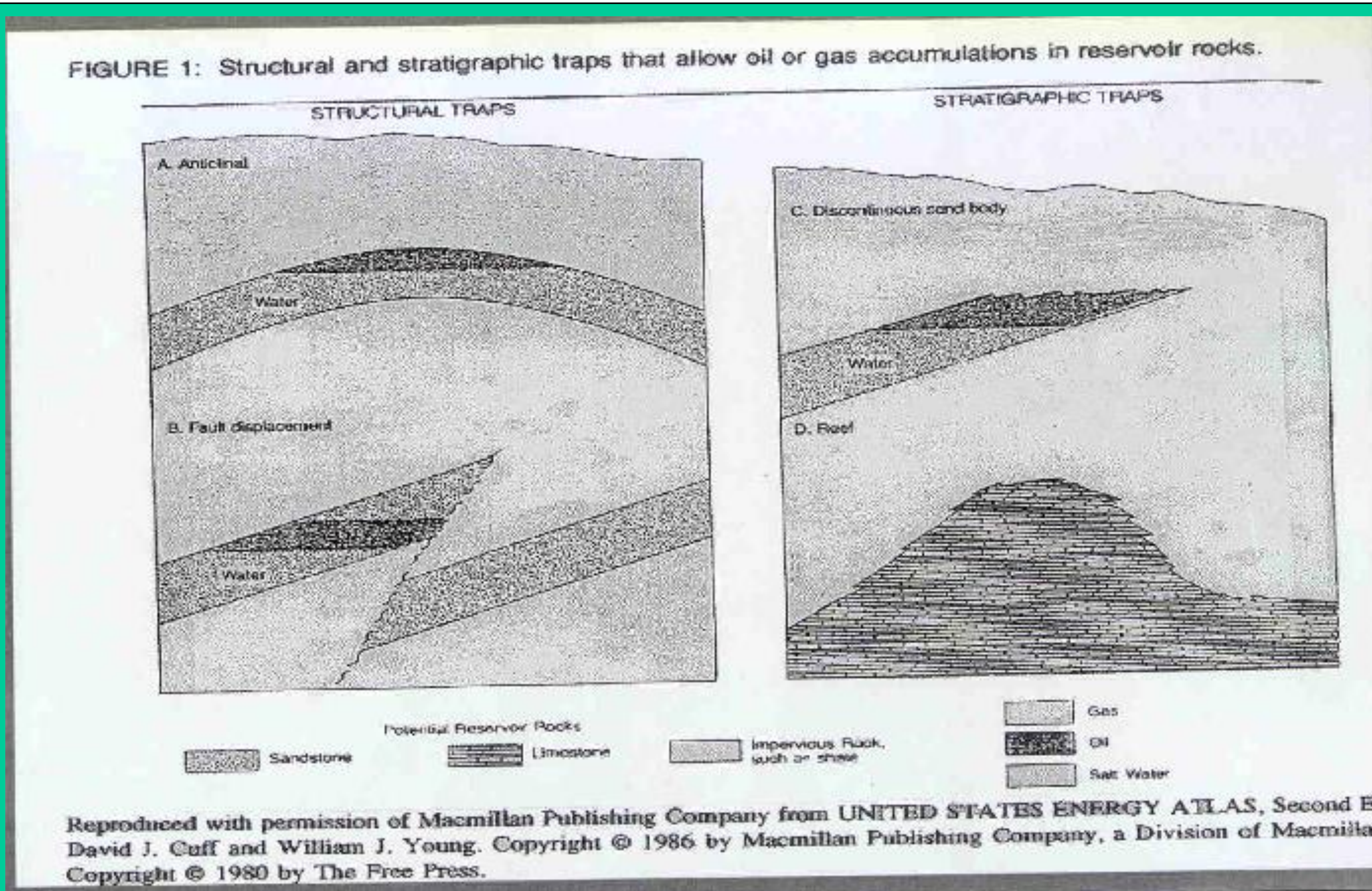
OIL-GAS THERMAL & PISTON ENGINE POWER PLANTS

- "Rock oil" was discovered in Pennsylvania in 1859 by a man drilling for water
- Crude oil accounts for 40% of energy use worldwide: 3% of power comes from oil, 16% from natural gas.
- High energy density, 43 MJ/kg (18,600 Btu/lb), and relatively clean burning, versatile.

Topics – Oil Thermal

- Oil & Gas Resource: Origin, Reserves, Extraction Rate, Life Time
- Properties of Liquid Fuels, Fuel Oils and Natural Gas
- Basic Principle of Oil-Gas Thermal Plant
- Ideal and Modified Rankin (Steam) Cycle Efficiency, Heat Rates
- Oil-Gas Burners (Circular, S-type, Reduced NO_x)
- Reducing NO_x Emissions (FGR, LEA, 2-stage air, Re-burning)
- Emissions from Power Plants
- Pollution Control Technologies used in Power Generation
- Cost of Power Generation (Capital, O&M, Levelized)
- Oil-Thermal and Diesel Plants in the Philippines
- Environmental Impact & Risks

OIL & GAS FORMATIONS



OIL & GAS RESERVES, EXTRACTION AND LIFETIME

Primary Energy Source	Proven Reserves (Jan. 1, 2000)	Annual Production 1999	Life Time (years)
Fossil Fuels:			
Coal (million short tons)	1,088,602	4,737	230
Petroleum (billion bbls) (crude oil & NGL)	1,017	71,854	39
Natural Gas(trillion ft3)	5,150	85	61
SOURCE: US DOE - EIA			

• Total reserves for crude oil and NGL is 1,017 billion barrels as of Jan. 1, 2000; extraction rate stood at 71,854,000 barrels per day; may be gone after 39 years.

• Natural gas reserves is 5,150 trillion ft^3 while annual gas production stood at 85 trillion ft^3; may be gone after 61 years.

