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College on Evaluation of Energy Technologies and Policies for Implementation of Agenda-21

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Fossil Fuel Resources and Technologies: Potential Economics & Environmental Aspects

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Fossil Fuel Resources and Technologies: Technical, Economic and Environmental Aspects

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Scope of the Presentation

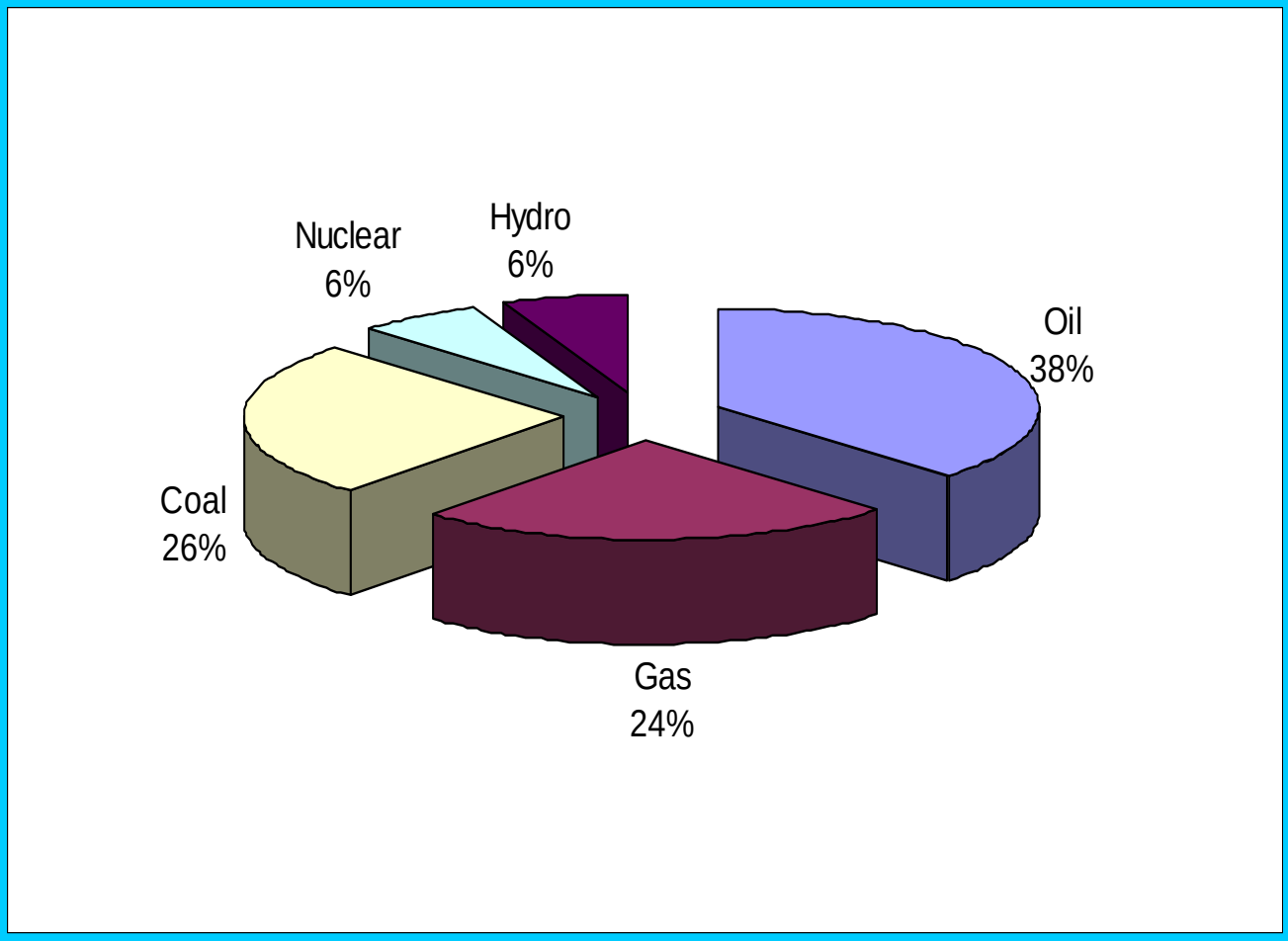
- Fossil Fuels (Coal, Oil, Gas) Resources
  - Ultimate Recoverable Resources
  - Proven Reserves
  - Developed Fields
- Supply Chain

  Resource Identification/ Assessment to

  Supply at Final Demand Level
- Main Aspects of Technology Evaluation
  a) Technical
  b) Economic
  c) Environmental

