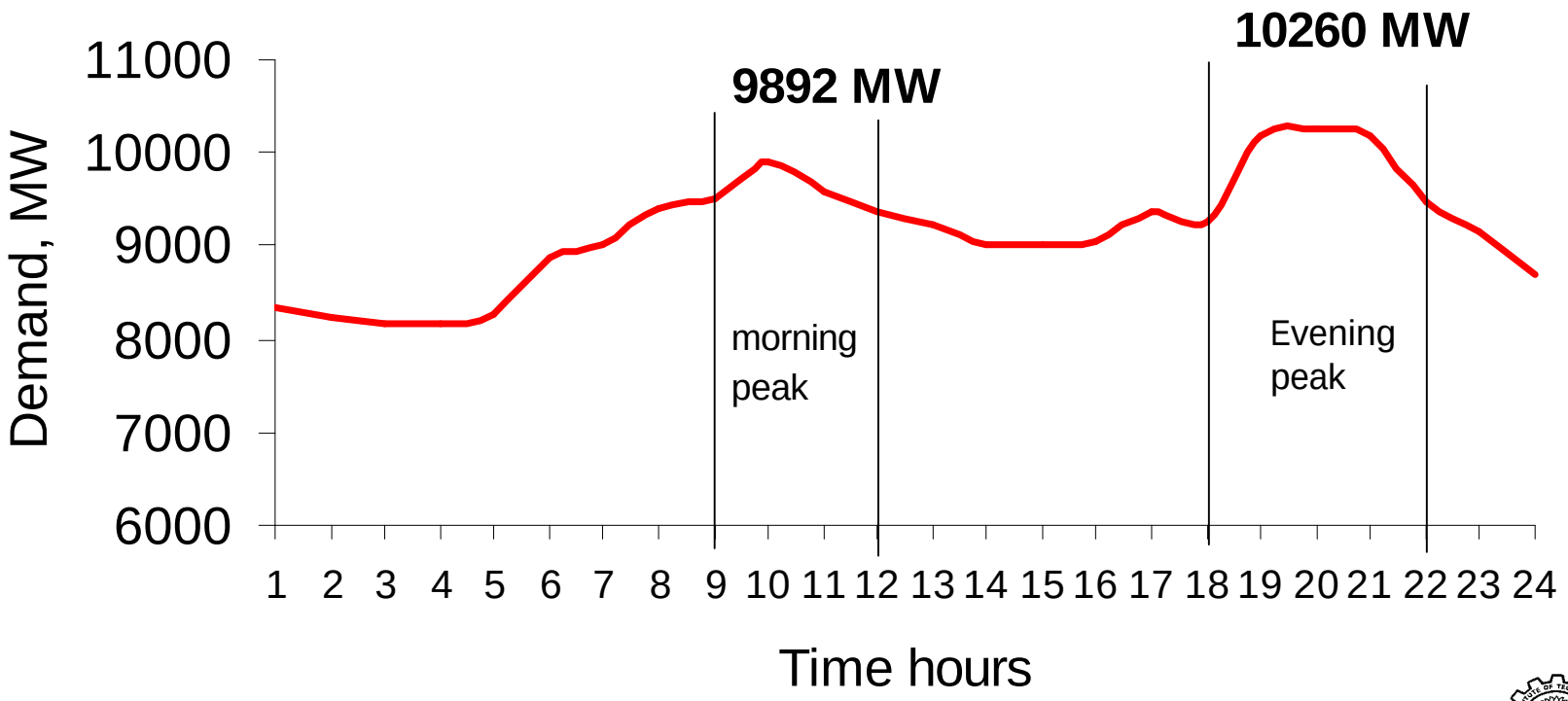
  2100 kWh/capita/year

Electricity Sector

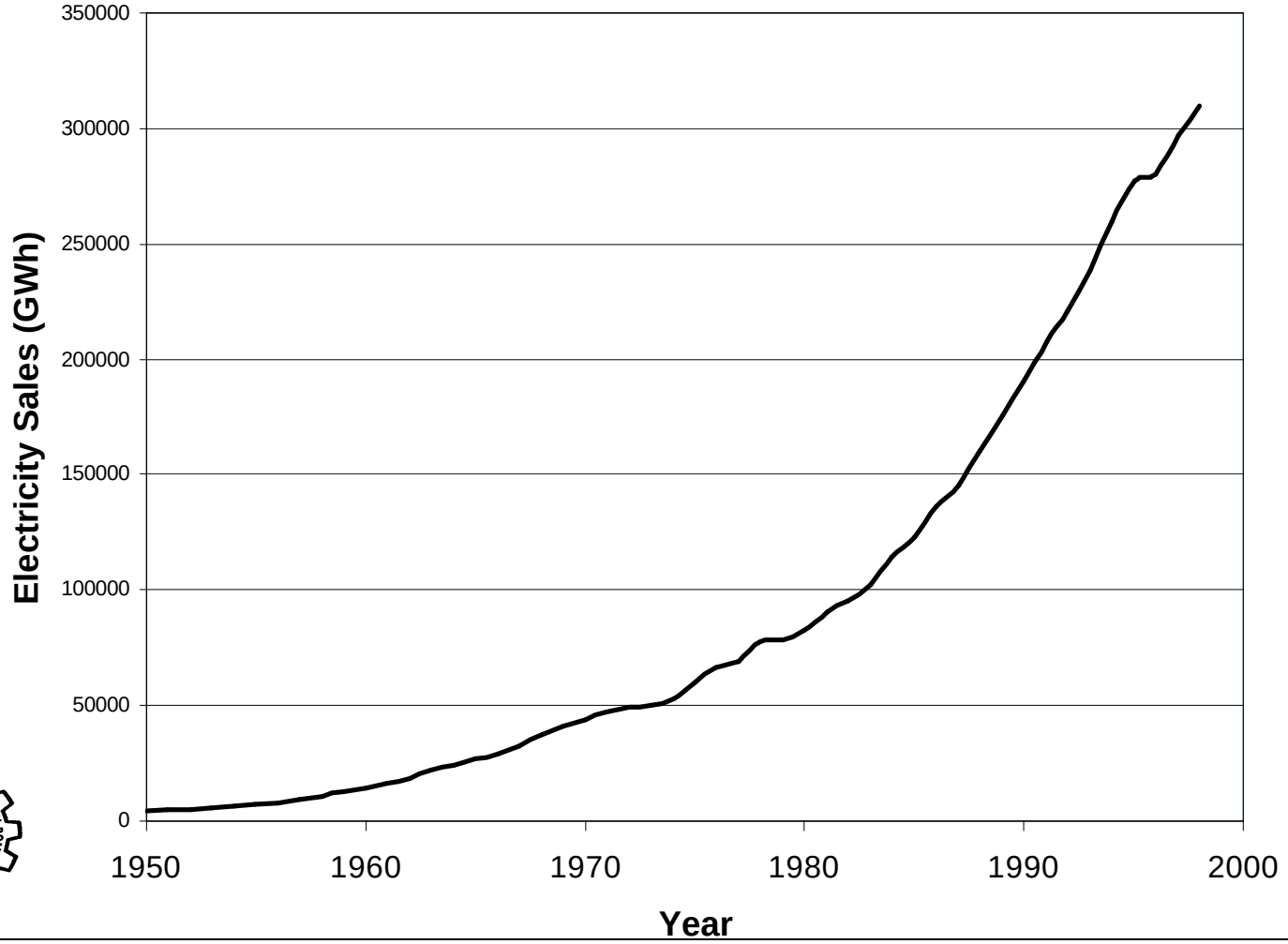
- SEB annual loss 2000-1 Rs 20,500 crores (US 4400 million $)
- Gap of 92 p/kWh - between cost of supply and revenue (2c/kWh)
- Peak shortage 13%, energy shortage 7%
- Estimated requirement of 100,000 MW additional capacity by 2012

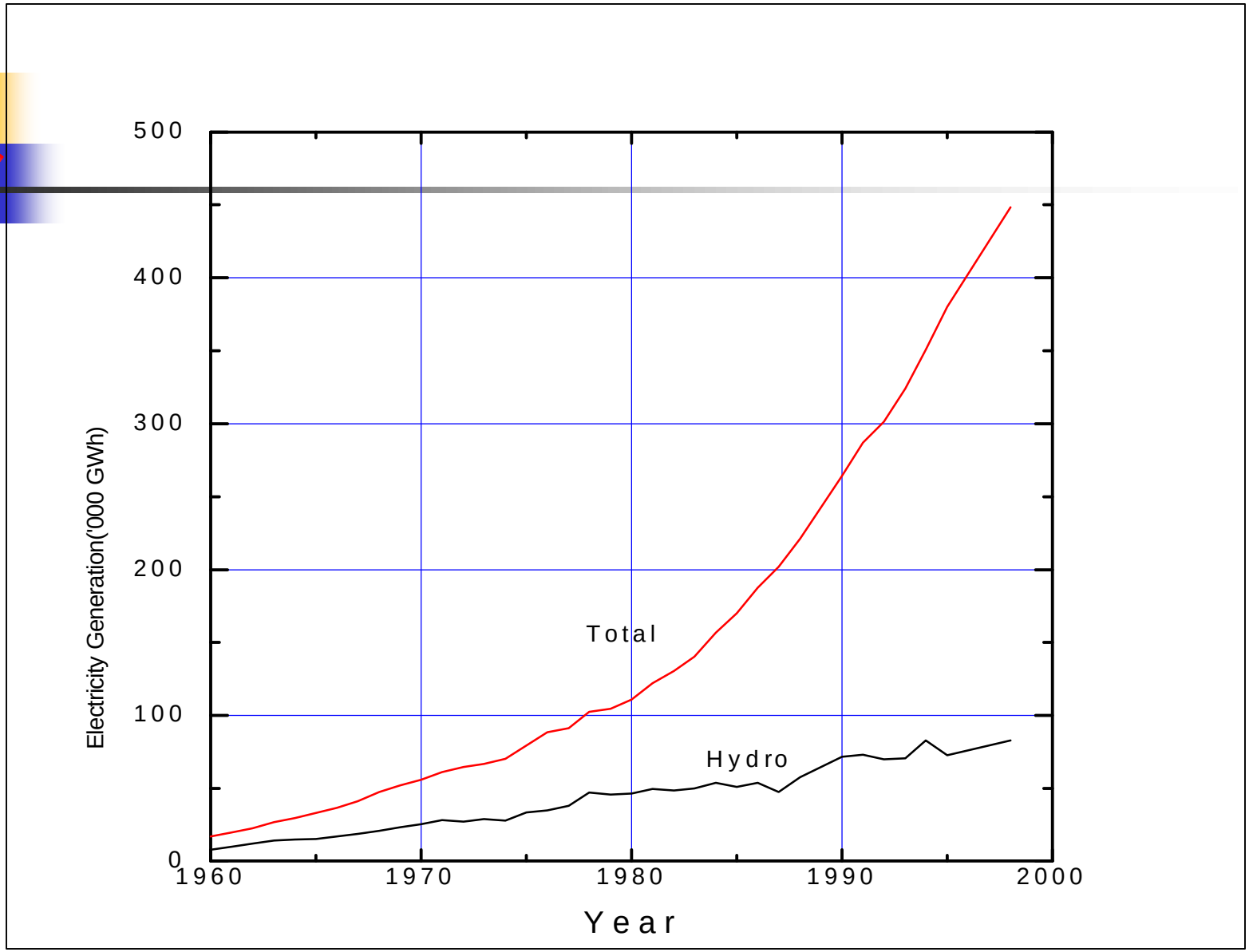
Load curve of a typical day –MSEB

(8/11/2000 source: WREB annual report-2001)