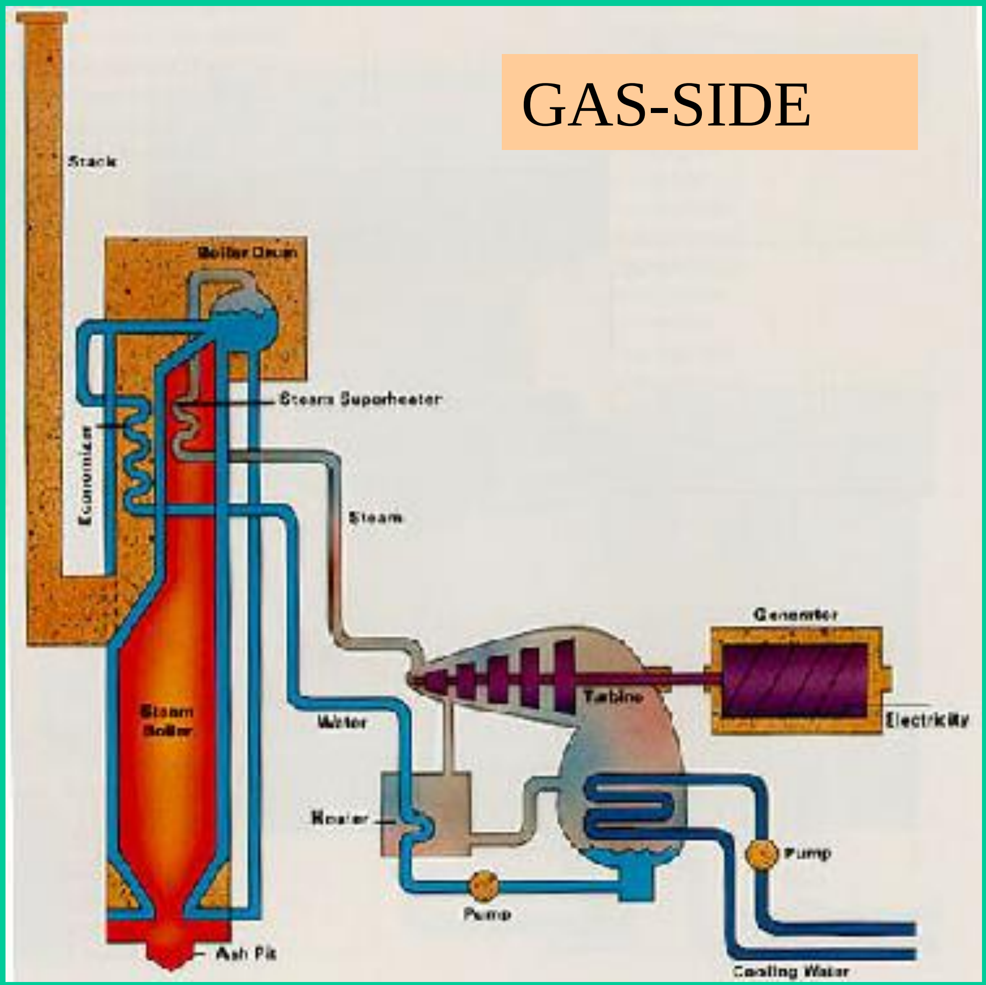
A. Oil-Gas Thermal Power

- *Features:* combustion of heavy oil or gas turns water in the boiler into super-heated steam, dried and directed towards the turbines; as it expands, steam spins the turbine which drives the generator; steam passes thru condensers which return it to liquid state for easy pumping; water is pumped back into the boiler and the steam cycle is repeated.
- *Fuels:* oil-gas thermal plant uses heavy fuel oil or natural gas.
- *Facilities:* jetty/pipeline for receiving fuel oil/gas from barge/tanker and heated storage tanks.
- *Emissions:* heavy fuel oil contains 2-5% sulfur and when burned emits SO_2 and also NO_X during high temperature combustion; both contributes to acid rain; having over 85% carbon, it releases large amounts of CO_2, a main greenhouse gas; natural gas has minimal sulfur.

Oil-Gas Thermal Power

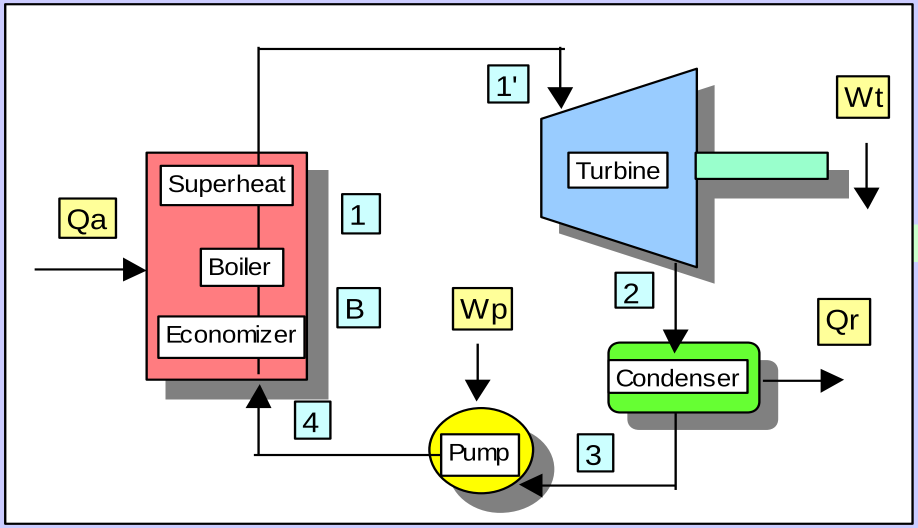
- *Thermal Efficiency:* simple steam cycle and sulfur in exhaust lowers exhaust heat recovery to avoid condensation & corrosion, hence a low 26-30%.
- *Pollution Abatement:* sulfur may be removed from the fuel at the oil refinery thru blending or hydrotreating; if high sulfur fuel oil is used, SO_2 is removed thru flue gas desulfurization
- *Risks:* being finite and controlled by the OPEC cartel, its price is very volatile and expensive.
- *Overnight costs* - $ 991 / kW
- *Variable O&M costs* - $0.050 / kWh
- *Fixed O&M costs* - $0.300 / kW / year
- *Levelized cost (1996$):* - 3.9 – 4.4 cents / kWh (gas)
  - 5.5 cents / kWh (oil)
- *Re-powering:* oil thermal plants may be converted to coal firing or to gas turbine combined cycle to provide heat to the boiler for producing steam