World Energy Consumption in 2002

- Grow Rate of 2.6%; 1.4% p.a.10-Year g.r.
- Total 10.4 Billion TOE, Commercial 9.4 Billion TOE
- Oil/Gas and Coal together 87%



Estimated URRs of Oil and Gas in the World

(Billion TOE)

	Estimated URRs	Cumulative Production upto 2000 **A**	Proven Reserves in 2000 **B**	Cumulative Discoveries **A+B**	Yet to be discovered
Oil	298 – 523 Avg. 411	97	121	218	81 – 305 (193)
Gas	267 – 545 Avg. 400	46	125	171	96 – 374 (235)

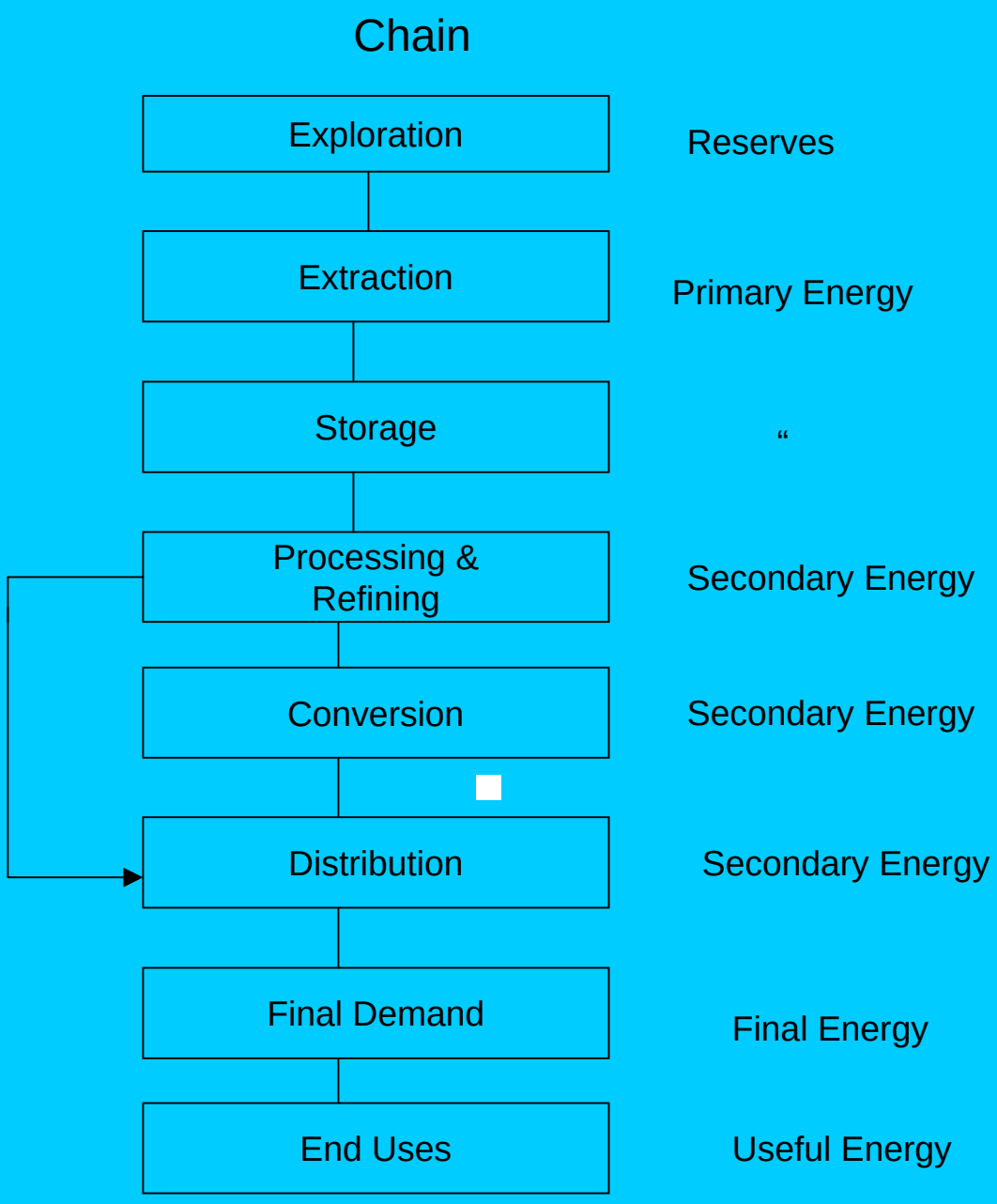
1. US Geological Survey, World Petroleum Assessment 2000