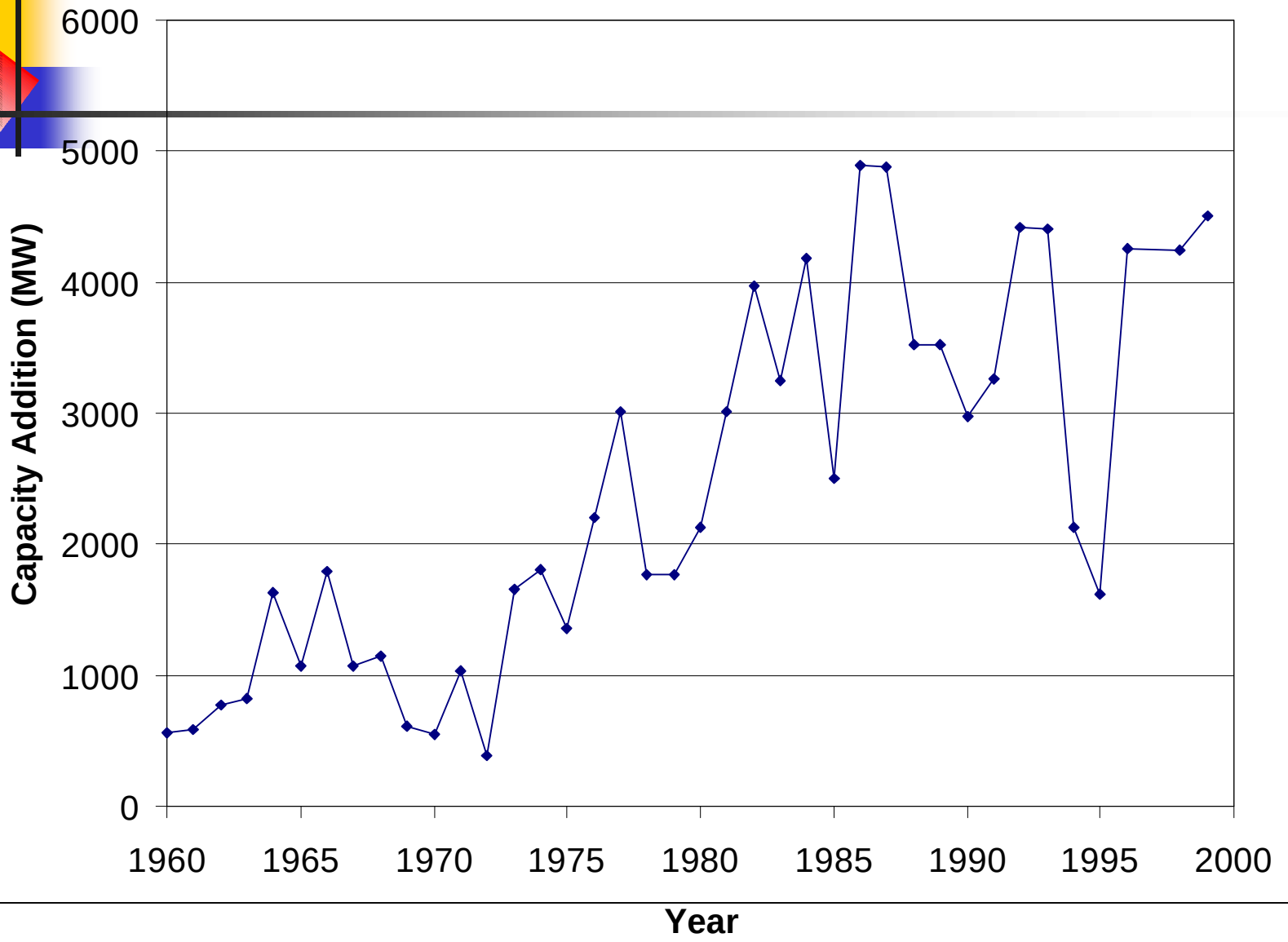


India - Electricity Sales




500
400
300
200
100
0
Electricity Generation('000 GWh)
Total
Hydro
1960
1970
1980
1990
2000
Year

Annual Capacity Additions



Carbon Dioxide Emissions

- Kaya identity: Total CO2 Emissions

= (CO2/E)(E/GDP)(GDP/Pop)Pop

CO2/E – Carbon Intensity

E/GDP- Energy Intensity of Economy

- Mitigation – increase sinks, reduce sources- aforestation, fuel mix,energy efficiency, renewables,nuclear, carbon sequestration
- Adaptation

GHG Emissions (Fuel Cycle Analysis)

	CO_2 g/kWh
Coal Conventional	960 -1300
Advanced Coal	800-860
Oil	690-870
Gas	460-1230
Nuclear	9-100
Biomass	37-166
PV	30-150
Hydro-electric	2-410
Wind	11-75

Source: John Holdren

Kirk Smith, World Energy Assessment, UNDP,2001

Distributed Generation Options

- Non-Renewable
  - IC Engine- diesel
  - IC Engine- Natural gas
  - Micro-turbine- Natural gas
  - PEM fuel cell- reformer - Natural gas
- Renewable
  - Wind Turbine
  - Solar Photovoltaic (PV)
  - Biomass Gasifier- Gas Engine
  - Bagasse - Cogeneration

Comparison

- Annualised Life Cycle Costs (ALCC) - annual cost of owning and operating equipment
- $ALCC = C_0\, CRF(d,n) + AC_f + AC_{O\&M}$
- $CRF(d,n) = [\, d(1+d)^n]/[(1+d)^n - 1]$
- discount rate d, Life n years, C_0 Capital Cost, AC_f, $AC_{O\&M}$, annual cost - fuel and O&M

Definition

- Distributed Generation- *Installation and operation of electric power generation units connected to the network on the customer site of the meter* [Ackerman,2001]
  "Dispersed" "Embedded" Generation
- Classification- Non-renewable/ renewable
- Based on Prime Mover- engine, turbine, fuel cell...

Option	Capital Cost (Rs/kW)	Life	η	O&M cost Rs/kWh	
Diesel	25000	20	40%	0.25	($530/kW)
Gas Engine	33000	20	35%	0.25	($700/kW)
Micro Turbine	45000	20	28%	0.25	($960/kW)
Fuel Cell	141000	10	45%	0.25	($3000/kW)

Discount rate = 10%,

Natural gas price = Rs 20/m^3

Diesel price = Rs 16/litre, density = 850 kg/m^3,

LHV = 9.7 kWh/kg

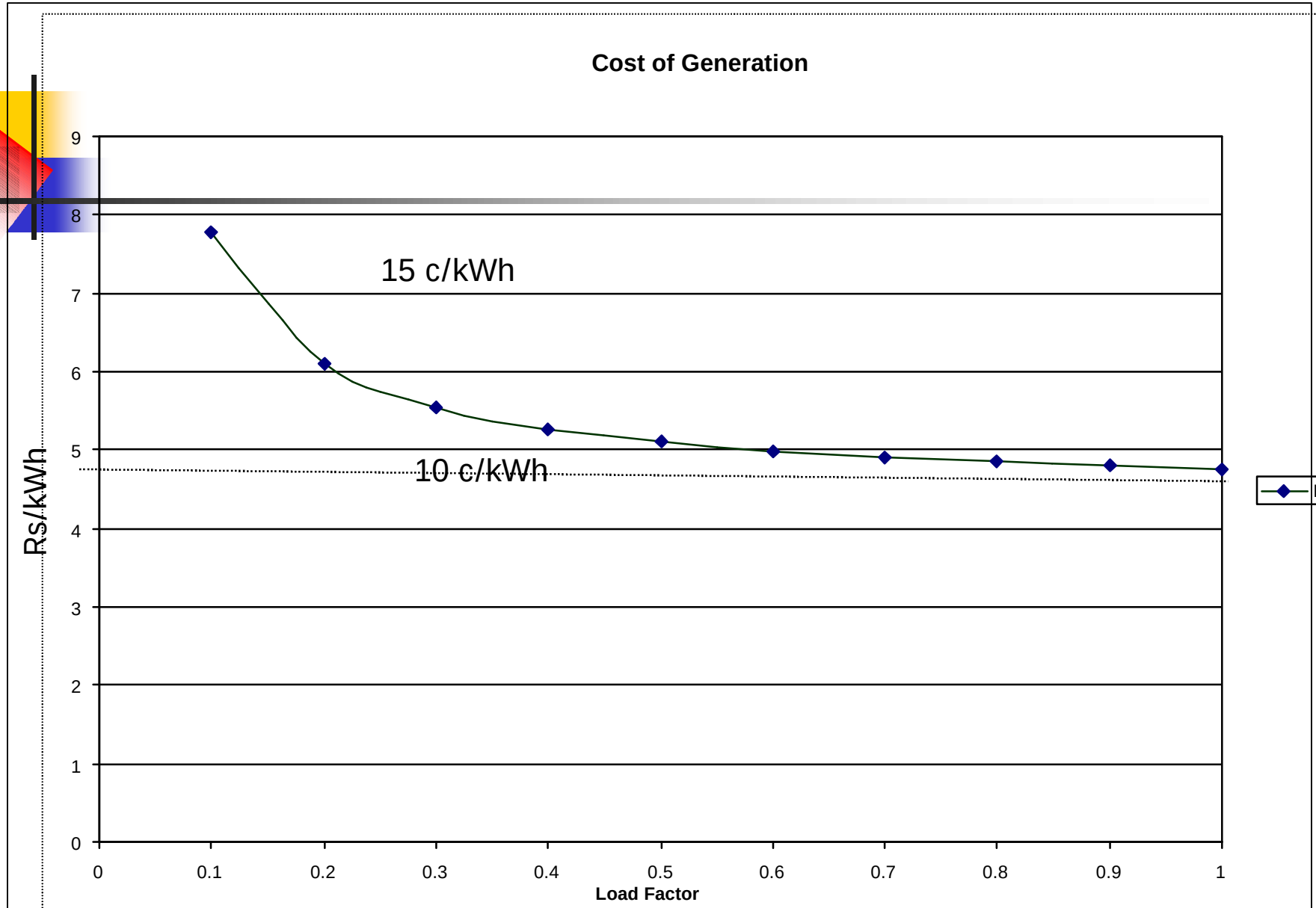
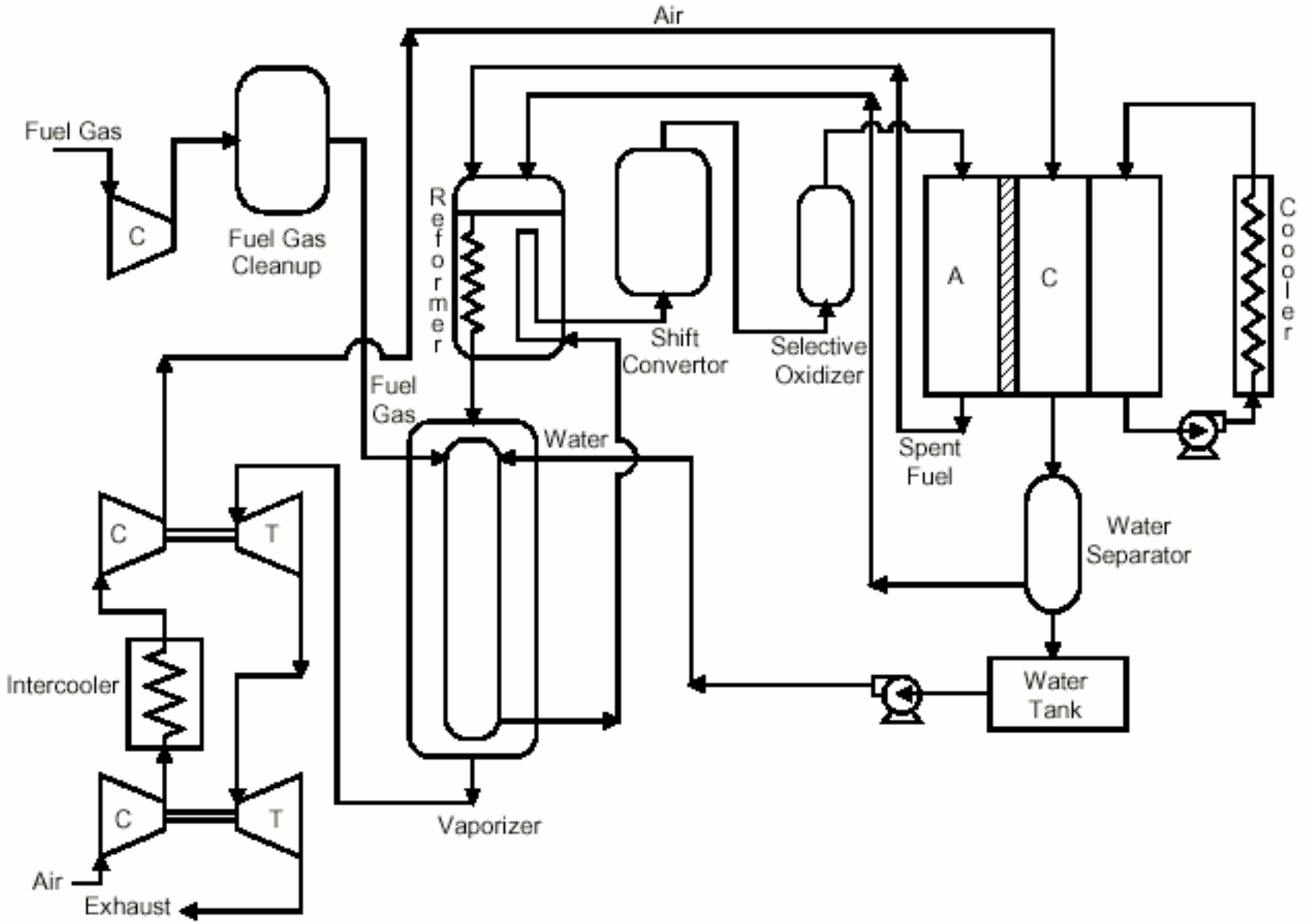