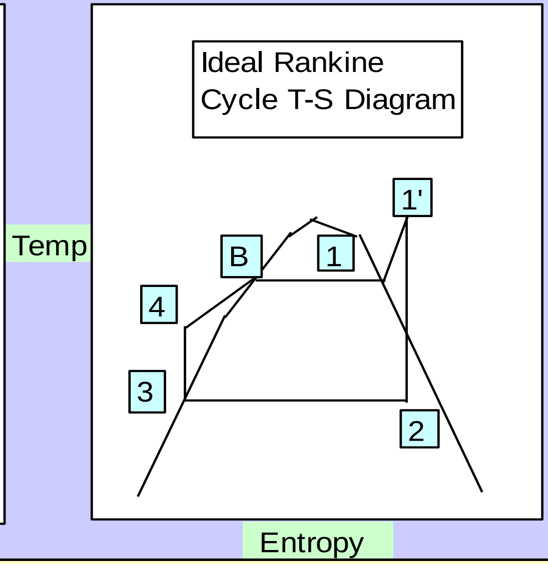
Gas-side of Thermal Plant



Pre-heated air mixes with fuel, swirls and atomizes fuel, burns fuel until complete combustion. Heated gas transfer heat to water-tubes at walls, boils the water, reheats LP steam and superheats the HP steam. Hot flue gas above dew point of water and SO_2 pre-heats incoming filtered air at recuperator. Exit flue gas treated for SO_2 and particulates.