Comparison of Current URRs with the Estimates in 1978

Oil	URRs	Cumulative Production	Proven Reserves	Yet to be Recovered
1978	354	53	89	212
2000	411	97	121	81-305 (193)
Gas				
1978	292	27	74	192
2000	400	46	125	96-374 (235)

Source: World Energy Conference (1980), Survey of Energy Resources (1980), Institute of Geo-Sciences, Handover IAEA (1998) Energy and Nuclear Power Planning in Developing Countries, Vienna.

Schematic Representation of Fossil Fuels Supply System



Some Technical Aspects of Technologies

- Present and future status
- Appropriateness of scale
- Indigenous capability for operation and maintenance
- Construction time
- Useful working life
- Availability factor (taking into account scheduled and unscheduled shut downs)
- Storage possibility
- System efficiency

Some Economic Aspects of Technologies

- Total investment cost and investment cost per unit capacity
- Share of foreign Currency involved
- Extent of domestic participation in planning, design and construction
- Discount rate for amortization of investment
- Annual fixed charges due to taxes, insurance etc.
- Annual operation and maintenance costs
- Capacity factor i.e. average fractional utilisation of installed capacity
- Production cost per unit output
- Reduction of import dependence

Environmental Aspects of Technologies

- Requirements of land and water
- Adverse impacts e.g. emission of particulates and noxious chemicals, release of radioactivity
- Abatement costs of environmental impacts
- External Cost of Environmental Impacts

Fossil Fuel Resources: Exploration and Extraction

- **Identification of Promising Basin**

  Geological work: Techniques such as Aerial photography; gravimetric; magnetic; seismic and radio-metric surveys; sinking of bore holes to a limited depth to test rock characteristics

- **Exploration of an Identified Resource**

  Exploratory drilling; laboratory analysis of the core sample

- **Assessment of Reserves**

  Appraisal drillings (after a discovery)

- **Extraction of oil/ gas and production of coal**

  Additional wells for production, normally oil & gas come out with natural reserve-pressure and production of coal needs mining

- **Secondary/Tersurary Recovery**

  – Water Flooding
  – CO_2 Injection

Air and Water Emissions, Solid Waste Generation and Energy Consumption associated with Oil Production

Environmental Characteristics	Value	Units	Reference
Air CO_2	140	kg/toe of oil or gas produced	Shell 1998
SO_x	0.2	kg/toe of oil or gas produced	Shell 1998
NO_x	3.7	kg/t of oil produced, onshore	World Bank 1998
	0.3	kg/toe of oil or gas produced	Shell 1998
Volatile Organic Compound (VOCs)	1.9	kg/toe of oil or gas produced (including methane)	Shell 1998
	3.3- 26	kg/t of oil produced, onshore	World Bank 1998
Methane (CH_4)	0.01-0.20	kg/toe of oil produced	USEPA 1995
Water Oil	17	mg/L of produced water@	Exxon 1999
	0.01	kg/toe of oil produced	USEPA 1992
Solid waste/Hazardous	0.2	kg/toe of oil or gas produced	Exxon 1999
	0.28	kg/toe of oil or gas produced	Shell 1998
Hazardous Non-hazardous	1.12	kg/toe of oil or gas produced	Shell 1998
Others Energy	1.2	GJ/toe of oil or gas produced	Shell 1998

@ Water produced along with oil and gas is called produced water, and it typically contains 100-1000 milli-gram of oil/Litre. Most of this oil is removed from produced water prior to its discharge to surface or ocean environment.

Storage of Oil/Gas

- Storage of oil and oil products at:
  - Gathering stations in oil fields
  - Refineries
  - Dispatch and receiving terminals
  - Distribution centers
- Storage of LPG, LNG
  Containers are specially shaped and made by special material that may withstand both very high pressure and extremely low temperature
- Storage of Natural Gas
  - Geological formation
  - Depleted field (Strategic reserves)

Oil Refining

Types of Refineries

- Primary Refinery:
  - Distillation
  - Catalytic reforming
  - Hydro treating / hydro fining
- Secondary Refinery
  - Cracking plant
- Integrated Refinery