Figure 2. Cost of Generation from Diesel Engine-Generator (d=0.1)

Schematic of a PEM Fuel Cell -Reformer



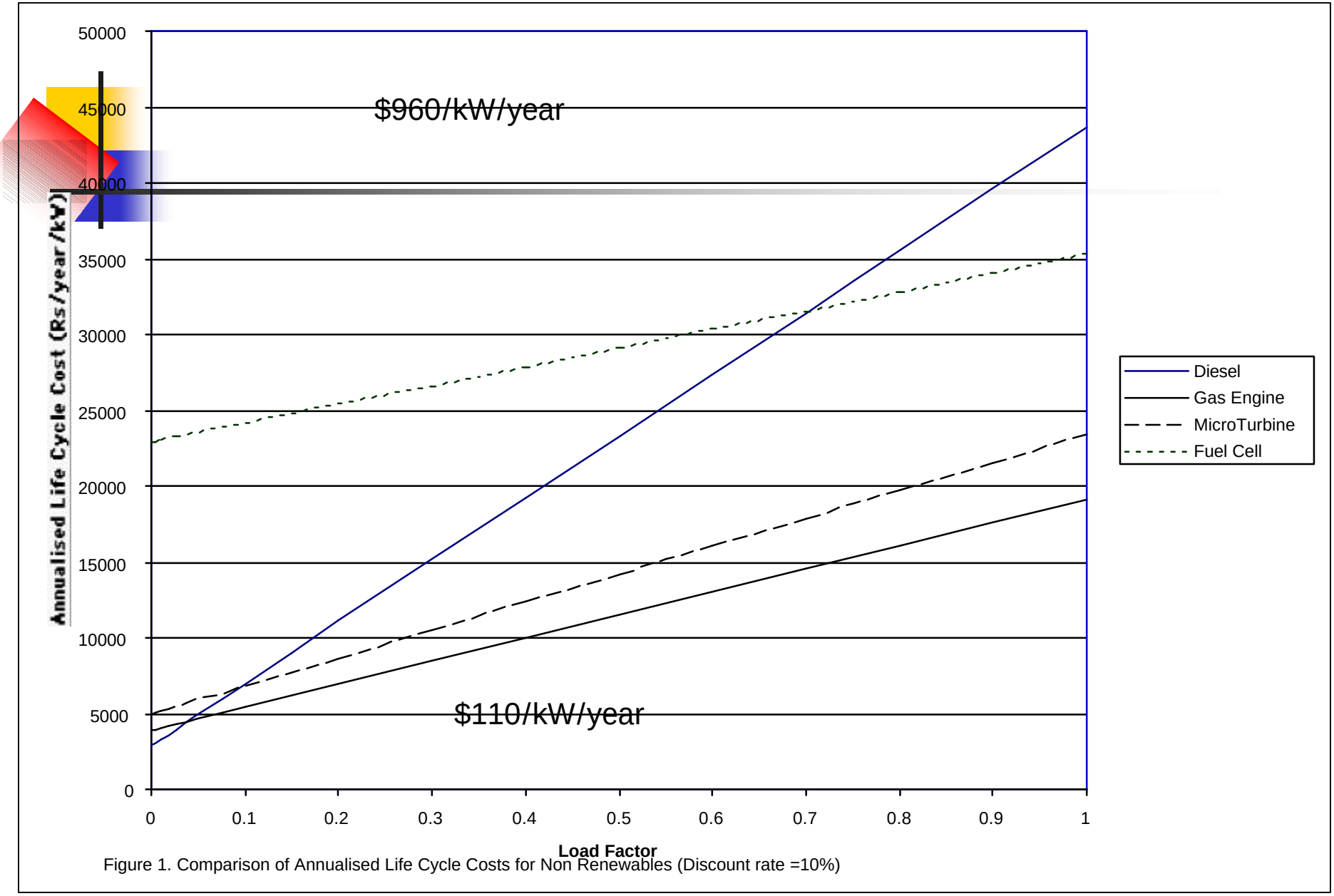


Figure 1. Comparison of Annualised Life Cycle Costs for Non Renewables (Discount rate =10%)

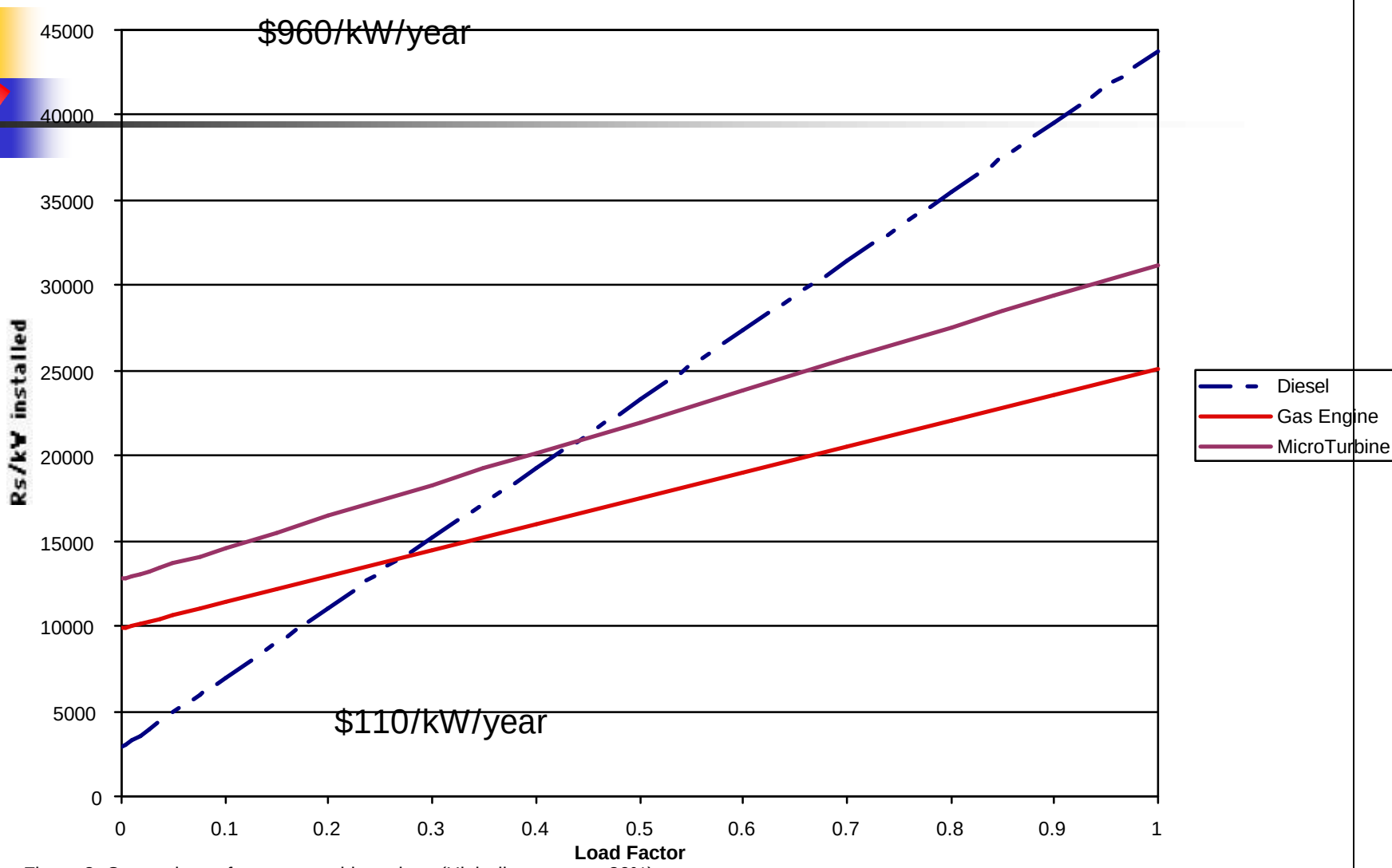
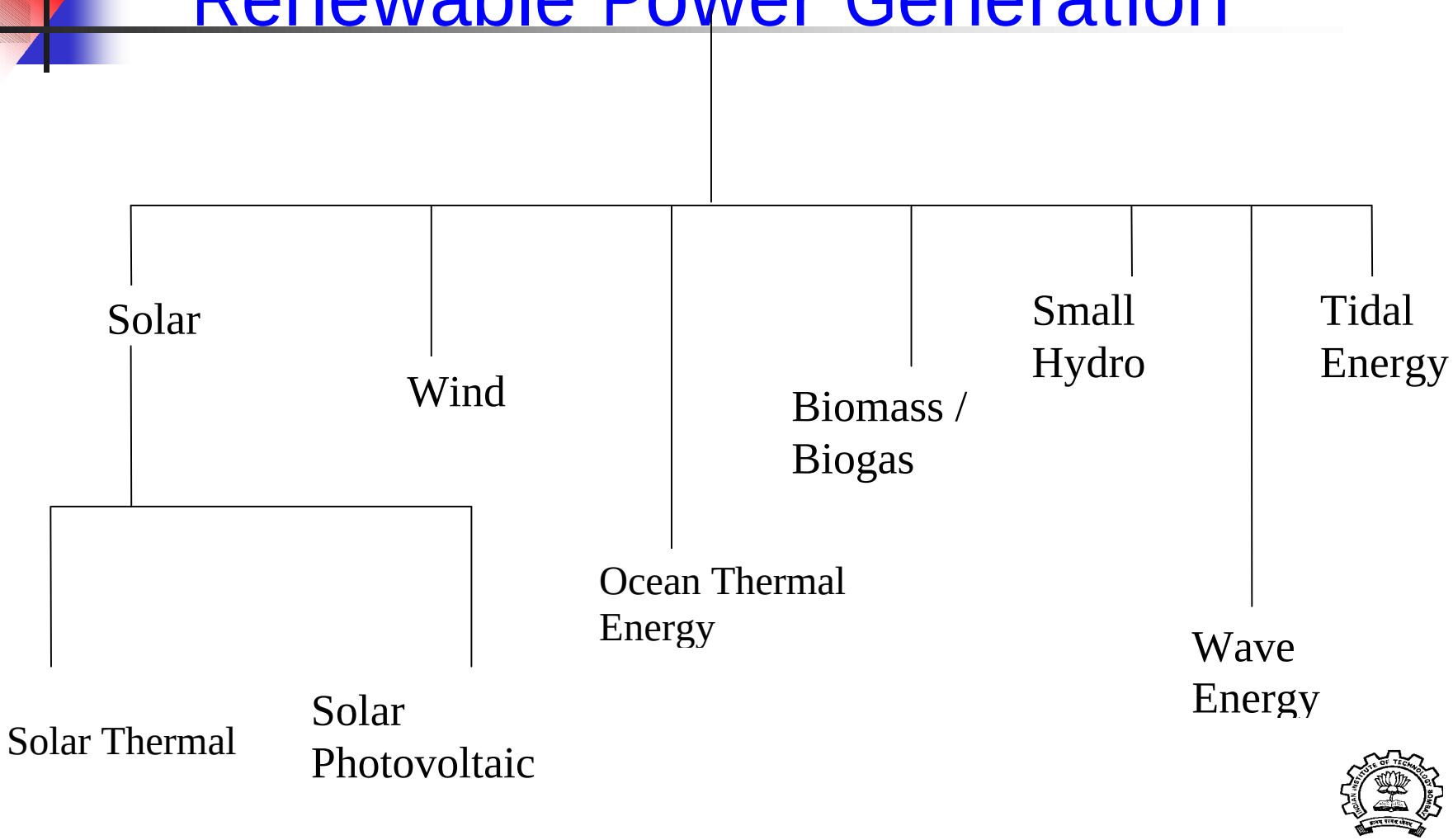
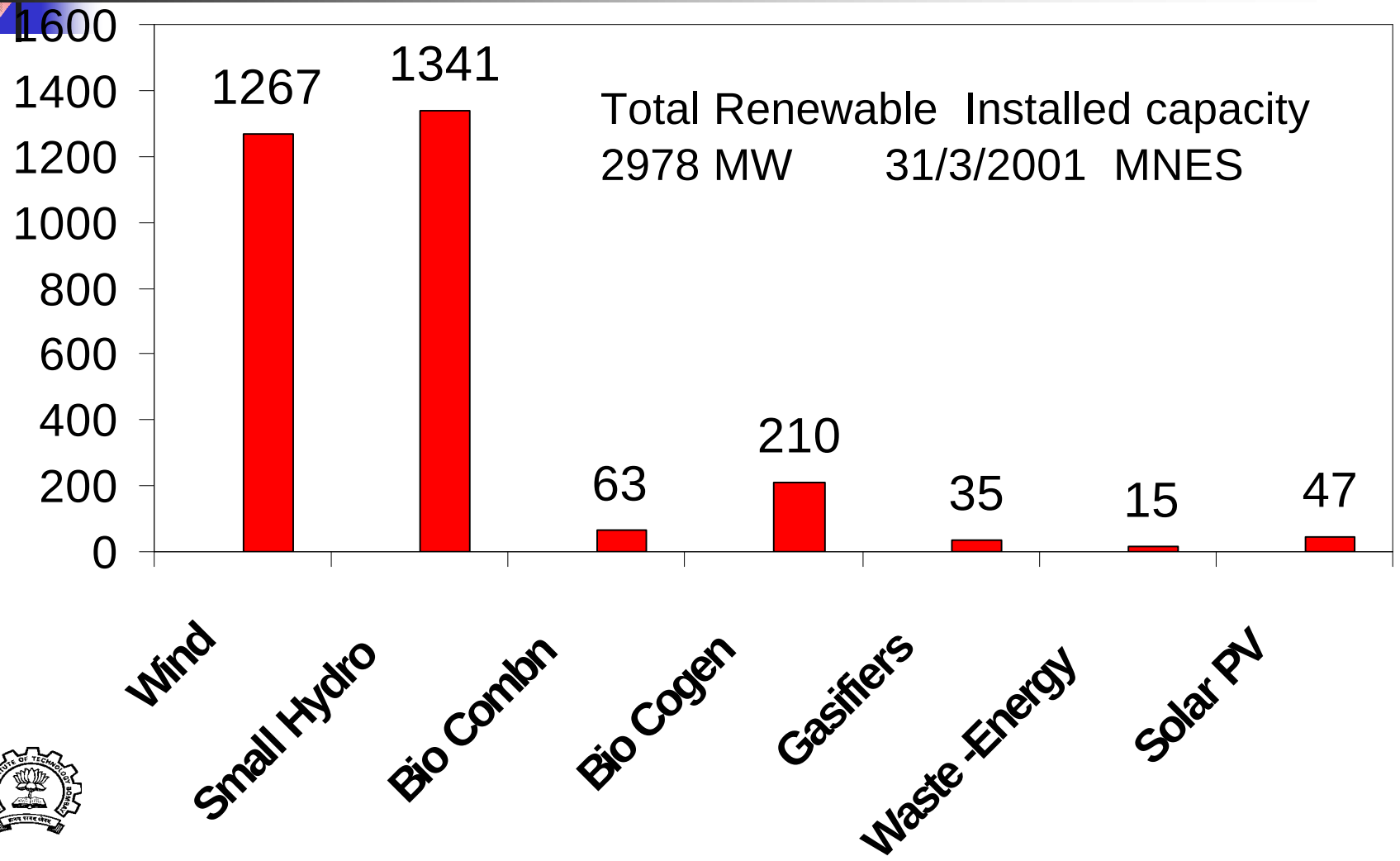