Ideal Rankine (Steam) Cycle

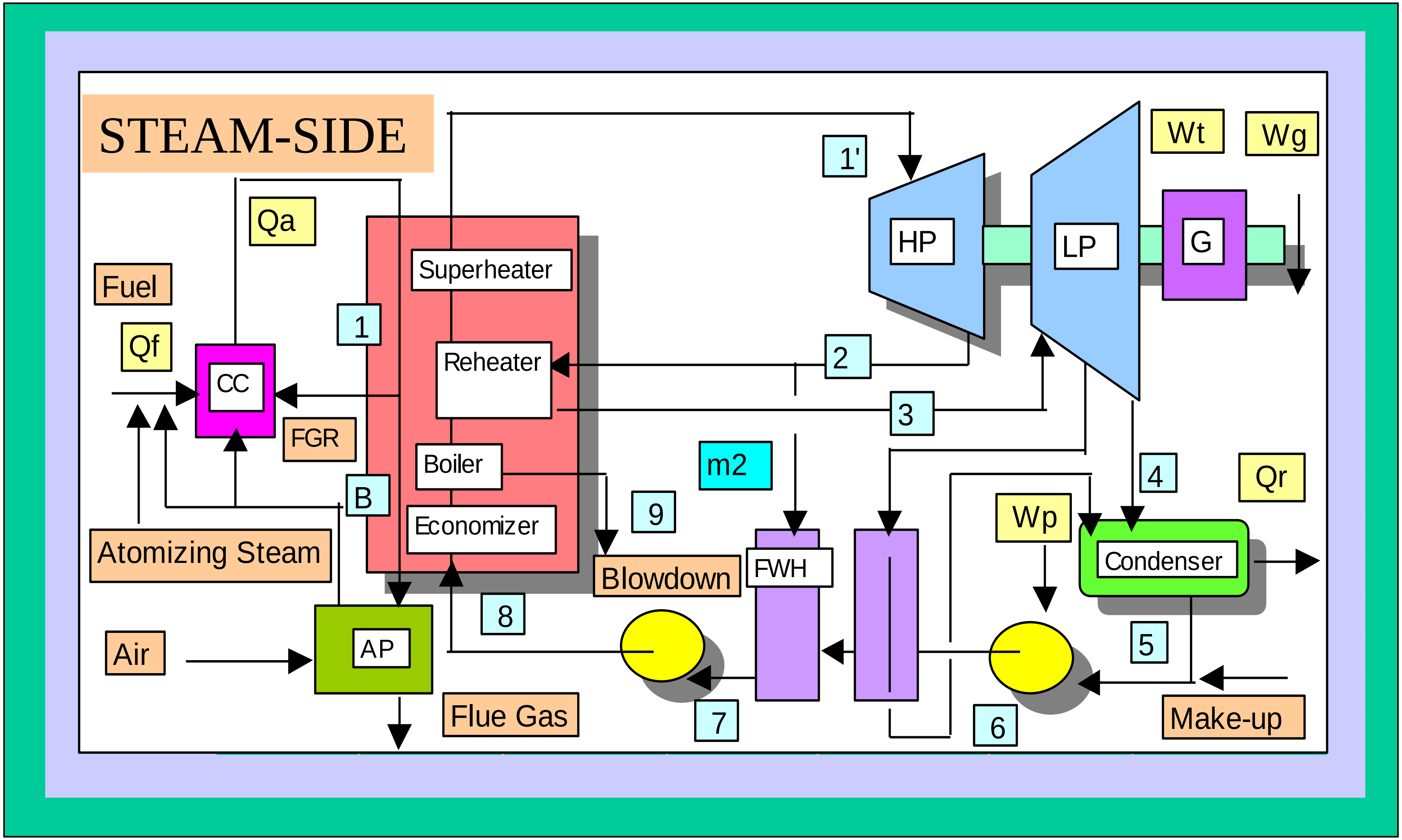




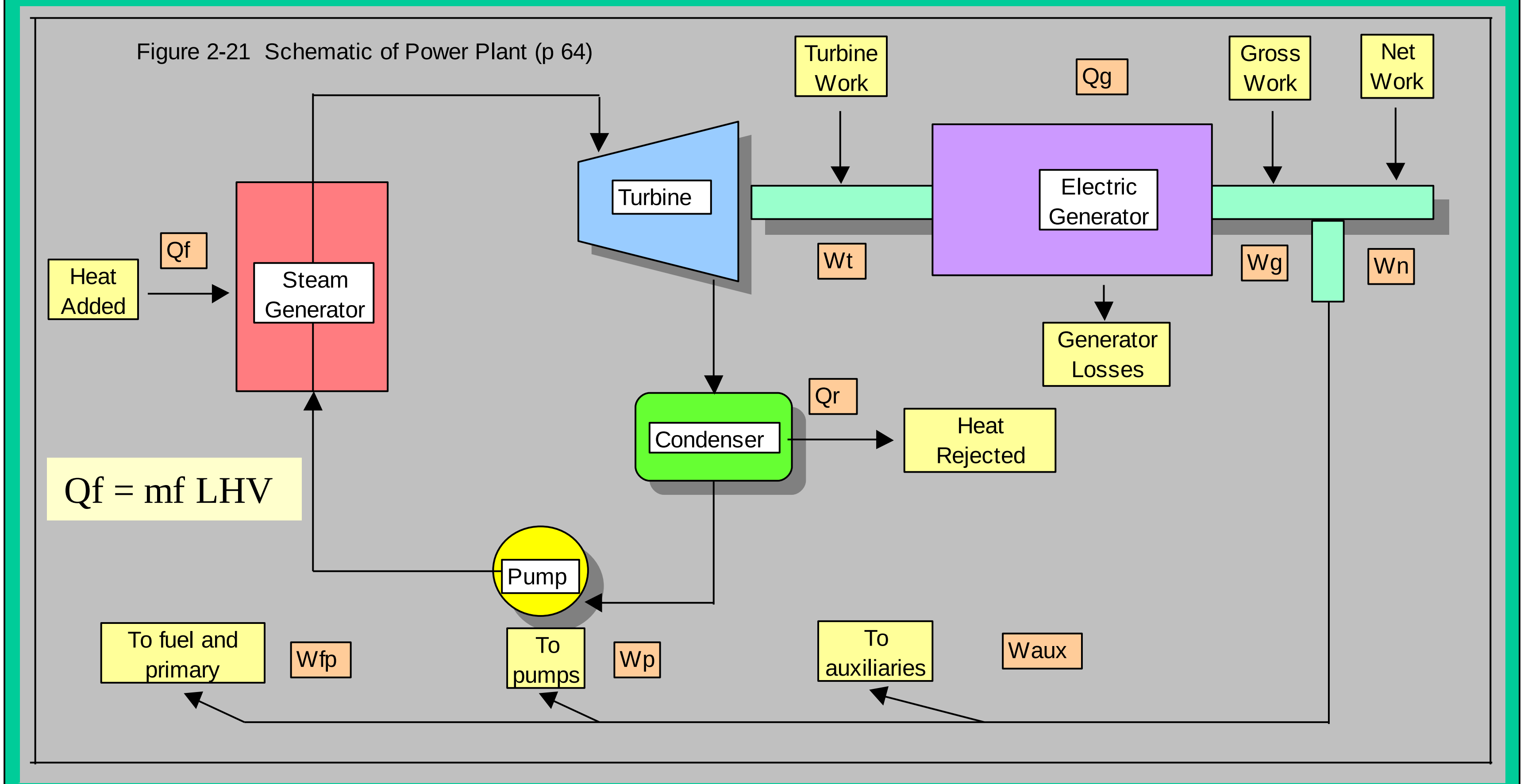
1'-2	**Adiabatic reversible expansion thru the turbine**
2-3	**Constant temperature, constant pressure, 2-phase mixture heat rejection in the condenser**
3-4	**Adiabatic reversible compression of saturated liquid at condenser pressure to a subcooled liquid**
4-B	**Heating of subcooled liquid to saturated liquid at economizer**
B-1	**Heating of saturated liquid to saturated vapor at constant pressure and temperature in the boiler**
1-1'	**Heating the saturated vapor to superheated vapor in the superheater**

Mv = 1	**Basis of 1 unit mass of vapor in the saturated cycle**
Qa = h1' - h4	**Heat added to cycle**
Wt = h1' - h2	**Turbine work**
Qr = h2 - h3	**Heat rejected at condenser**
Wp = h4 - h3 = v3 (P4 - P3) factor / (Peff J)	**Pump work**
Wnet = Wt - Wp	**Net work = Turbine work - Pump work**
EFFth = Wnet / Qa	**Cycle thermal efficiency**