  Combination of primary and secondary

Simple Refinery Typically

- F.O. 30-45%
- Gasoline 10-15%

Complex Refinery

- F.O. < 10%
- Gasoline >30%

World (2002) Installed Capacity: 84 million barrels/day

Output : 69 “ “

Capacity utilization Rate: 82%

Oil Refining

- Typical Efficiency 88-93%

- Capital cost per unit capacity
  US $ 111-275 per tonne of Crude Processed

- Heating value of different oil/products

	MBTU/tonne
Pakistani crude oil	41.895
Crude Oil Persian Gulf	43.313
F.O.	40.792
M.S.	44.761
LPG	45.326

Environmental Impact of Oil Refining

- Large volume of water for cooling system

  Waste water : 3.5 – 5 m^3 per tonne of crude processed

- Solid waste and sludge

- Energy consumption

  3% for hydroskiming refinery

  5 – 6% for complex refinery

Typical Ranges of Refinery Emissions

		Min.	Avg.	Max.	Units & observations
Environmental Characteristics					
Air	**Particulates**	< 0.1	0.8	3	kg/t of crude processed.
	SO_x	0.2	1.3	6	kg/t.
	NO_x	0.06	0.3	0.5	kg/t
	BTX	0.75	2.5	6	g/t.
	VOC	0.5	1.0	6	kg/t
Water	BOD	150	n.S	250	mg/L
	COD	300	n.S	600	mg/L
	Phenols	20	n.S	200	mg/L
	Oil	100	n.S	300	mg/L. (In desalter water)
	Chromium	0.1	n.S	100	mg/L
	Lead	0.2	n.S	10	mg/L
Solid wastes		3	n.S	5	kg/t
Oil consumption as fuel & losses			< 3.5		% of throughput. For simple refineries.
			5-6	10	%. For complex refineries.

Note. n.s: not specified.

Gas Processing

- **Minimal processing, efficiency of 99%**

  Impurities: Nitrogen, CO_2, hydrogen sulphide

- **World Capacity (1997)**

  No. of Gas processing plant: 1,600

  Processing 5,606 million m^3/day

  Utilization factor 71.0%

- **Gas Liquids Production (LNG, LPG):**

  213 million US Gallons/ day

Gas Conversion

- **Gas Conversion**
  - Compressed (CNG) for transport sector
  - Liquefied Natural Gas (LNG) for Export
  - Liquefied Petroleum Gas (LPG)
- **Volume reduction by a factor of about 600 and trade without pipeline**

Environmental Impact of Gas Processing

- Sources of emissions compressor engine, Dehydrated vent streams
- SO_2 emission from gas sweetening plant 26.98 Kg/1000 m^3 of sour gas processed if sulphur recovery plant is not present.
- Fugitive emissions from process equipment

Liquefied Natural Gas

- Natural Gas trade
  - 23% of world production (2002)
- Gas trade (581 billion cubic meters)
  - 74% by pipeline
  - 26% in LNG form
- No of LNG plants in 11 countries (Algeria, Australia, Brunei, Indonesia, Libya, Malaysia, Nigeria, Qatar, Trinidad & Tobago, UAE, USA)
- Energy Intensive fuel Handling Process
  - 8-10% of the feed gas as fuel
  - 1% in loading to ship

Gas Storage & Environmental Impacts

Underground Storage Site

In 1996/97, 580 underground storage sites world-wide with Capacity of 262 G m^3 which was12% of world natural gas production in 1997

Energy consumption 1% of the storage capacity receiving terminal

Storage at Receiving Terminal

Nine Countries

16.3 million m^3 capacity

Depleted Reservoirs

76 Aquifers (1997) of

0.1 - 4 giga m^3 capacity

Environmental Impact

- Fugitive atmospheric emission of methane
- combustion gases from energy use in compression unit

Natural Gas Transportation and Environmental Impacts

- Pipeline needs recompression stations
- Typically about 2% of gas input per 1000 Km (max. 3%) is used in these stations
- Leakage of methane from the network
- (0.6% in 1997 in the British Gas, UK distribution network)
- Emission from combustion of fuel used
- Impact associated with pipe-laying and maintenance
- BG system (1997)

NOx from compressor	2,731 tonnes
CO_2 " "	3.5 million tonnes
CH_4 from network	0.36 million tonnes

Proven Reserves of Coal in the World and Their Distribution

	Coal Reserves (Billion TOE)		R/P 2000
	1985	2002	
OECD Countries	214	216	220
Russian Fed. & East	139	87	517
Developed Countries	352	303	263
OIC Countries	1	26	20
Non-OIC Developing Countries	140	172	49
Developing Countries	142	198	161
World	494	501	211

Coal Extraction

Production Methods:

Thickness of over burden, surveys, seam thickness (10-100 feet), extern of coal, stripping ratio, Thickness of overburden to thickness of coal seam, cubic yard of overburden to tons of coal of ton of overburden to ton of coal.