Figure 3 Comparison of non-renewable options (High discount rate 30%)

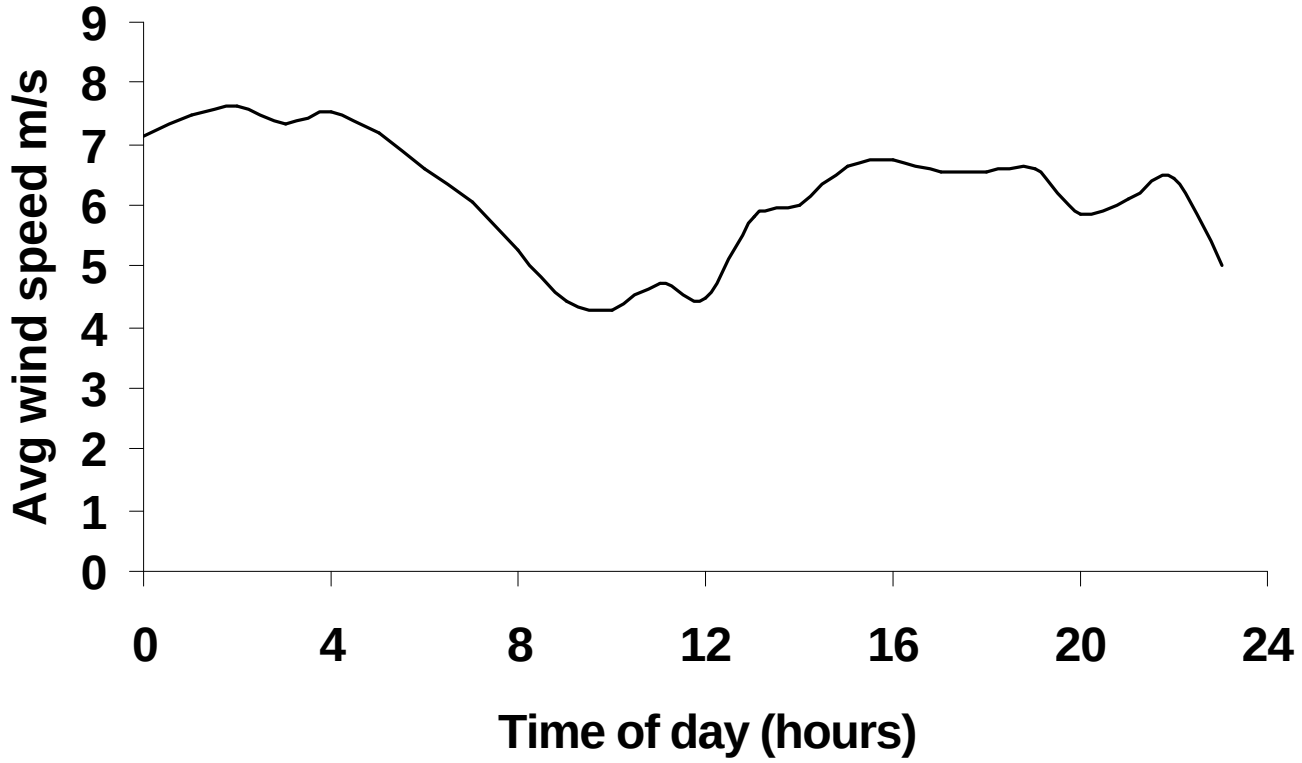
Renewable Power Generation



Installed Capacity of Renewables in India

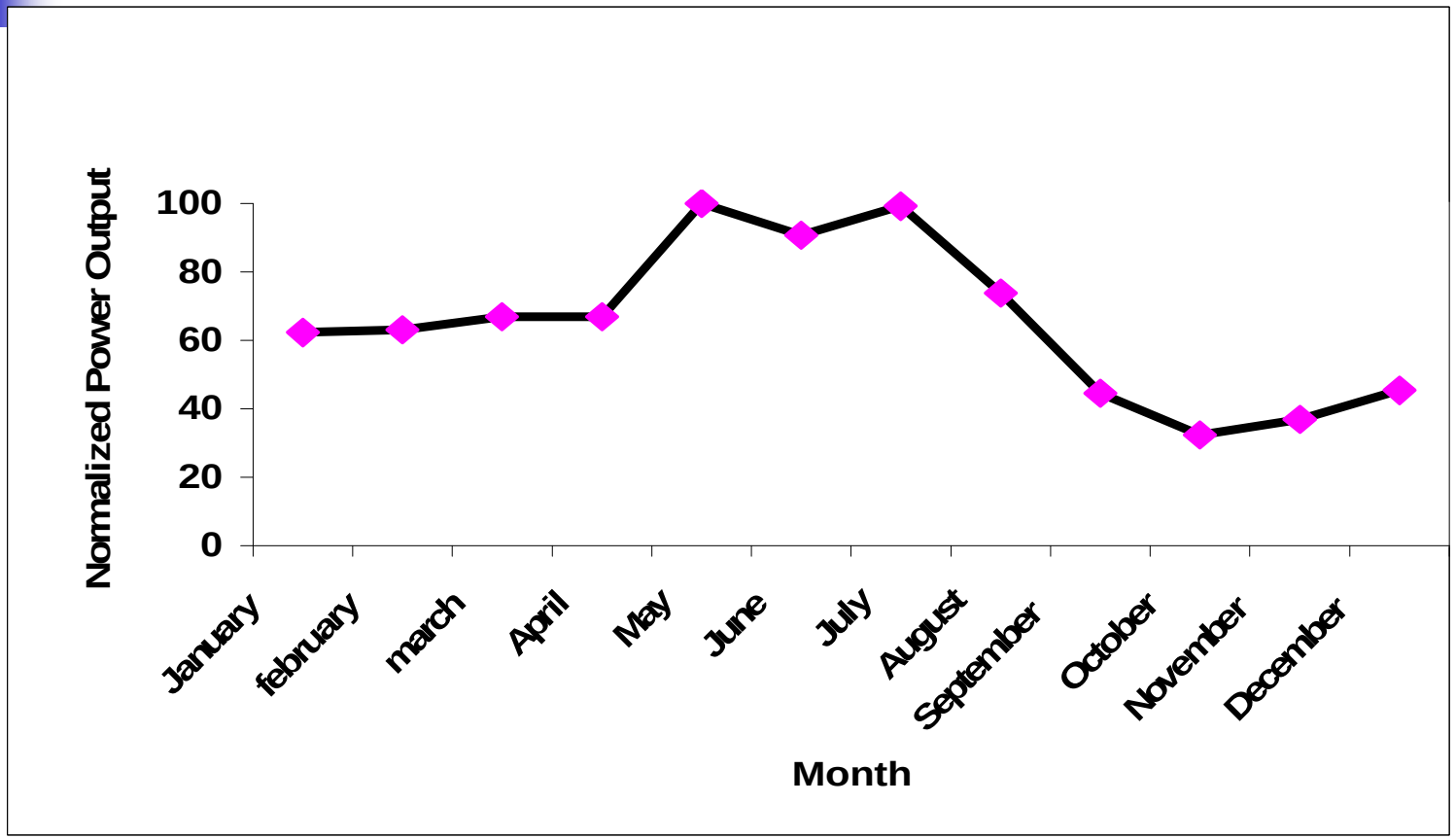


Daily Wind Variation



Daily variation Sanodar (West Coast)