Modified Rankine Cycle: superheater, reheater, feedwater heater, air pre-heater



Net Heat Rates



Net Heat Rate = Qf / (Wt – Qg – Wp – Waux – Wfp), (btu/h)/kW

Steam Generator Energy Flow

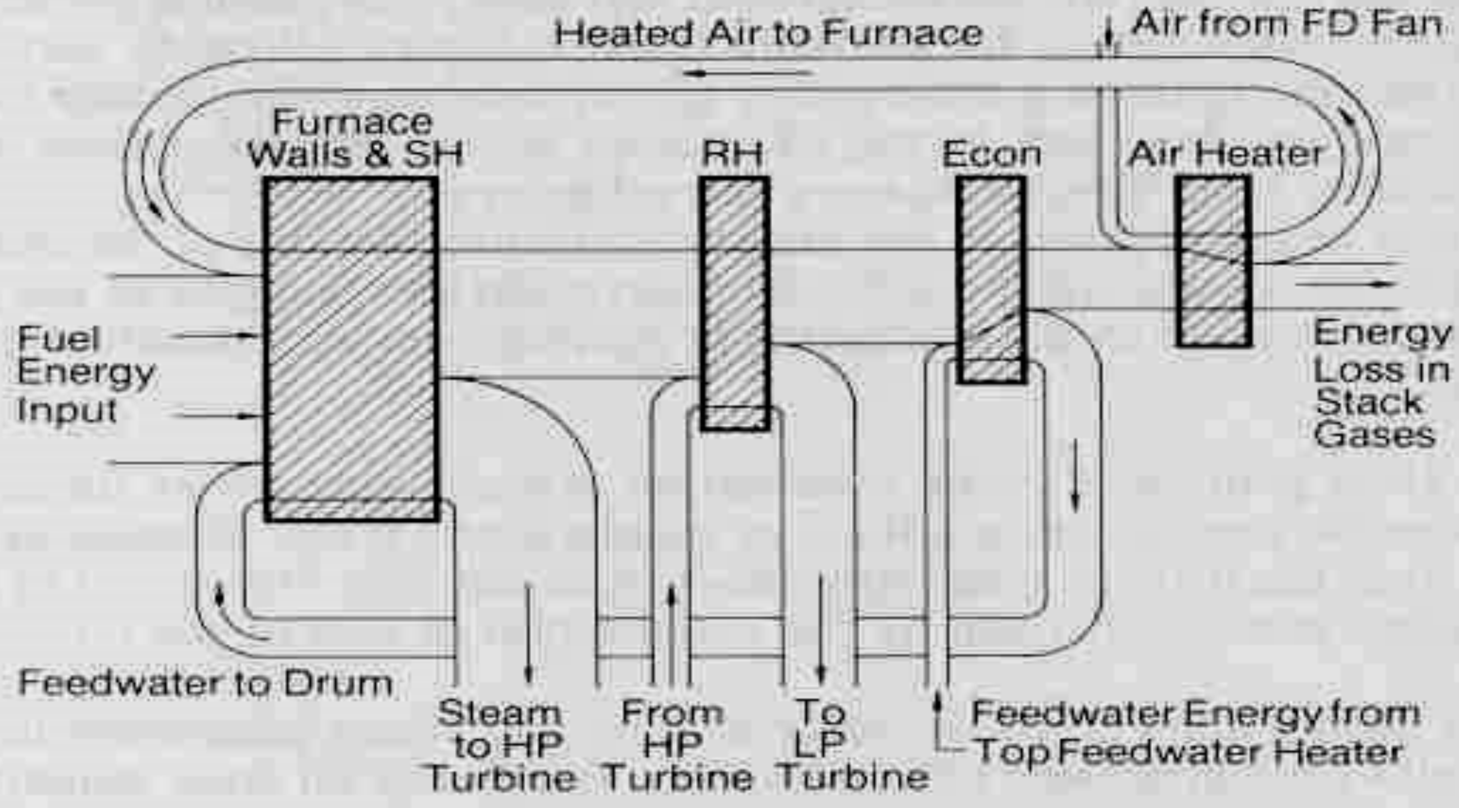


FIG. 1.2 Steam generator energy flow.

Circular Burner

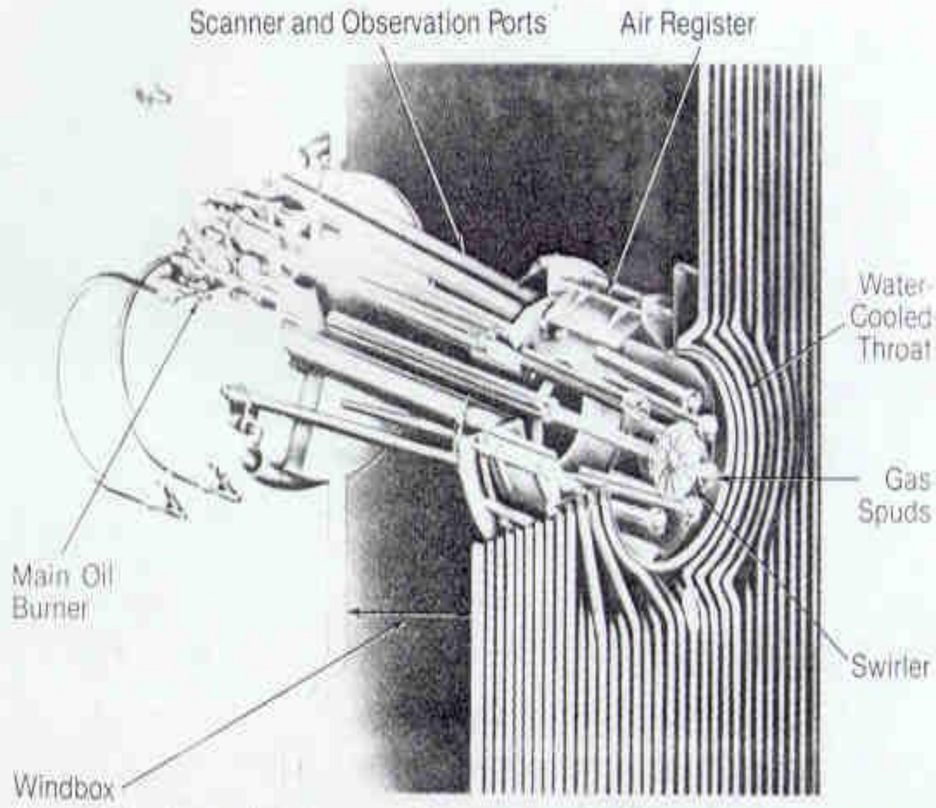


Fig. 6 Circular register burner with water-cooled throat for oil and gas firing.

