NOT YET COMMERCIALLY AVAILABLE FUEL CYCLES

Near Term (within 20 years)

Not Yet Commercially Available Fuel Cycle Technologies

	Fuel Cycle Technology				
NT	*Coal* Direct Liquefaction				
	Coal Indirect Liquefaction				
	Coal Pyrolysis				
	Petrothermal - Hot Dry Rock				

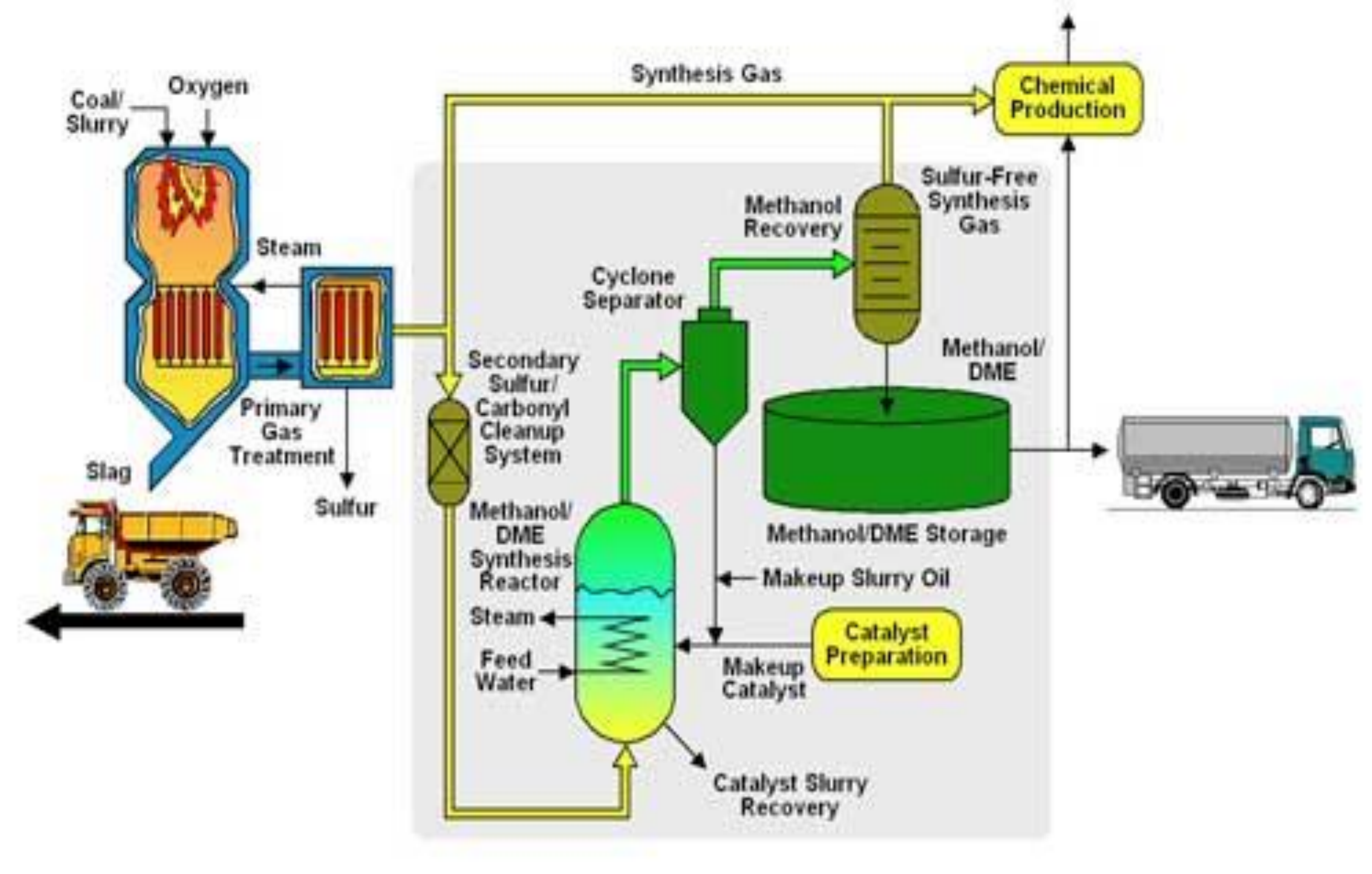
Coal Direct Liquefaction

- Liquefaction is divided into two categories: indirect and direct.
- Direct liquefaction uses the process of gasification to produce chemicals, such as methanol, for use in manufacturing other products.
- Direct liquefaction is also known as hydroliquefaction because the process involves large amounts of hydrogen.
- Direct liquefaction is accomplished by crushing coal and mixing it with a solvent to produce a 'slurry'.
- Hydrogen is added and the "hydrogenated slurry" is heated and pressurized to produce a synthetic gas and liquid oils such as gasoline, diesel fuel and kerosene.