Underground mining: (5 - 10 years)

- Room and pillar technique
- Long wall technique

Environmental impact

- Land use
- Fugitive methane emission from surface mines

Coal Processing and Conversion

Cleaning

- Impurities: In-combustible material, sulphur, moisture
- Cleaning upto 18% ash contents for power generation
- 5-20% of BTU contents are lost in cleaning
- 20-70% total sulphur can not be removed

Conversion

- Gasification
- Liquefaction
- Electricity

Coal Transportation Methods and Environmental Impacts

- Rail, Trucks, Barges and Ships
- Slurry pipeline in few countries
- Environmental impacts due to transport, storing, loading and unloading
- A typical exposed pile in USA, 6.4 gram/kg of coal stock
- Dust produced by rapid air displacement, falling speed of coal and operation of heavy machinery

Methane Emissions in Some Selected Countries

Country	Average depth (meters)	1990 coal production		Gross methane emissions	
		million tonnes	by under ground mining	million tonnes	gram/ tonne
China	330	1053	93%	7.70	7,312
United Kingdom	500	95	83%	0.86	9,053
Poland	670	216	64%	1.35	6,250
S. Africa	200	206	60%	0.85	4,126

Methane Emission Factors in Underground Coal Mining

Country	Emission factor (m^3/tonne)	Conversion Factor (kg/m^3)	Emission factor (g/tonne)
Former Soviet Union	17.8-22.2	0.67	11,926-14,874
United States	11.0-15.3	0.67	7,370-10,251
Germany	22.4	0.67	15,008
United Kingdom	15.3	0.67	10,251
Poland	6.8-12.0	0.67	4,556-8,040
Former Czechoslovakia	23.9	0.67	16,013
Australia	15.6	0.67	10,450

Estimated Methane Emissions in Surface Coal Mines

Mine	Pollutant	Avg. Value	Unit
CMWS+P	CO_2	5,030	g/t
	CH_4	201-1,340	g/t
CMES+P	CO_2	5,450	g/t
	CH_4	208-1,350	g/t

Typical Emissions from Coal Transportation Ship

	Particulate	SOx	CO	NOx*
Emission factor (g/liter)	6.78	19.1xS**	0.872	7.63
Fuel use	85.58 kJ/tkm = 2.209e-03 liters/tkm			
Emissions (g/tkm)	0.015	0.042-0.147#	0.0019	0.017

* NO_2 only ** Sulphur content # 1%-3.5% sulphur

Fuel Requirements Data for Barge for Coal Transportation

Source	Year	Value
IAEA(1995)	1989, 1992	167 kJ/tkm
Khan(1982)	1975	335 kJ/tkm (for North America)
Japan(1992)	1990	506 kJ/tkm
	-	

Estimated Emissions of Coal Transportation by Barges

		CO_2 (g/tkm)	NOx (g/tkm)
IAEA (1995)		13.21	0.014
Khan (1982)		26.50	0.027
Japan (1992)		40.03	0.041

Emission from Diesel Locomotives Transporting Coal

			Min	Avg	Max	Unit
Air	Greenhouse	CO		0.24		g/tkm
Air	Greenhouse	CO_2		29		g/tkm
Air	Acidification	NOx		0.72		g/tkm
Air	VOC	NMVOC		0.05		g/tkm
Air	Greenhouse	CH_4		0.002		g/tkm
Others	Energy	Fuel Req.	225	398	570	KJ/tkm

Based on Ref.(Japan:1992, ORNL:1981, IPCC:1995)

Environmental Emission of Coal Transportation by Trucks (G/tkm)

	Truck of 20 tonnes		Truck of 40 tonnes	
	ASAG	DECADES (RTDB)	ASAG	DECADES (RTDB)
CO	2.0-2.5	5.0	1.09-1.34	2.45
CO_2	290	267	156	157.8
N_2O	0.0075	n.a.	0.004	0.001
Nox	1.5-4.0	15	0.81-2.15	16.05
SOx	0.315	0.286	0.169	0.169
NMVOC	0.4-0.7	4	0.21-0.38	1.75
CH_4	0.02-0.04	0.4	0.01-0.02	0.2
Particulate	0.05	n.a.	0.02	0.2