Monthly Wind Output



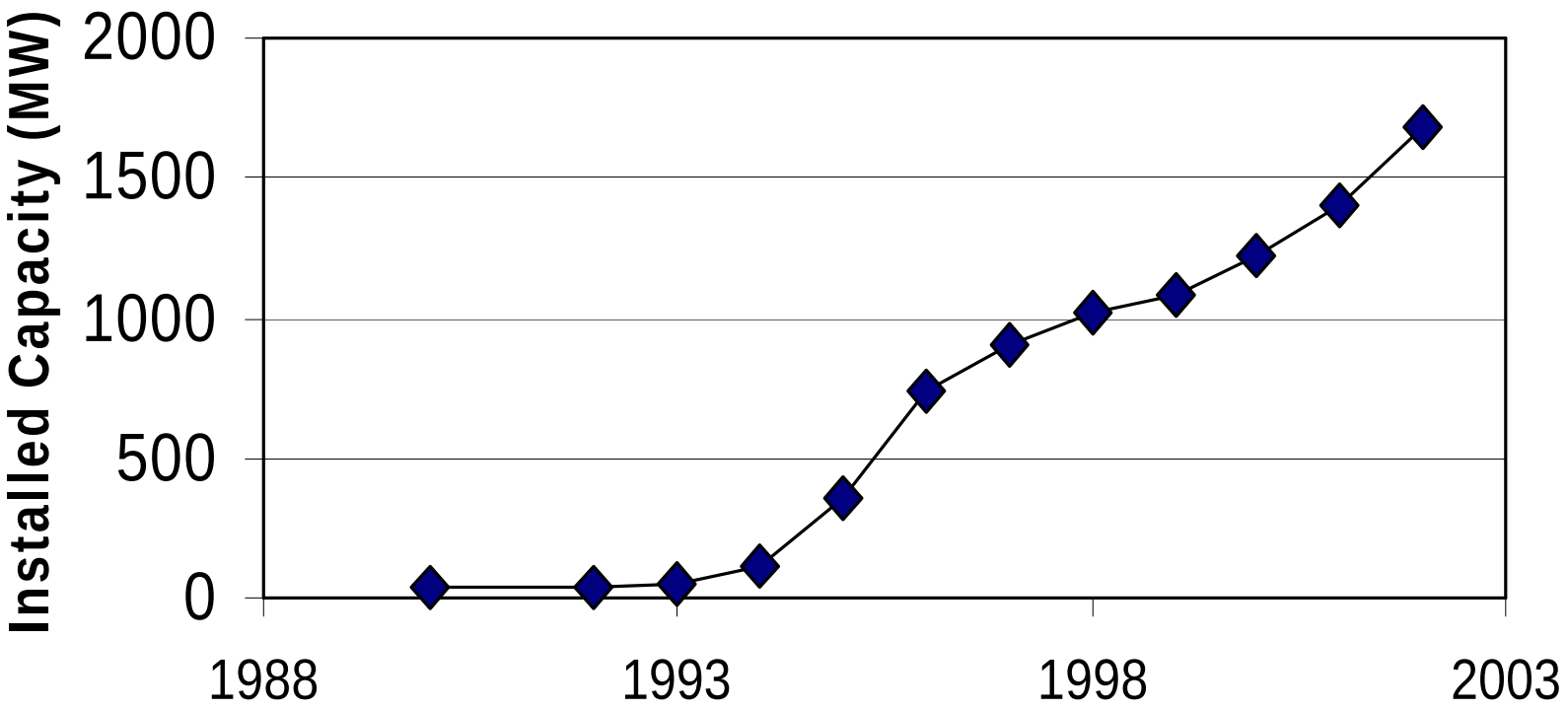
SITE: SANODAR

Wind -Cost of Generation

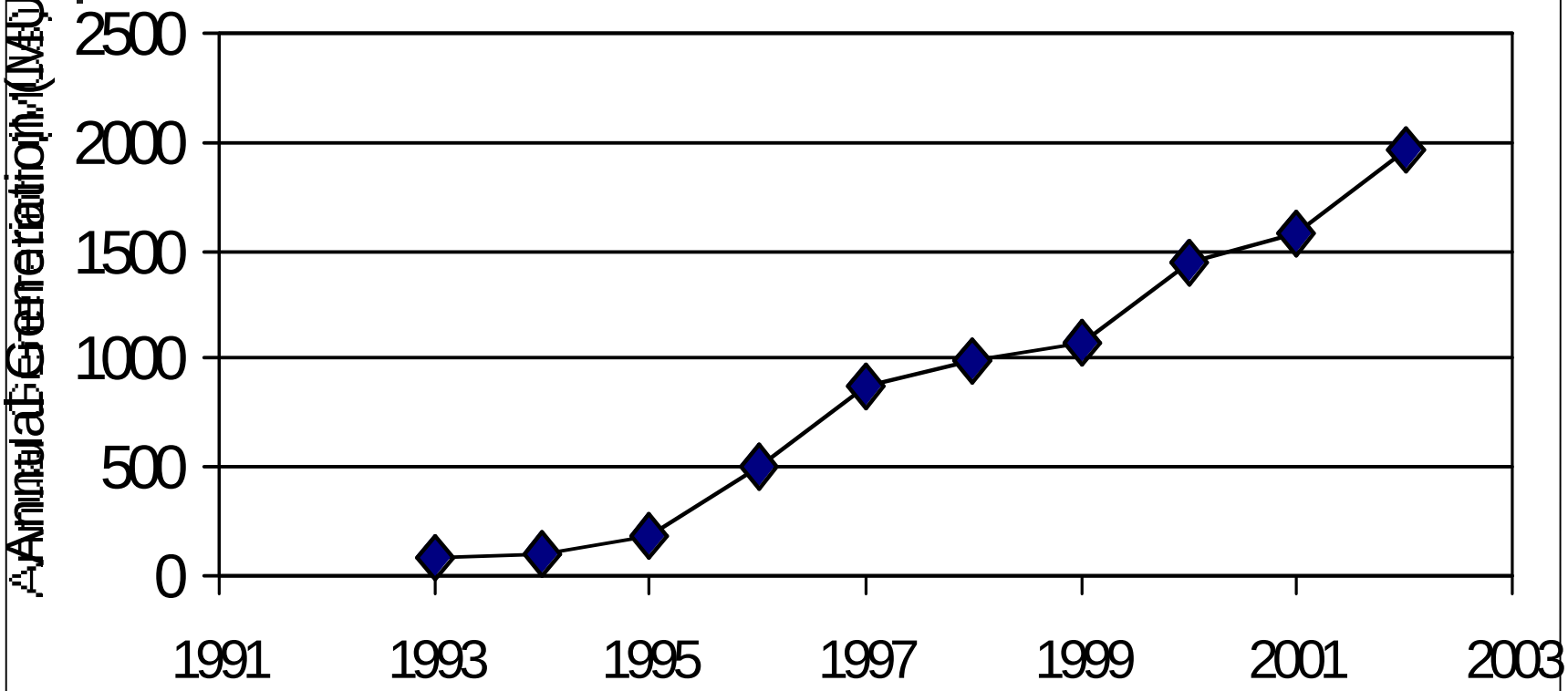
Load Factor	0.1	0.2	0.3	0.4
d=0.1 ALCC Rs	$130 5960	6048	6136	6223
Rs/kWh	14c 6.80	7c 3.45	5c 2.33	4c 1.78
d=0.3 ALCC Rs	15167 $320	15255	15342	15430
Rs/kWh	17.31 37c	8.71 18c	5.84 12c	4.40 9c
Capital cost Rs 50,000/kW, O&M cost Rs 0.1/kWh, Life 20 years				

$1060/kW

India- Wind Installed Capacity



India- Wind Generation

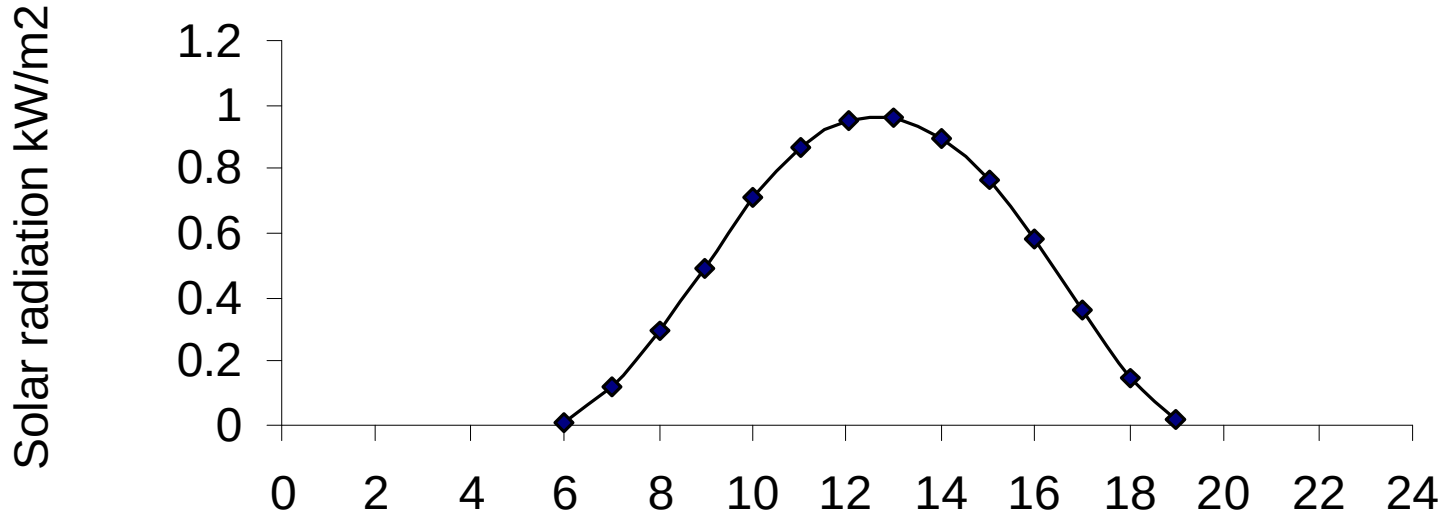


Wind -Trends

- 1999- Wind Energy 24 TWh (13.3%) – World 13.6 GW (20.1% Load Factor)
- 1 million Wind pumps , 10000+ small battery charging wind generators
- World- Growth rates 27-33%
- India 45000 /13000 MW potential estimated
- Wheeling, Third party sale, depreciation