Coal Indirect Liquefaction

- Can produce methanol from coal-derived synthesis gas using the LPMEOH™ process.
- LPMEOH™ process has been developed to enhance integrated gasification combined-cycle (IGCC) power generation by producing a clean burning, storable liquid fuel (methanol) from the clean coal-derived gas.
- Methanol has a broad range of commercial applications; it can be substituted for conventional fuels in stationary and mobile combustion applications and is an excellent fuel for utility peaking units.
- Methanol contains no sulfur and has exceptionally low NO_x characteristics when burned.

Coal Indirect Liquefaction



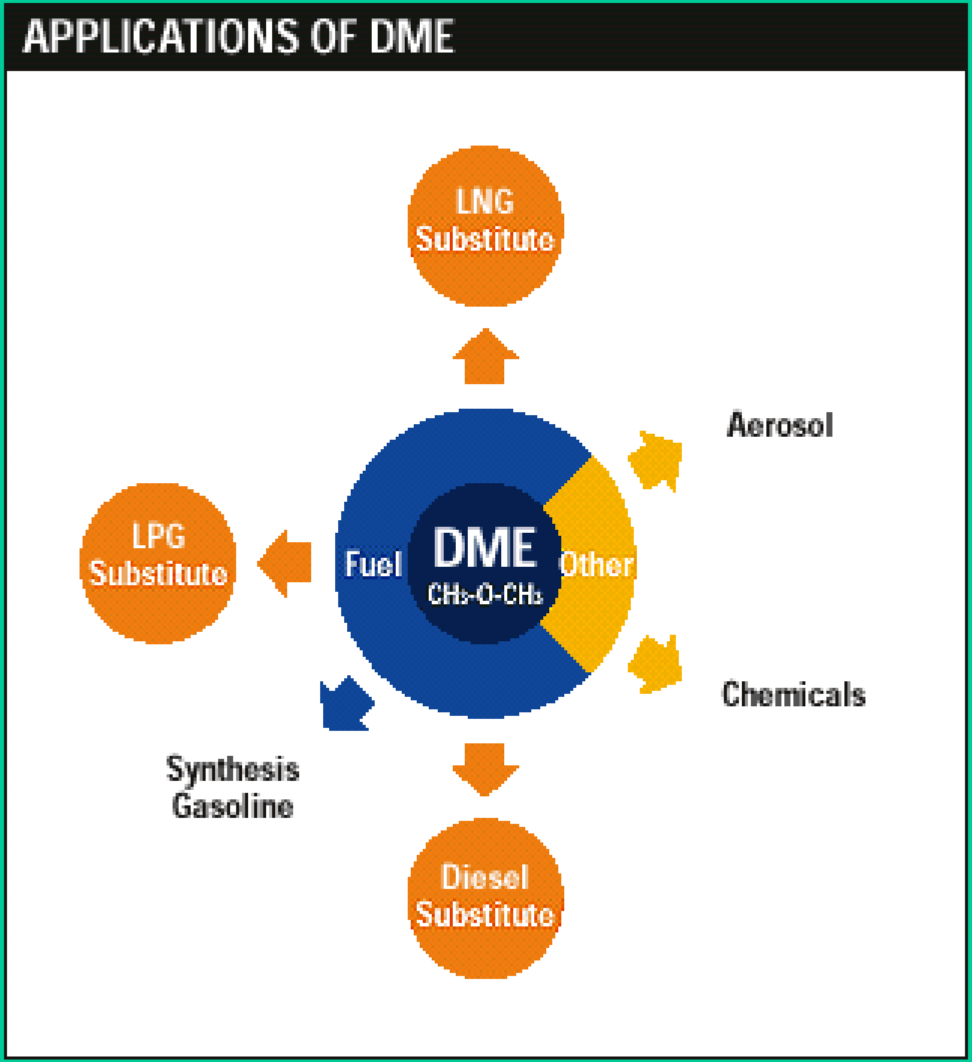
Coal Indirect Liquefaction - DME

- The chemical that replaced fluoro-chloro carbons in spray cans may also serve as a new fuel for power generation, domestic use and transport, according researchers.