n.a. not available

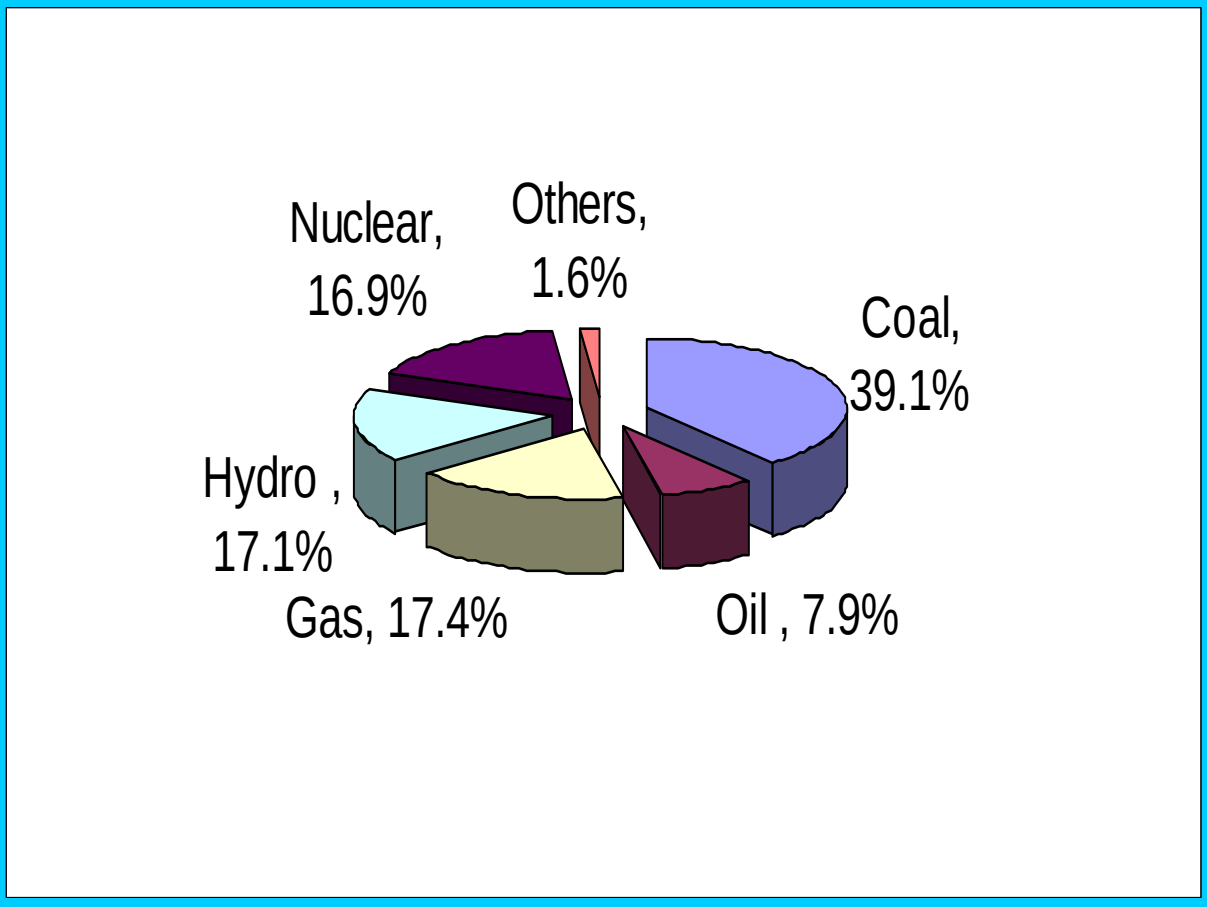
Data for Coal Slurry Pipeline

			Avg.	Unit
Technical Characteristics				
Capacity			25×10^6	t/y
Environmental Characteristics				
Air	Greenhouse	CO	0.003	g/tkm
Air	Greenhouse	CO_2	20	g/tkm
Air	Acidification	NOx	0.09	g/tkm
Air	Acidification	SOx	0.29	g/tkm
Air	Greenhouse	CH_4	0.044	g/tkm

Capital and O&M Costs of Energy Sector Infrastructure Facilities

Capacity of Million TOE/Year	Capital cost (Million $)	O&M Cost (Million $)
Oil Refinery	111-275	7-19
Oil Pipeline (1000km)	26-78	13-39
Gas Processing Plant	10-90	13-39
Gas pipeline (400 km)	52-155	
Coal Mining	216-260	28-30

World Electricity Generation (2000)



Electricity Production From Coal of Top Ten Countries (2000)

	TWh
United States	2110
People's Rep. of China	1062
India	420
Germany	299
Japan	254
South Africa	193
Russia	176
Australia	161
Poland	138
Korea	126
Rest of the World	**1074**
World	**6013**
Source: Key World Energy Statistics from the IEA, IAEA.	