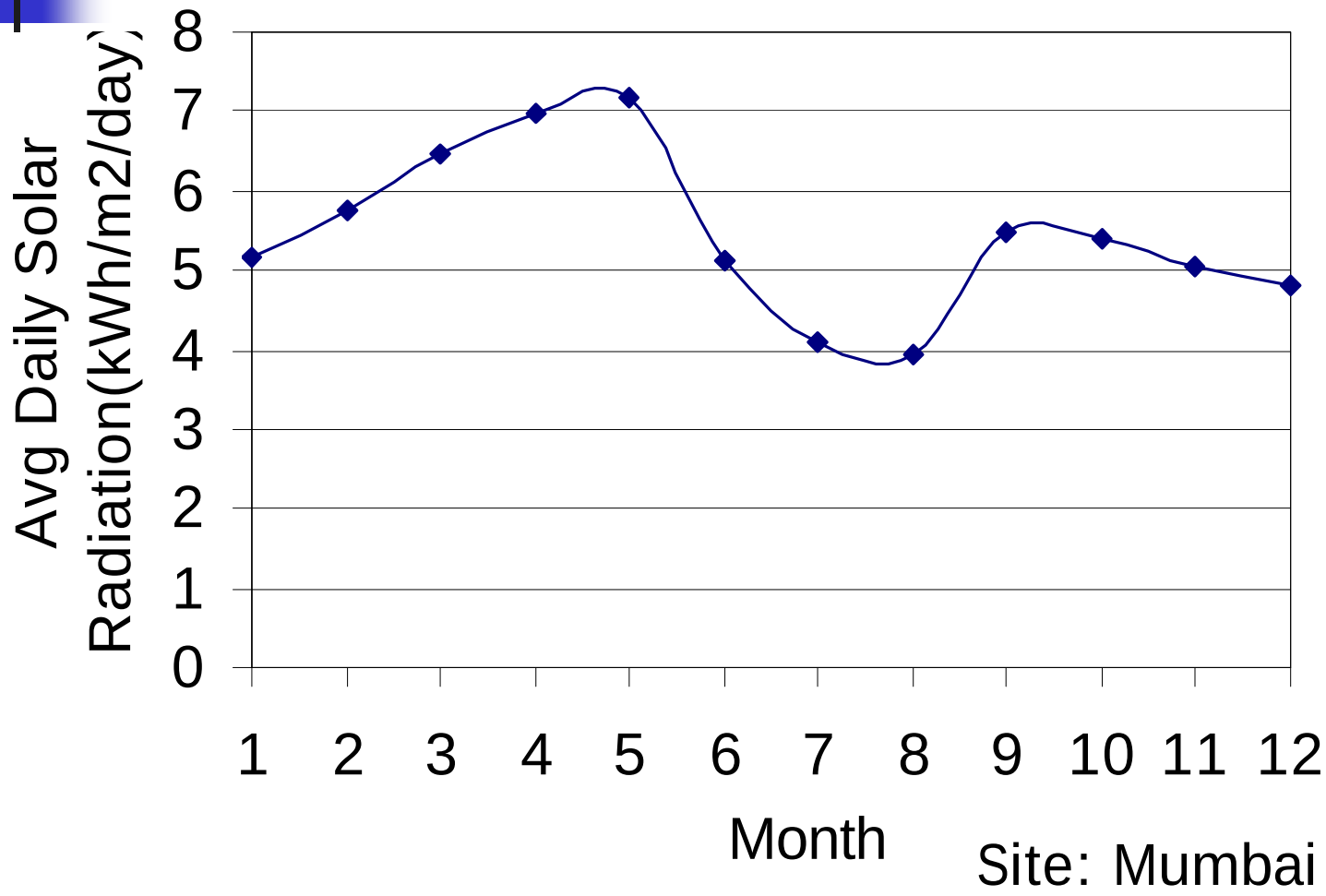
39% (1990-2002), 21% 2001-2 CAGR

Daily Solar Radiation



Site :Mumbai, May

Monthly Solar Radiation



PV- Cost of Generation

Capital cost/kW	$4300	$5300	$6400
IF=0.2 ACCR/kWh	2,860	3,526	4,256
R/kWh	29c 1366	36c 1701	43c 2036
IF=0.25 ACCR/kWh	2,039	2,513	3,035
R/kWh	1998 23c	1366 29c	1634 35c

$760

O&M=$25/kW Life=20 years discount rate=10%

Solar PV

- Total Installed Capacity 65 MW
- 1999-2000 Prodn 9.6 MW cells, 11 MW modules
- Grid Connected 2.5 MW (2002) - 31 systems - average 80 kW, largest 240 kW peak
- Daily insolation 4- 7 kWh/m^2 , 300 sunny days
- Capital subsidies on grid connected systems - 2/3rd of initial capital cost
- Manufacturers - Tata BP, Shell, BHEL, CEL