- Burner design and operation have great impact on emissions of NO_X, CO and unburnt HC. High temperature ensures complete combustion of CO and HC but promotes NO_X formation.
- Circular burner has been the standard design for oil and gas firing; produces short compact flames

S-type Burner

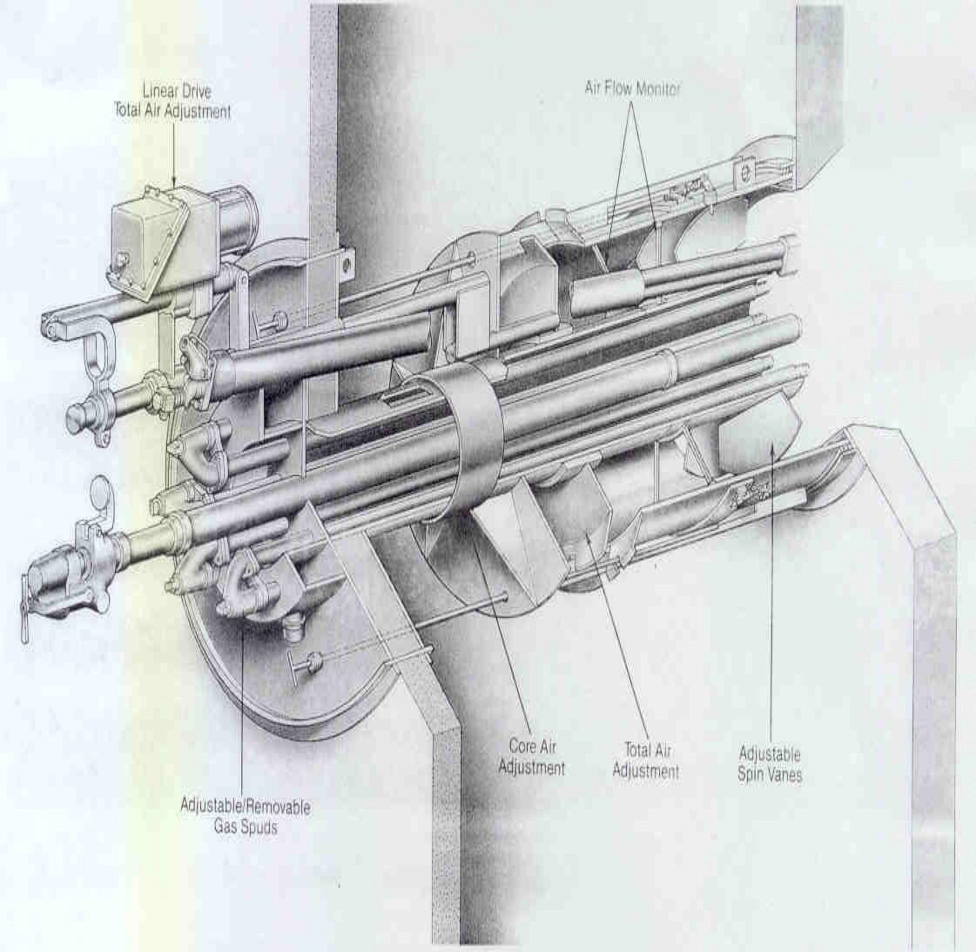


Fig. 7 S-type burner for oil and gas.

- S-type burner was developed to replace the circular burner
- Can measure air flow and regulate total air flow for improved combustion control, independent of swirl.
- No need for oil impeller or swirler; inner or core zone and outer secondary air zone ensures stable ignition.

DRB-XCL Reduced Emission Burner

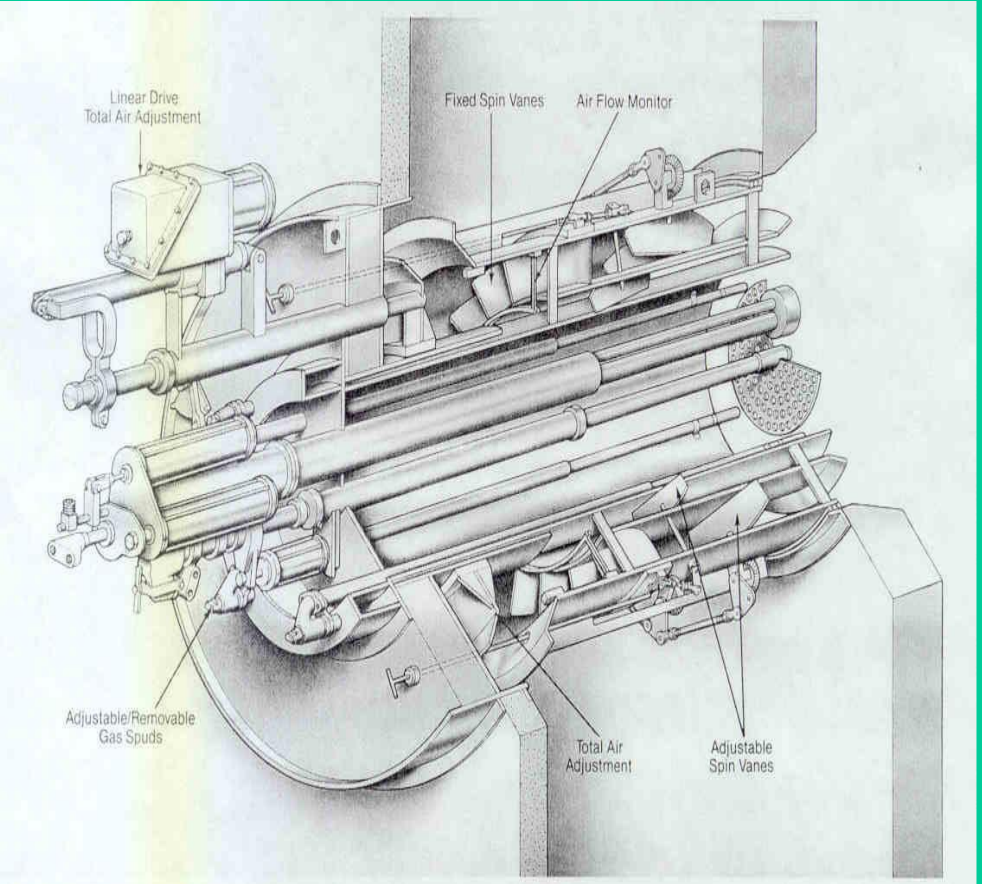


Fig. 8 DRB-XCL™ type burner for reduced emissions.