Electricity Production From Oil of Top Ten Countries (2000)

	TWh
Japan	159
United States	125
Mexico	97
Italy	86
Saudi Arabia	81
People's Rep. of China	46
Chinese Taipei	35
Iraq	33
Russia	33
Pakistan	27
Rest of the World	**496**
World	**1218**

Source: Key World Energy Statistics from the IEA, IAEA.

Electricity Production From Gas of Top Ten Countries (2000)

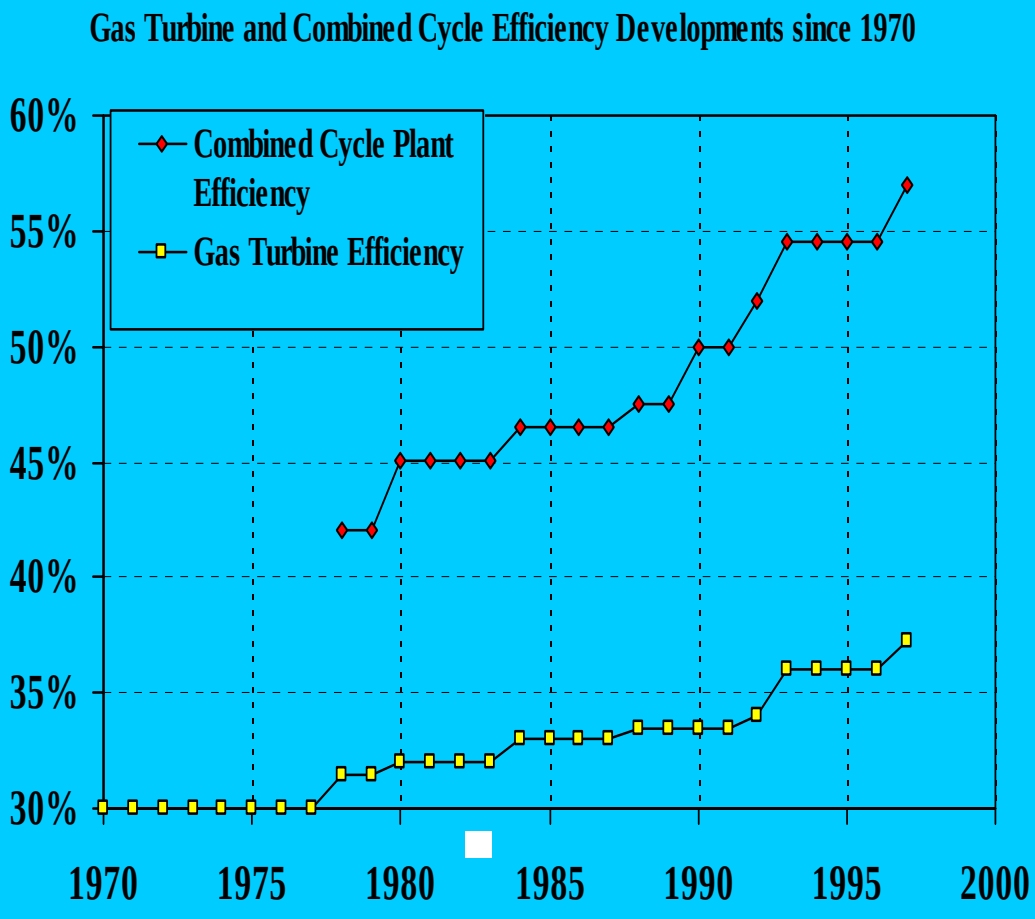
	TWh
United States	630
Russia	370
Japan	239
United Kingdom	147
Italy	101
Islamic Rep. of Iran	93
Thailand	61
Malaysia	54
Germany	53
Netherlands	52
Rest of the World	**877**
World	**2677**
Source: Key World Energy Statistics from the IEA, 2000.	