- DME or dimethyl ether is a clean and safe fuel that is normally produced by dehydration of methanol, but can also be made from natural gas, coal or biomass. In addition to its applications in power generation, domestic fuel use and diesel engines, DME has a potential use in fuel cells. It is environmentally benign and can be handled like LPG.

- Diesel fuel has a cetane of 45 while DME has a cetane of 55. DME has no natural lubricating properties and will need a lubricating additive.

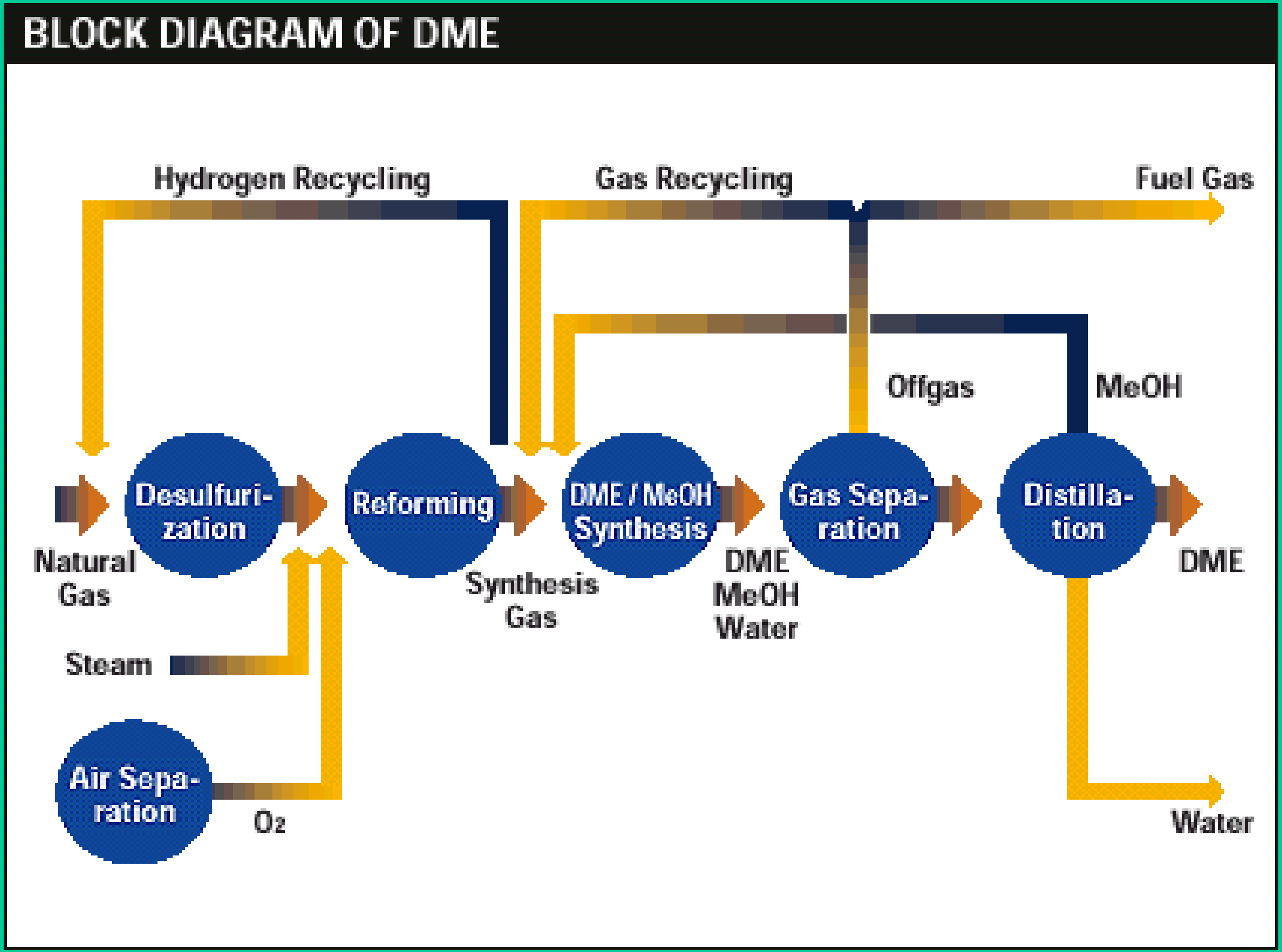
Coal Indirect Liquefaction – DME Uses



DME has many uses:

- LNG substitute
- LPG substitute
- Diesel substitute
- Ultra clean GT fuel
- Synthesized to gasoline
- Aerosol
- Chemicals

Coal Indirect Liquefaction – DME Sources



Coal or Biomass Pyrolysis

- CHP via biomass gasification connected to gas-fired engines or gas turbines can achieve higher electrical efficiencies between 22-37 % compared to biomass combustion with steam generation and steam turbine (15-18 %).