- The DRB-XCL oil and gas burner was developed specifically for NO_X reduction.
- Incorporates air and fuel staging (2-stage combustion).
- Controls rate of combustion and apparent stoichiometry to reduce peak NO_X formation.
- Air flow is controlled independent of swirl.

Flu Gas Re-circulation (FGR)

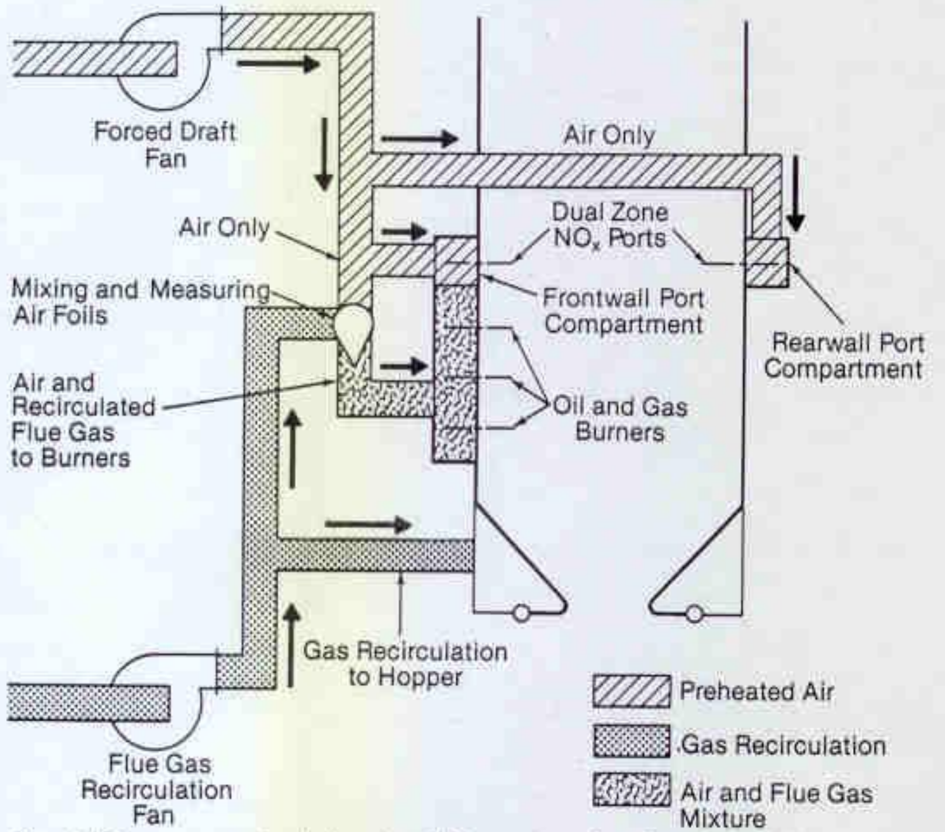


Fig. 4 Flue gas recirculation low NO$_x$ system for oil and gas firing.

- FGR to burners is instrumental in reducing NO_X emissions when the contribution of fuel nitrogen to total NO_X formation is small; FGR limited only to natural gas and fuel oils.
- Introduce flue gas from the economizer lowers burner peak flame temperature and NO_X emissions are significantly reduced.

Lowering NO_x Emissions

- **Low excess air (LEA) –** effectively reduces NO_X emissions with little capital expenditure; it reduces NO_X by 10-20%.
- **Two-stage combustion –** combustion air is directed to burner zone in quantities less than theoretical, with the remainder to be introduced through over-fire air ports; O_2 concentration is reduced at burners; lowers peak flame temperature and NO_X.
- **Re-burning –** combustion gases from main burner zone pass thru a second combustion zone termed the re-burning zone where remaining fuel is added.

Emissions from Power Plants

- **Sulfur dioxide (SO_2)** – acid rain, corrosion, health
- **Nitrogen oxides (NO_X)** – acid rain, corrosion, health
- **Carbon dioxide (CO_2)** – greenhouse gas just like methane (CH_4), contributes to global warming
- **Carbon monoxide (CO), unburnt hydrocarbon fuel (UHC)** – lower efficiency, smoke, health
- **Particulates (unburnt fuel and fly ash)** – lower efficiency, smoke, health
- ***Solid wastes:*** *bottom ash, pyrite from pulverizer, gypsum*
- ***Other effluents:*** *waste water, unrecovered catalysts, chemicals, reagents, sorbents, heavy metals e.g. Mercury*

Pollution Control Technologies Used in Power Generation

- **Flue Gas Desulfurization** (removal of SO_2)
  * Wet scrubbing
  * Spray dry scrubbing
  * Sorbent Injection
- **Control of Oxides of Nitrogen** (reduction of NO_X)
  * Low NO_X burners
  * Selective catalytic reduction – SCR
  * Selective non-catalytic reduction – SNCR
- ***Removal of particulates and fly ash***
  ** Fabric or bag-house filters*
  ** Electro-static precipitator (ESP)*
- ***Waste treatment***
  ** Dewatering, stabilization, fixation, impoundment, landfill*
  ** Recovery of gypsum ($CaSO_4$) as fertilizer and wall-board material*

Cost of Oil-Gas Power

- Cost of oil-gas power (EIA, 1996):