Oil/Gas-based Power Plant Categories

- Gas Steam Boiler
- Gas Fired Combustion Turbine
- Simple Cycle Heavy Duty (GTSCH)
- Simple Cycle Aero derivate (GTSCa)
- Steam Injected Gas Turbine (STIG)
- Humid Air Turbine (HAT)
- Combined Cycle (GTCC)
- Oil Steam Boiler (OSB)
- Diesel Engine (DE)
- Oil Fired Combustion Turbine

Features of Some Latest Gas-based Power Plants

- Latest GTs Unit sizes upto 280 MWe
  Efficiency 38-39%
- GTs with turbine inlet temperature
  second generation <1200 C^0
  Third generation >1200 C^0
- Combined Cycle Efficiency 57-60%


Gas Turbine and Combined Cycle Efficiency Developments since 1970
Combined Cycle Plant Efficiency
Gas Turbine Efficiency
60%
55%
50%
45%
40%
35%
30%
1970
1975
1980
1985
1990
1995
2000

Coal-based Power Plant Categories

- Coal Steam Boiler
  - Pulverised Coal (PC)
  - Cyclone Furnace (CF)
  - Spreader Stoker (SS)
- Atmospheric Fluidized Bed Combustion
  - Circulating (CFBC)
  - Bubbling (BFBC)
- Pressurized Fluidized Bed Combustion (PFBC)
  - Combined Cycle Circulating (CPFBC)
  - Bubbling (BPFBC)
- Coal Gasification
  - Non-integrated (GCC)
  - Integrated (IGCC)
  - Integrated Gasification HAT
- Coal Fired Combustion Turbine
  - Improved Cycle (IC)
  - Gasification/PFBC hybrid

Gas-fired Power Plant Investment Costs (US $ of1996/kWe)

Country	Technology/ emission control equipment	Base construction cost	O&M Costs per Year
Brazil	CCGT CCGT	677 766	8.39 8.62
Turkey	CCGT/deNOx	402	6.07
Korea	CCGT, LNG	583	21.80

Source: Projected Costs of Generating Electricity, Update 1998, NEA, IEA, OECD.

deNOx: Unspecified NOx control System

Gas-fired Power Plant Expected to be Commercially Available by 2005-2010 investment costs (US $ of1996/kWe)

Country	Technology/ emission control equipment	Base construction cost	O&M Costs per year
Netherlands	CCGT	664	23.71
United States	ACCGT/SCR	419	17.42
	Fuel cell/LNB, ESP	1408	27.48

Source: Projected Costs of Generating Electricity, Update 1998, NEA, IEA, OECD.

SCR: Selective catalytic reduction

LNB: Low NOx burner

Coal-fired Power Plant Investment Costs (US $ of 1996/kWe)

Country	Plant type/ emission control equipment	Base construction cost	O&M Costs per year
China	PF(SC)/FGD, ESP	772	36.05
India	PF/ESP	935	27.89
Japan	PF/FGD, deNOx, dust	2561	81.33
Korea	PF(SC)/FGD, SCR	1174	53.13

Source: Projected Costs of Generating Electricity, Update 1998, NEA, IEA, OECD.

PF: Pulverized Coal

ESP: Electrostatic Precipitator

SC: Super critical

FGD: Flue gas desulphurisation

SCR: Selective catalytic reduction

Coal-fired Power Plant Expected to be Commercially Available by 2005-2010 (US $ of 1996/kWe)

Country	Plant type/ emission control equipment	Base construction cost	O&M Costs per year
Netherlands	PF(SC)/FGD, SCR	1450	53.35
	IGCC/FGD, deNOx	1553	54.51
United States	IGCC/LNB, ESP	1154	32.84

Source: Projected Costs of Generating Electricity, Update 1998, NEA, IEA, OECD.

Environmental Impact of Fossil Fuels Fired Power Plants

			(thousands tones per GWYr)
	Oil F.O. 3.5% Sulphur)	Gas C.C.	Coal Steam Without FGD 1.2% Sulphur)
SO_2	152	*	51
NOx	29	13	32
Particulates	3	*	59
CO_2	6,900	5,250	7,760
Liquid Wastes	525	350	880
Solid Wastes	-	-	530

* Less than 1.

Source: IAEA-SM-338/52, 1996

Costs of Flue-Gas Desulphurisation Units

	Dry		Wet	
	New	Retrofit	New	Retrofit
Removal Efficiency (%)	70-90	70-90	80-90	80-90
Capital Costs ($/kW)	110-165	140-210	120-210	150-270
Variable O&M Costs (mills/kWh)	2.1-3.2	2.1-3.2	1.3-3.2	1.5-3.3
Total O&M Costs	7.4-11.0	6.0-9.0	7.4-13.0	6.6-12.0

Note: Costs are expressed in 1990 US $.