- If produced gas is used in fuel cells for power generation, an even higher overall efficiency between 25-50 %, even in small scale biomass gasification plants and under partial load operation.

- Potential reduction in CO_2 and NO_X may be achieved due to higher electrical efficiency or when used in fuel cells instead of gas-fired engines or GTs.

- Pyrolysis of biomass generates three different energy products in different quantities: coke, oils and gases.

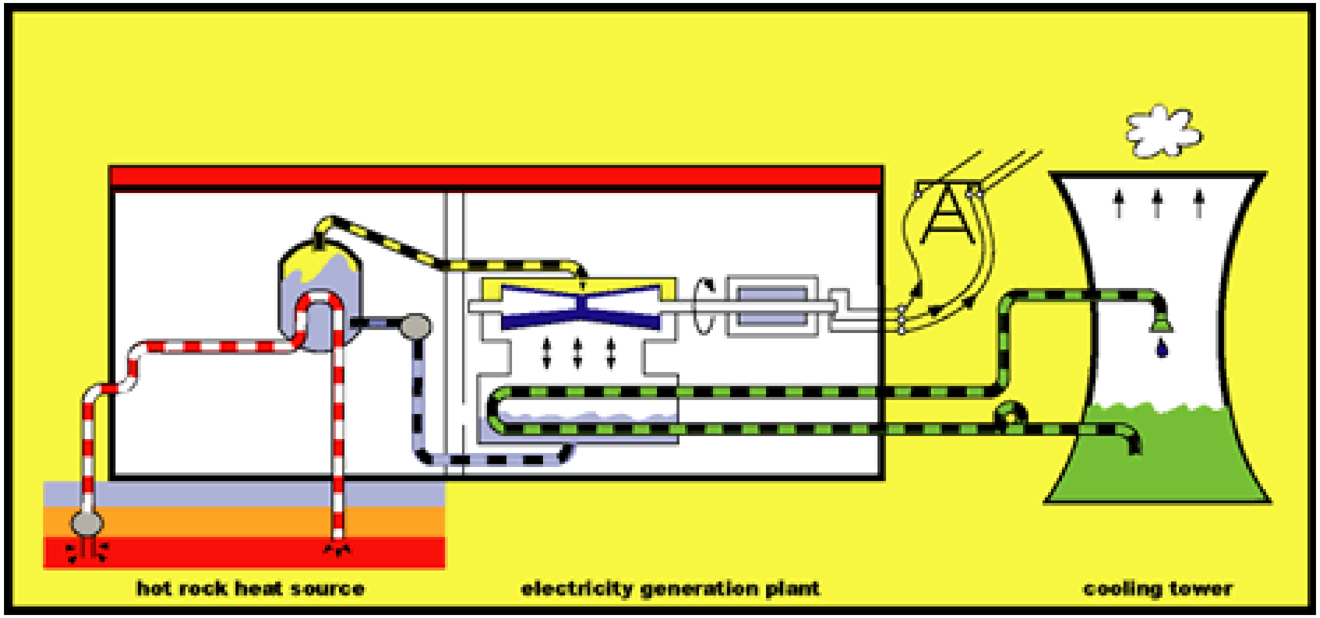
Coal or Biomass Pyrolysis

- Flash pyrolysis gives high oil yields, but because of the technical efforts needed to process pyrolytic oils, this energy generating system does not seem to be very promising at the present stage of development.

- However, pyrolysis as a first stage in a two-stage gasification plant for straw and other agricultural feedstocks deserves consideration.

- Power generation in high-temperature MCFC or SOFC with integrated biomass gasification also has the advantage that no separate unit is needed for CO-shift reaction prior to gas injection into the fuel cell, and that in addition to electricity, process heat is provided by the fuel cell at a high temperature level.