Resource type	Base load or Peaking
Capacity factor	varies if peaking or base load
Real levelized cost (1996$)	3.9 – 4.4 cents / kWh (gas)
	5.5 cents / kWh (oil)
Construction lead time	
Economic life	25 years
Overnight capital cost	$ 991 / kW
Fixed O&M costs	$0.300 / kW / year
Variable O&M, $/kWh	$0.050 / kWh
Thermal efficiency	38 – 45 %

Oil-Thermal/Diesel Plants in RP

Plant Name/ Proponent	Location	Owner	Contract Type	Grid	Region	Year Comm.	No.	Unit Size	Capacity MW
FPPC-Bauang	La Union, Bauang	IPP	BOT	Luzon	I	1994-95	21	11.2	235.20
Malaya 1-KEPCO	Rizal, Pililia	NPC-IPP	ROM	Luzon	III	1975	1	300.0	300.00
Malaya 2-KEPCO	Rizal, Pililia	NPC-IPP	ROM	Luzon	III	1978	1	350.0	350.00
Bataan CC A	Bataan, Limay	NPC-IPP	BTO	Luzon	III	1993	4		310.00
Bataan CC B	Bataan, Limay	NPC-IPP	BTO	Luzon	III	1994	4		310.00
Edison global	Bataan, Mariveles, EPZA	IPP	PPA	Luzon	III	1994-95			63.00
Sucat Thermal 2	Paranaque, Sucat	NPC		Luzon	NCR	1970	1	200.0	200.00
Sucat Thermal 3	Paranaque, Sucat	NPC		Luzon	NCR	1971	1	200.0	200.00
Pinamucan-ENRON	Batangas, Pinamucan	IPP	BOT	Luzon	IV	1993	8		110.00
Subic-ENRON	Zambales, Olongapo	IPP	BOT	Luzon	IV	1994	8	14.8	118.00
Magellan Cogen	Cavite, Rosario, EPZA	IPP	PPA	Luzon	IV	1995			63.00
Bohol Diesel Unit 1 & 2	Bohol, Tagbilaran City, Dampas	NPC		Visayas	VII	1978	2	5.5	11.00
Bohol Diesel Unit 3	Bohol, Tagbilaran City, Dampas	NPC		Visayas	VII	1986	1	5.5	5.50
Bohol Diesel Unit 4	Bohol, Tagbilaran City, Dampas	NPC		Visayas	VII	1996	1	5.5	5.50
Diesel Barge #101	Bohol, Cortes	NPC		Visayas	VII	1981	4	8.0	32.00
Panay Diesel I	Iloilo, Dingle	NPC		Visayas	VII	1979-83	5	7.3	36.50
Diesel Barge #103	Iloilo City, Estancia	NPC		Visayas	VII	1985	4	8.0	32.00
Diesel Barge #104	Cebu, Naga	NPC		Visayas	VII	1985	4	8.0	32.00
Diesel Barge #107	Cebu, Naga (under rehab.)	NPC		Visayas	VII	1992	4	3.6	14.40
Cebu Diesel I-ZALCON	Cebu, Naga, Colon	NPC-IPP	ROM	Visayas	VII	1993	6	7.3	43.80
Maricalum	Negros Occidental, Sipalay Mine	IPP	PPA	Visayas	VII	1995			1.00
Zamboanga Diesel	Zamboanga del Sur	IPP	BOO	Mindanao	IX	1997			100.00
Gen. Santos Diesel	Gen. Santos City	IPP	BOO	Mindanao	IX	1998			50.00
Mindanao Barge #117	Agusan, Nasipit	NPC-IPP	BTO	Mindanao	X	1994	2	50.0	100.00
Mindanao Barge #118	Davao Del Norte, Macao	NPC-IPP	BTO	Mindanao	XI	1994	2	50.0	100.00
NMPC Units 1 & 2	Iligan City, Dalipuga	IPP	BOT	Mindanao	XII	1993			98.00
OIL (Thermal)									**2,920.90**
Hopewell GT-MIRANT 1-3	Metro Manila, Navotas	IPP	BOT	Luzon	NCR	1990-91	3	70.0	210.00
Hopewell GT-MIRANT 4	Metro Manila, Navotas	IPP	BOT	Luzon	NCR	1993	1	100.0	100.00
Naga GT Land Based	Cebu, Naga	NPC-IPP	ROM	Visayas	VII	1993	2	27.5	55.00
OIL (Diesel)									**365.00**
TOTAL OIL									**3,285.90**

Environmental Impact

- Heavy fuel oil contains 2-5% sulfur; **emits SO_2 and also NO_X** during high temperature combustion; contributes to acid rain/snow and respiratory illness.
- During start-up or abnormal conditions, **high levels** of **CO, UHC and particulates** are emitted which contribute to thick smoke and "smog" – leading also to respiratory illness and difficulty of breathing
- Fuel oil (86-89% carbon) **generates more greenhouse gas CO_2 than natural gas** (70-75% carbon) which contains less carbon and more hydrogen, aside from being more efficient. CO_2 emission in kg/kWh is computed:

CO_2 = (heat rate, kJ/kWh) / (LHV, kJ/kg) * (% C/100) * (mw CO_2/mw C)

= (3600 / efficiency) / (LHV, kJ/kg) * (% C/100) * (mw CO_2/mw C)

Risks

- **Basic Technology –** Oil-gas thermal is a well known power generation technology, hence the technology risk is *low*.
- **Environmental regulations –** Combination of economic, more stringent environmental regulations and public awareness has reduced oil thermal power generation over the last decade; it dropped from 4.1% to 2.9% of total power generated in the US alone; *low to medium risk.*
- **Fuel supply risk –** Cost of crude has been fluctuating from $12-33-25/barrel from 1985-1990-1999 but remained relatively steady in recent past at $25/barrel despite OPEC price interventions. However, there is still a *medium to high* fuel supply risk as oil reserves at current extraction rates may be gone in 39 years and will continue to be influenced by OPEC price-fixing activities.

Historical Data - World Oil Price