Schematic of Gasifier Engine

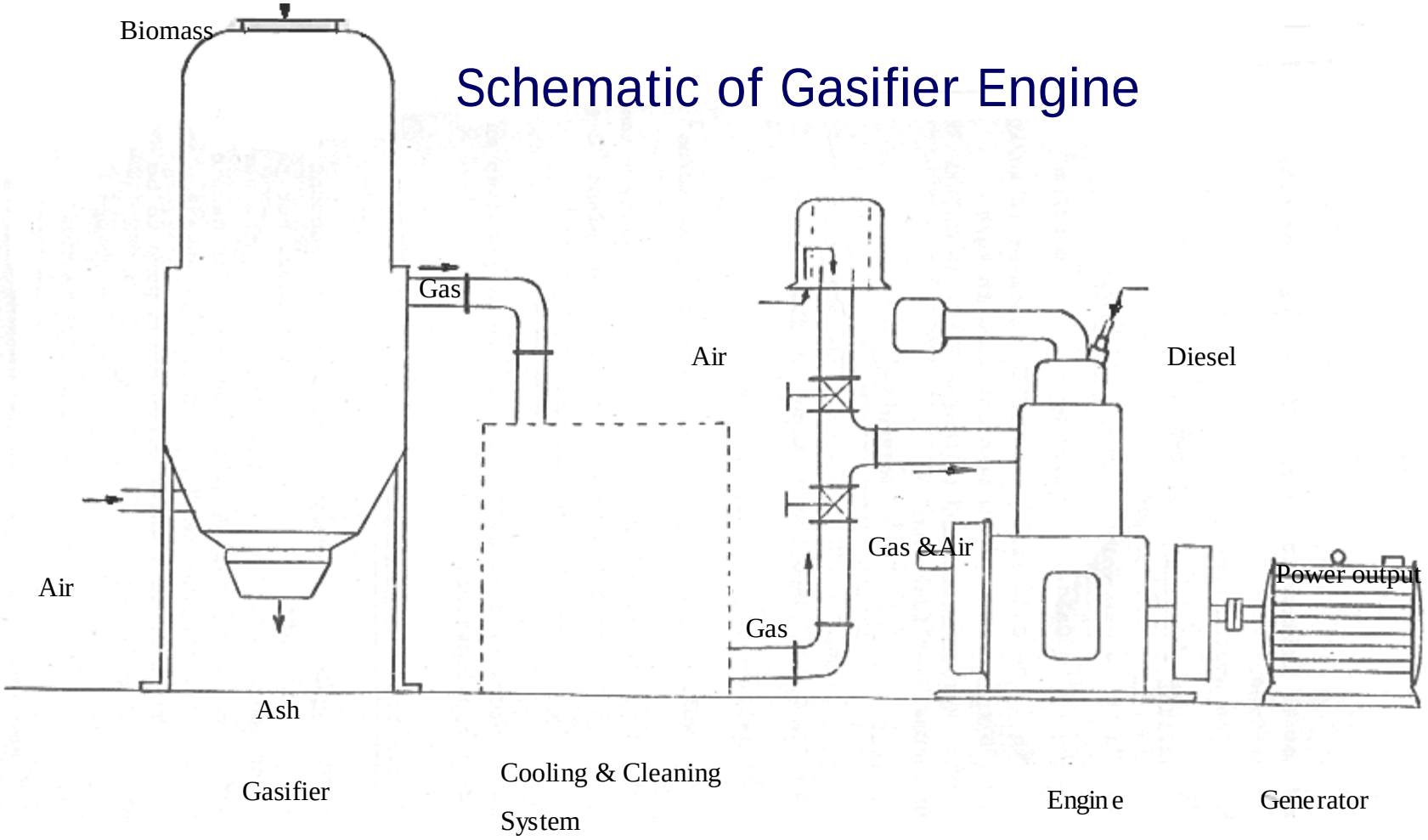


Fig. Schematic Diagram of Gasifier –Engine System

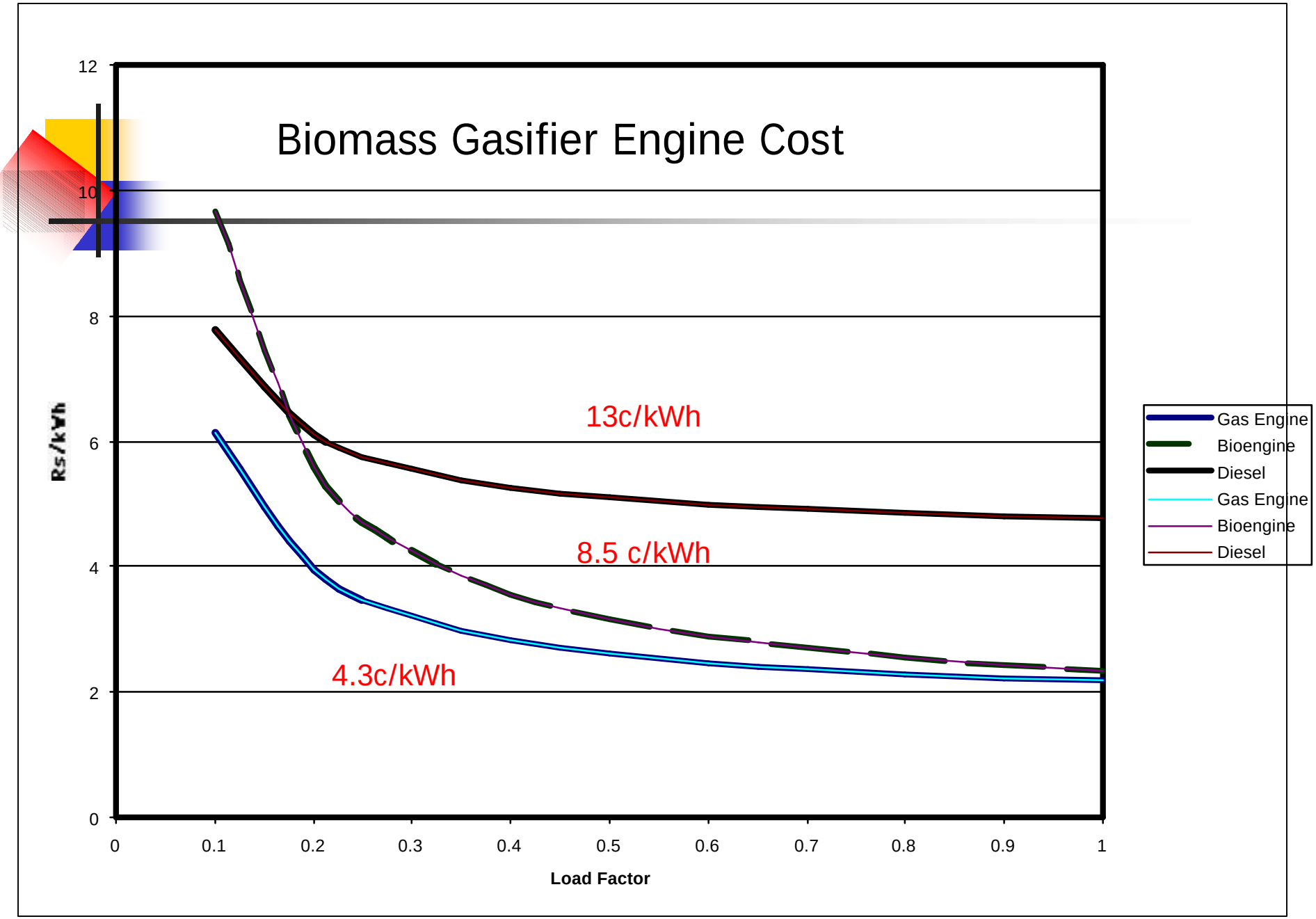
Source: Parikh

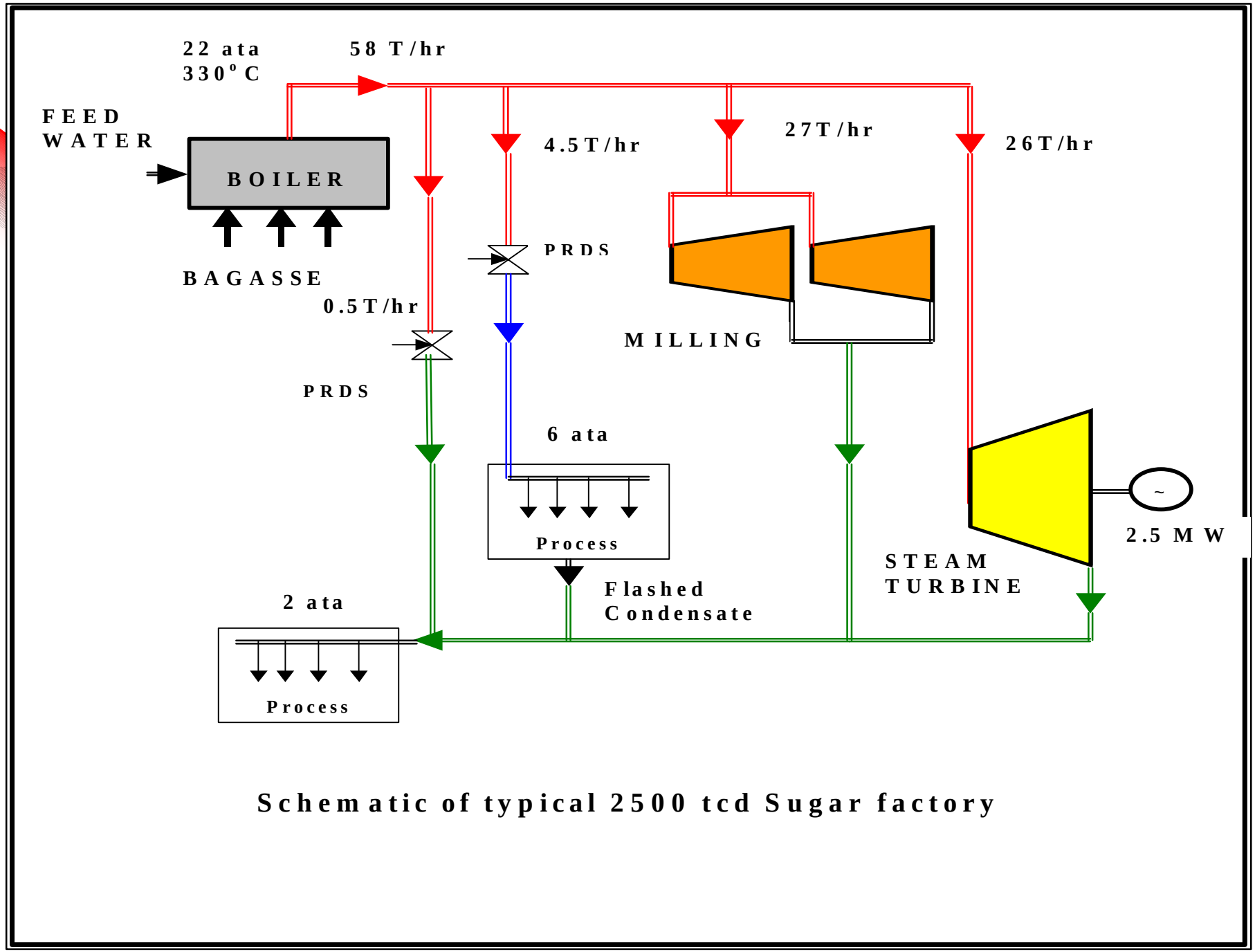
Biomass

- Fuelwood, agricultural residues (rice husk,sugarcane trash, coconut shells..), animal wastes.
- 40% India's primary energy use.
- Estimates - residue 16000-18000 MW (6000 hrs/year).
- Dedicated plantations - waste land - 500 million tonnes - 60000 MW (6000 hrs/year).
- Atmospheric gasification (incomplete combustion)
- Diesel costly - prefer dedicated engine based on producer gas

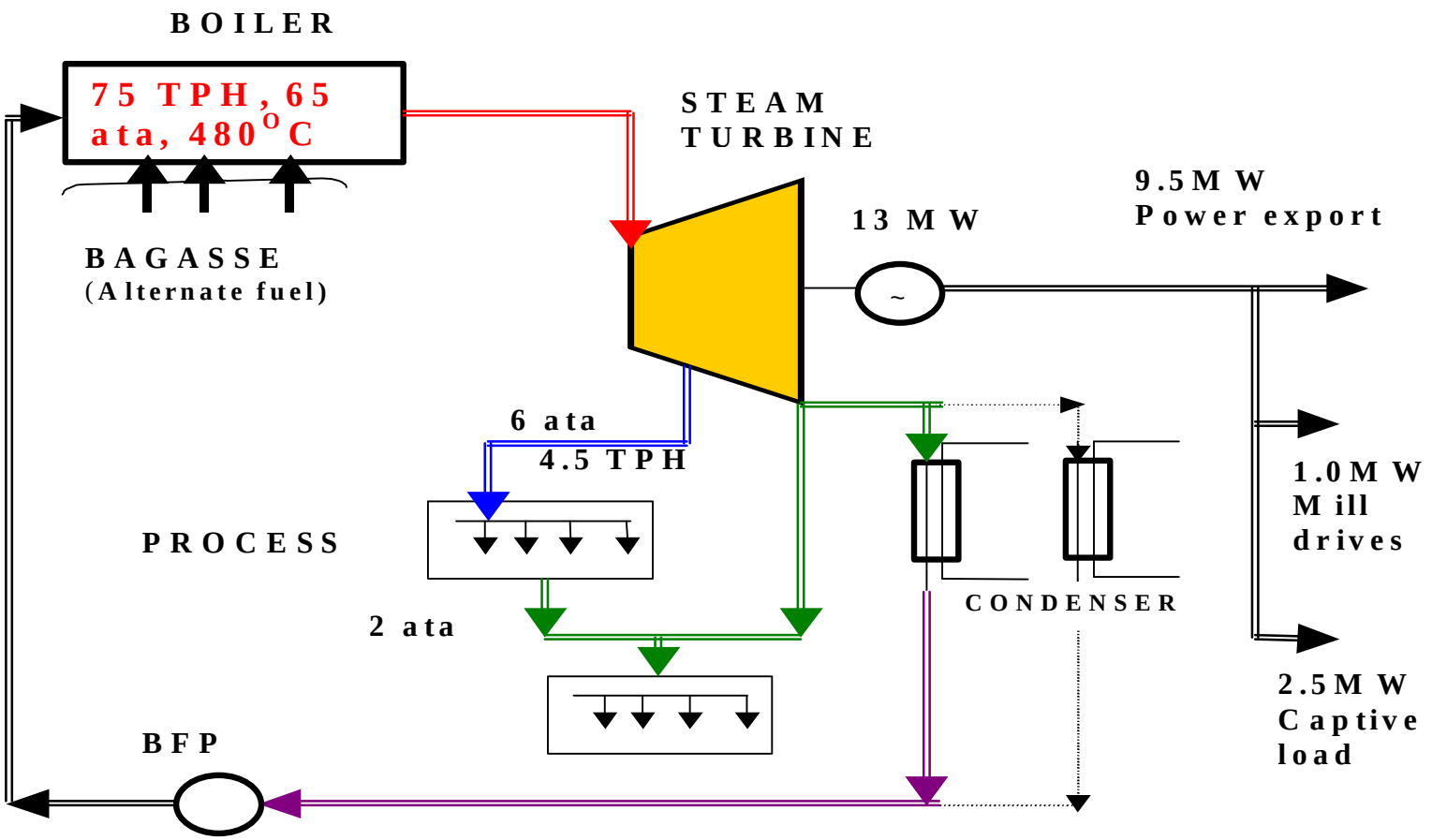
Input Data - Biomass Gasifier

	Gasifier	Engine-generator
Capital Cost (Rs/kW)	20000	33000
Life	10 years	20 years
Efficiency	70%	35%
Biomass NCV=3400 kcal/kg, Price=Rs 1/kg Discount rate=10%, O&M cost=Rs 0.5/kWh		


Biomass Gasifier Engine Cost
12
10
8
6
4
2
0
Rs/kWh
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Load Factor
13c/kWh
8.5 c/kWh
4.3c/kWh
Gas Engine
Bioengine
Diesel
Gas Engine
Bioengine
Diesel



Schematic of typical 2500 tcd Sugar factory

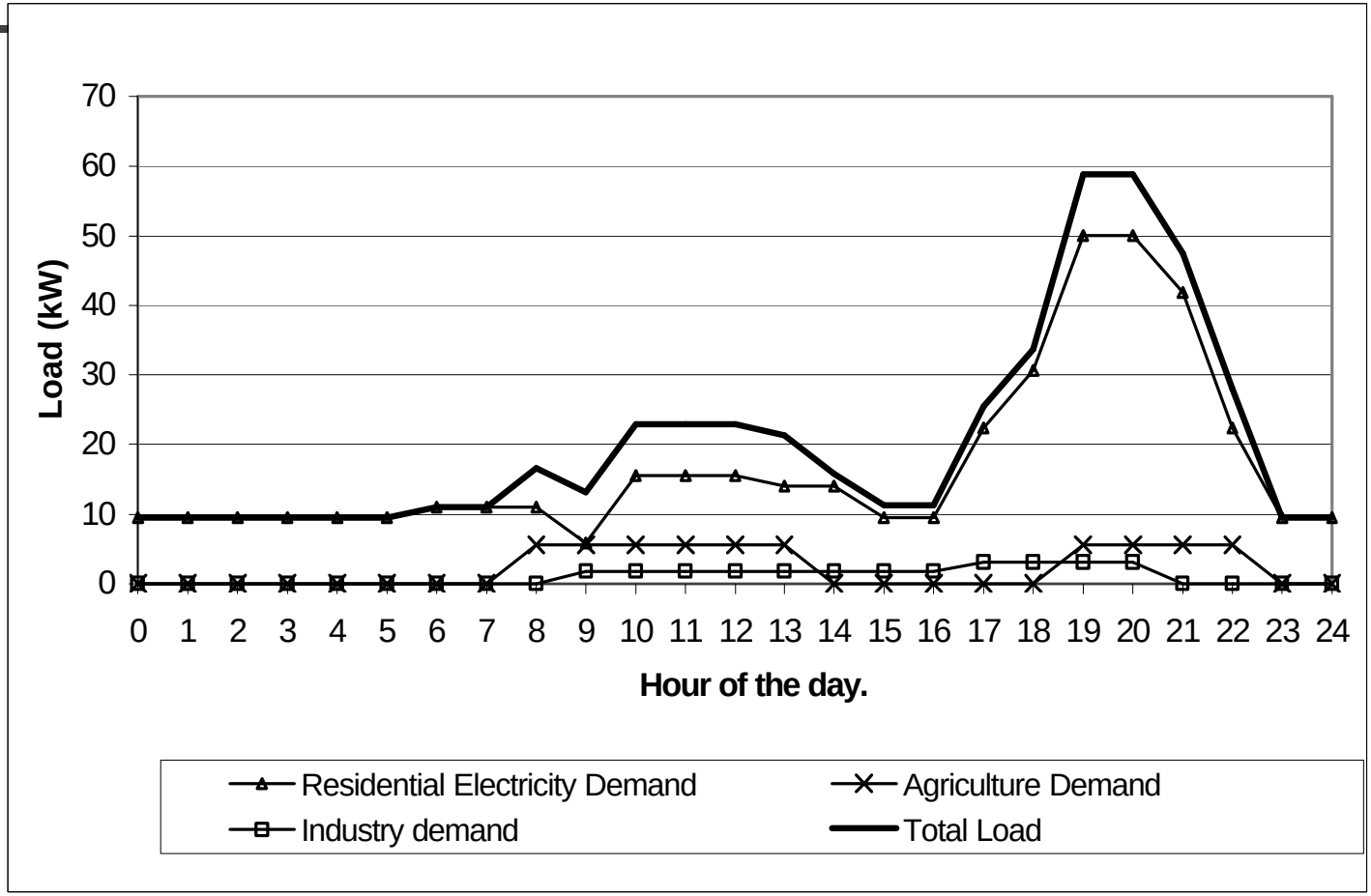


PROPOSED PLANT CONFIGURATION: OPTION 2

Bagasse Cogeneration

Incremental Capital Cost (Rs/kW)	30000 $680/kW		
Life	20 years		
Boiler Efficiency	70%		
Bagasse NCV = 3400 kcal/kg, Price Rs1.50/kg Discount rate = 10%, O&M cost = Rs0.75/kWh 2500 tcd plant 9.5 MW export, 0.93 kg extra/ kWh			
Load factor	0.4	0.5	0.6
Rs/kWh	1.20 2.6c	1.00 2.1c	0.87 1.9c

Typical Load Curve (Rural India)



What is a Hybrid Energy System?