Petrothermal - Hot Dry Rock



- The above diagram shows a plant called a Hot Dry Rock (HDR) or petrothermal electricity generation plant. Brine (saltwater) is pumped into holes drilled into hot rock, and heated. The hot brine is then used to heat a working fluid called iso-butane which becomes a gas used to drive the turbine. The turbine is connected to the alternator which produces electricity. The ISO Butane gas is kept in a closed system and is re-used. The brine is also re-used by pumping it back to the HDR.

NOT YET COMMERCIALLY AVAILABLE POWER GENERATION TECHNOLOGIES

Near Term (within 20 years)

Not Yet Commercially Available Power Generation Technologies

	Power Generation Technologies Levelized Cost in Nominal 1996 $	**Baseload 60 - 75 %**	**Intermediate 20 - 35%**	**Intermittent Varies**	**Peaking 0 - 5%**
NT	*Oil & Gas* Advanced GT Cycles:				
	- Intercooled Steam Recuperated GT (SRGT)	5.0 - 6.6	6.9 - 11.6		
	- Chemically Recuperated GT	4.9 - 6.8	7.1 - 12.6		
	- Humid Air Turbine (HAT)	4.3 - 6.1			
	- Intercooled Reheat Combined Cycle (IRCC)	4.9 - 6.2			
	- Intercooled Aeroderivated GT	6.8 - 10.2			
	Coal Pressurized Circ. Fluidized Bed Combustion (PCFBC)	6.0 - 7.3			
	Coal Integrated Gasification Combined Cycle (IGCC)	5.0 - 6.7			
	Geothermal Liquid Dominated Binary Plant Kalina Cycle	5.5 - 6.9			
	Municipal Solid Waste RDF Co-Firing (20% coal)	14.4 - 19.1			
	Solar Thermal Electric Central Receivers (Towers)	8.1 - 9.1	11.8 - 13.1	14.8 - 22.7	
	Solar Thermal Electric Parabolic Dishes		7.9 - 19.5	9.7 - 26.7	
	Solar Photovoltaic Utility-Scale Systems (e.g. IHCPV)		14.0 - 14.3	18.2 - 18.5	
	Ocean Energy Tidal Energy	14.1 - 28.5			
	Fuel Cells Phosphoric Acid (PAFC)	8.4 - 9.9			
	Fuel Cells Molten Carbonate (MCFC)	9.9 - 15.2			

Oil & Gas Advanced GT Cycles
Intercooled Steam Recuperated GT (SRGT)

- GT has an efficiency of 37% without recuperation, increasing by 25% and increased mass flow through the engine with recuperation. Fuel savings are 10% at full power and 50% at idle, (off-peak running is important in navy ships, where they run for 25-33% full power for most of the time).
- Recuperator is a full counterflow PFHE, tension brazed, and is rated at 16 MW (the engine's ISO rating is 25 MW). It uses a high grade stainless steel. It operates in an environment where corrosion and creep can occur.
- Typical duty is cooling 70 kg/s gas from 575°C to 275°C. The temperature difference between the top and bottom of the recuperator is 300°C.

Oil & Gas Advanced GT Cycles
Chemically Recuperated GT (CRGT)

- There are 2 methods to reduce CO_2 from power plant flue gas: physical and chemical absorption (with liquefaction of CO_2 removed).

- Using the advanced mixed cycle (AMC) achieves CO_2 emissions of about 0.04 kg/kWh and electrical efficiency of 50% compared to 38.4% for IGCC and 47.8% for CC.

- The AMC is a mixed gas-steam cycle consisting of a reheat GT with steam injection in the 1st combustion chamber, a ST for steam expansion a HRB for superheated and resuperheated steam generation (reheater) and atmospheric separator for water recovery from exhaust gas mixture.

Oil & Gas Advanced GT Cycles
Humid Air Turbine (HAT)

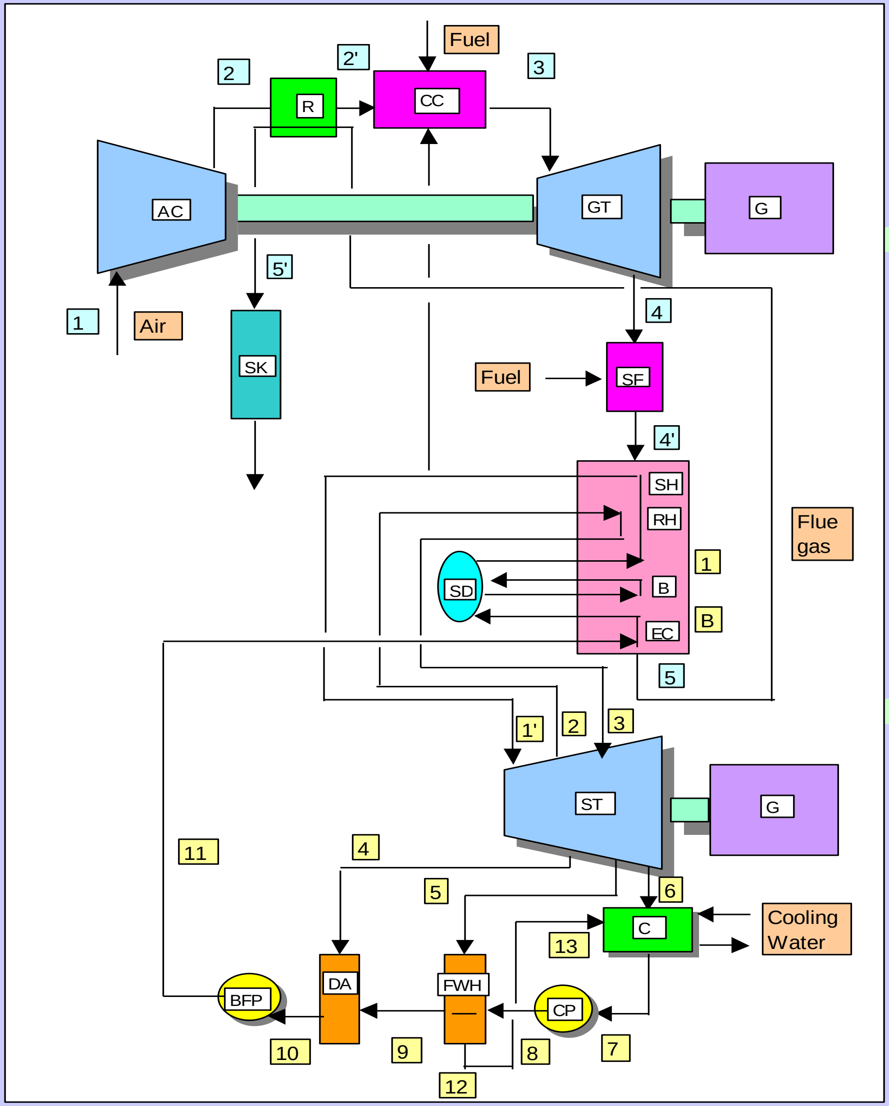
- Converting the heat in a GT exhaust into steam and then converting steam into electric power through a conventional steam cycle involves losses and inefficiencies which reduce the overall cycle efficiency. Adding water up to 25% by weight raises performance.

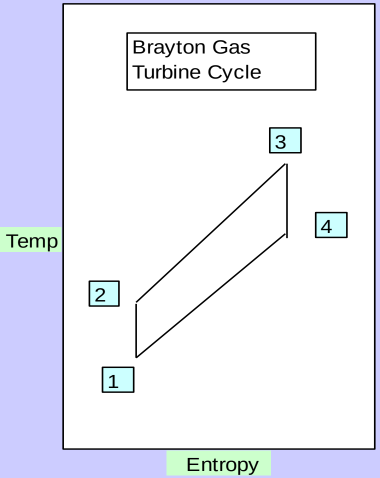
- One feature of a GT is that it already has a turbine creating mechanical power from a flowing gas stream, and this power output can be raised (within limits) by increasing the mass flow of gas.

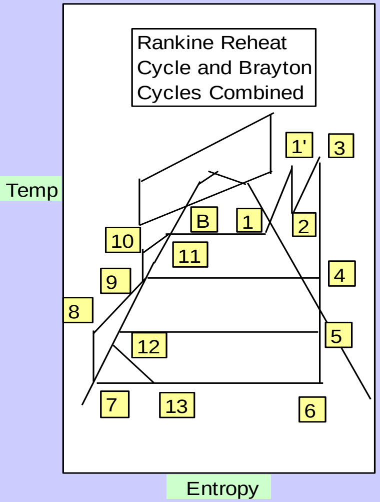
- The flue gas can be cooled by injecting water which evaporates as it cools the gas and increases the mass flow of gas through the GT. *Injecting steam from the waste heat boiler into the GT upstream or in the combustion chamber further raises the mass flow.*

- Such cycles are known as Humid Air Cycles and can raise efficiency by about 3% points compared to a standard IGCC plan and 30% lower NO_X emissions.