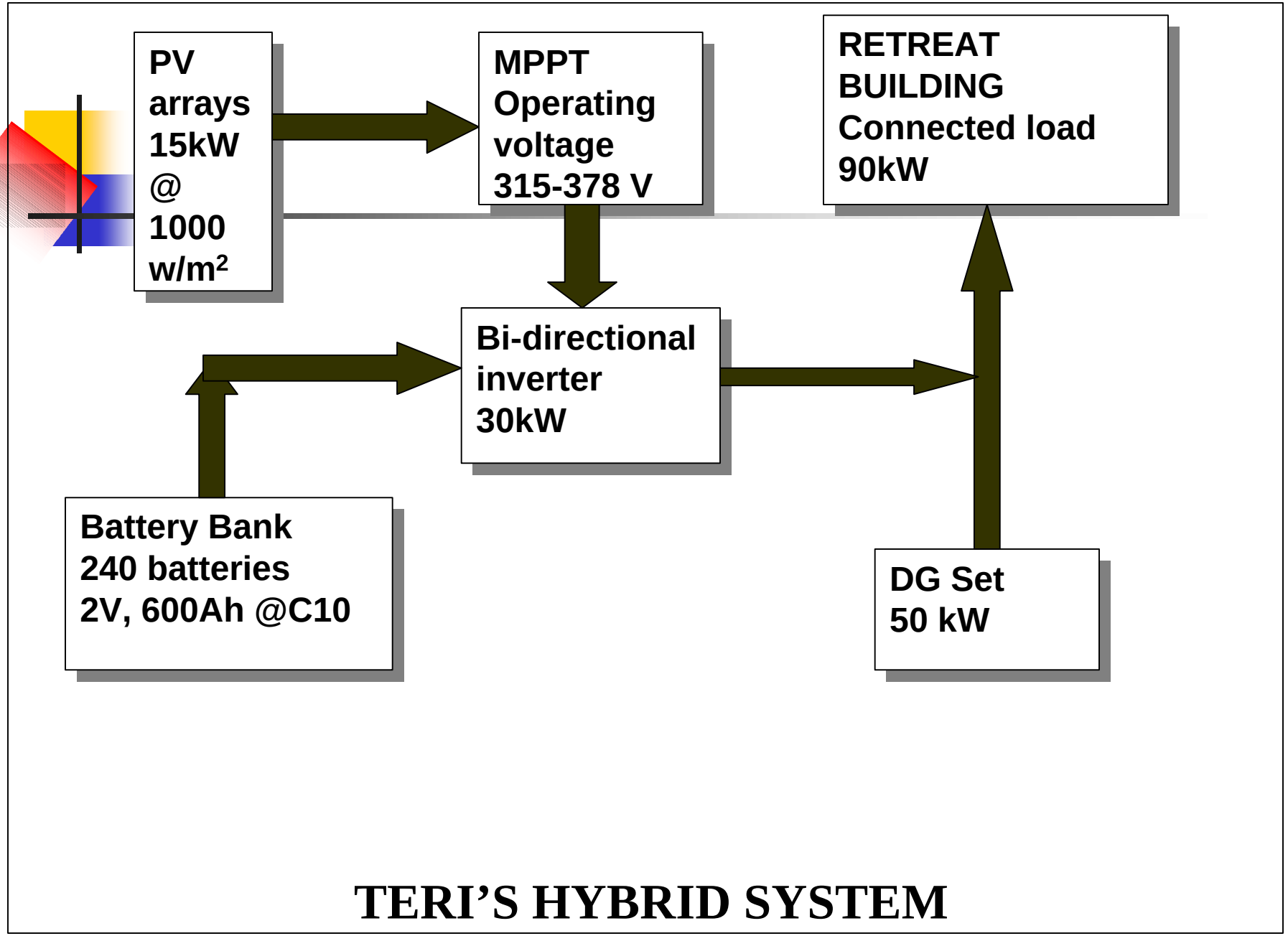
- Hybrid –
  - n. Something heterogeneous in origin or composition
  - n. an offspring of different breeds,varieties
- *Hybrid Energy Systems combine two or more different energy conversion devices to provide a common energy service(s).*

Why Hybrid ?

- Daily and Monthly variation in Renewable Resource Availability
- Daily and Monthly Variation in Demand Profile
- Hybrid of two renewables may help overcome limitations of both
- Retrofitting/ provision of fossil backup may provide easier acceptability of renewable technology

Hybrid Options

- Several options – e.g. PV Hybrids-
  - PV- Wind, PV-Diesel, PV-Diesel-Wind, PV-Micro-Hydel
- Different Devices- Prime Movers – Engines, turbines, fuel cells
- Different Storage Options – Batteries, Pumped Hydro, Flywheels...



TERI'S HYBRID SYSTEM

Criteria

- Autonomy A = 1- HLOL/(HTOT)
  HLOL no of hours of loss of load
  HTOT total no of hours of load
- Emissions
- Cost
- Trade-off between criteria

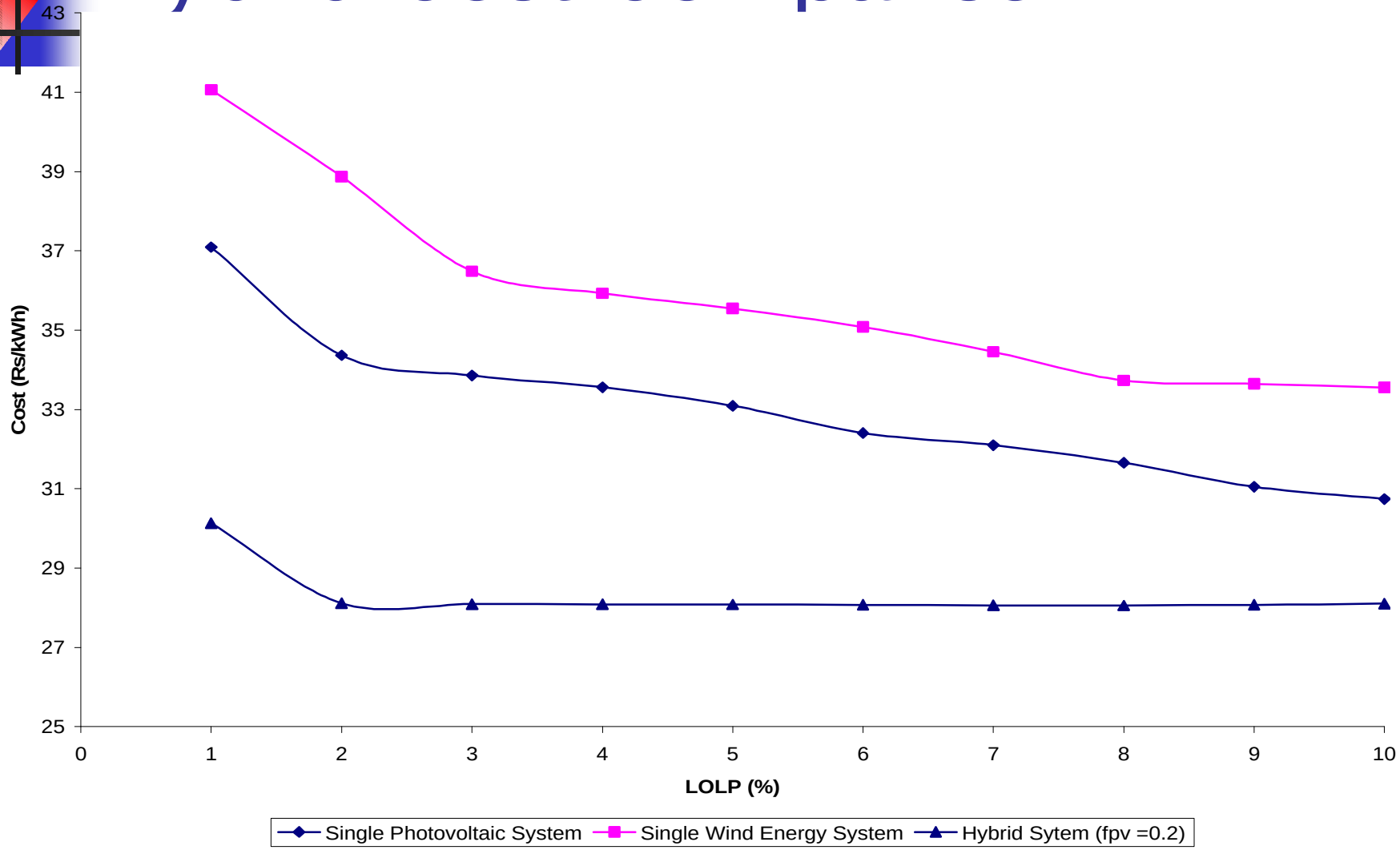
Indian Experience -Hybrid

- Wind-Solar PV – 9 systems- 42 kW total
  e.g 5 kW Chunnambar Island – 3.3 kW Wind, 1.8 kW PV, 800 Ah Battery
- PV-Diesel - Kiltan, Minicoy (100kW)
- 500 kW Wind-Diesel – Sagar Island – West Bengal(10-50 kW wind m/cs with 2 -360 KVA generators)

Possible Applications

- Islands- Existing Diesel grids
- Remote locations – Hilly terrain
- Industries with captive power (DG)
- 80,000 Non-electrified villages – relatively remote
- Estimate – 100 households – Average 30kW – 540 MW of off-grid systems

Hybrid Cost Comparison



Renewables- Policies

- Subsidies/Incentives - offered by Govt of India on Renewables
- Target Oriented - Installation not actual generation
- Only country with separate Ministry for renewables
- 10% of power generation target by 2010
- Preferential tariff for renewables
- Centralised vs Decentralised

Renewable Issues

- Resource Variability Site Specific
- Load Uncertainty
- System Selection/Sizing – Incomplete assessment of options, “Satisficing”
- Most Renewables – promoted by individual technology /component suppliers
- Systems Analysis/Load Forecasting – Software/modelling support required

Renewable Issues

- Load management- cost effective method of matching supply-demand (DSM)
- Experience with Control strategies/R&D needed –Pilot systems
- Need for indigenous controller & inverter development
- Need to have well documented pilot systems that provide “unbiased” data on actual performance of hybrid systems. Independent assessment and dissemination of results

Hybrid Issues

- Affordability to end-user? How much of costs to be recovered? Remote areas lower ability to pay- Need to try different models
- Externalities need to be quantified – to level playing field
- Govt- Manufacturers –R& D institutions- partnerships
- Clearly specified criteria
- Tracking of Hybrid Programme & mid-course corrections

End-Note

You can never plan the future by the past

Edmund Burke

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Thank You

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