Combined Cycles with HAT







Oil & Gas Advanced GT Cycles
Cascaded Humid Air Turbine (CHAT)

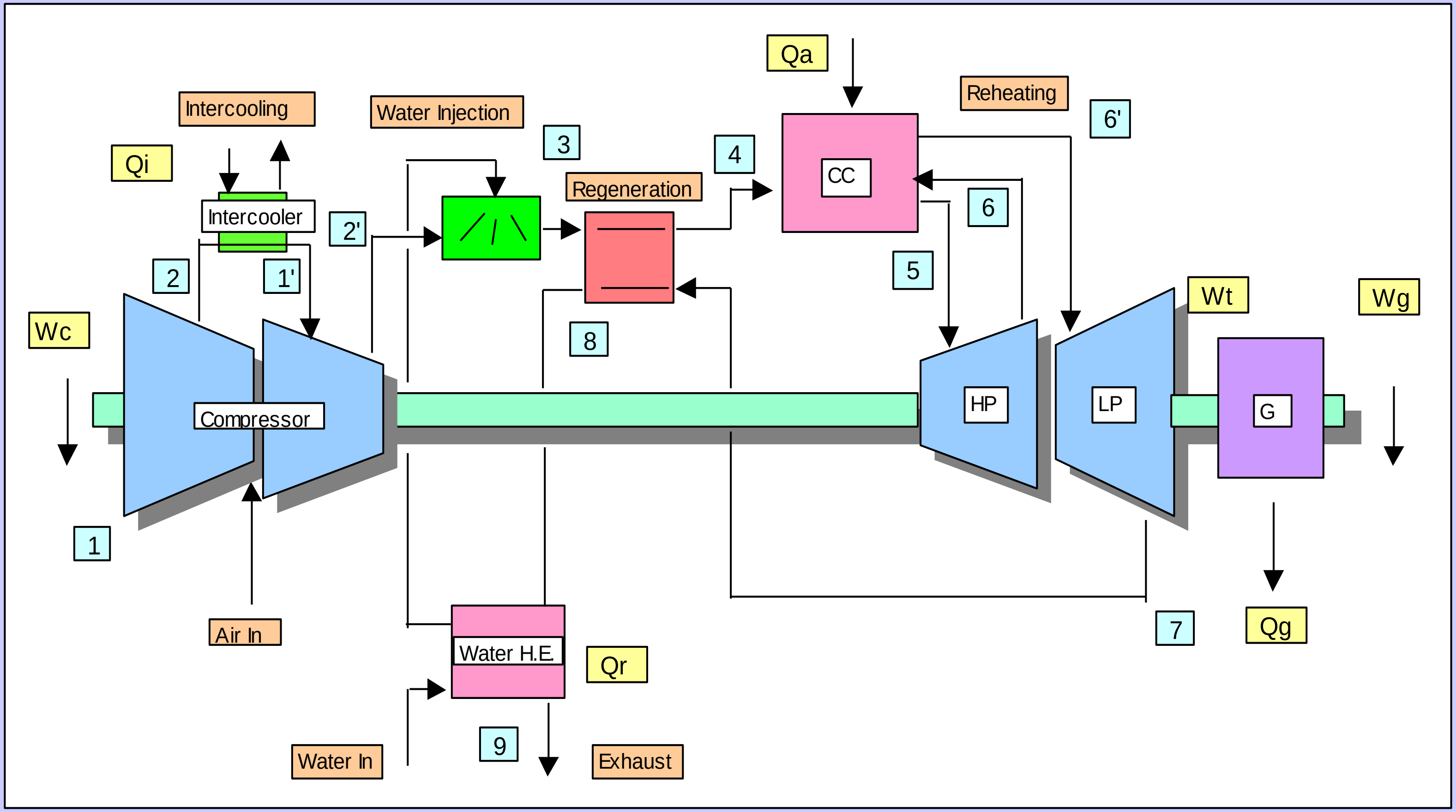
- CHAT is essentially a reheat HAT cycle with a turbocharger to allow very high pressures in the saturator (65-70 atm) and higher than the 25% mass fractions of the HAT cycle.

- The high-pressure humidified stream is heated in the high-temperature air furnace (HITAF), expanded to drive the turbocharger, reheated in the HITAF, and then heated further in the duct heater before expansion in the turbine. The HAT and CHAT cycles can be in the 55-60% (HHV) range and perhaps higher.

- At comparable turbine inlet temperatures, the CHAT cycle yields more power than the HAT cycle.

- CHAT could enjoy a 20% advantage in capital cost v.s. CCGT.

GT CHAT Cycle: regeneration or recuperation, compressor intercooling, reheating, water injection



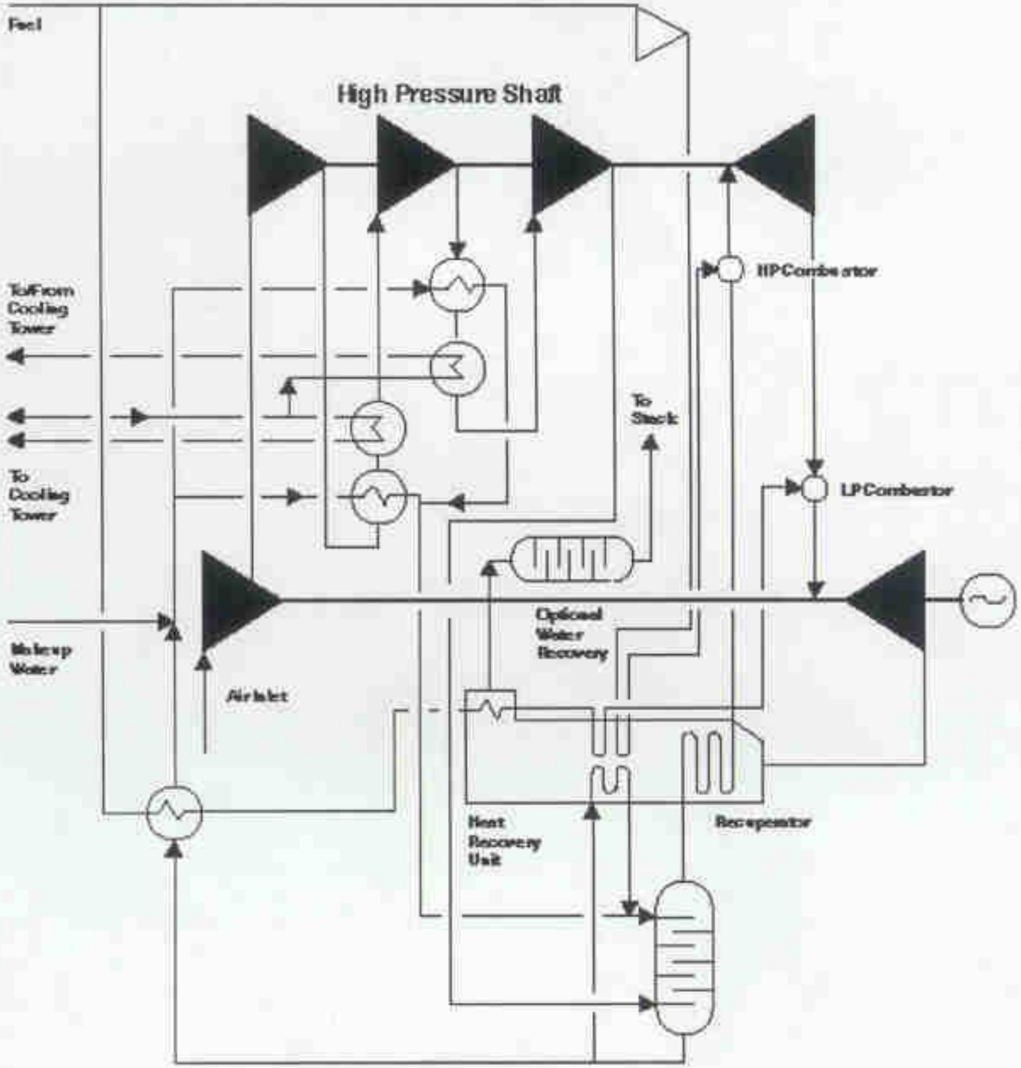


Figure 4. The CHAT Design Incorporates Compressor Intercooling, Recuperation, and Reheat into a Humidification Cycle

Oil & Gas Advanced GT Cycles
Intercooled Reheat Combined Cycle (IRCC)

- Intercooled and reheat cycles have a lower efficiency than that of a simple-cycle gas turbine at low-to-moderate pressure ratios.

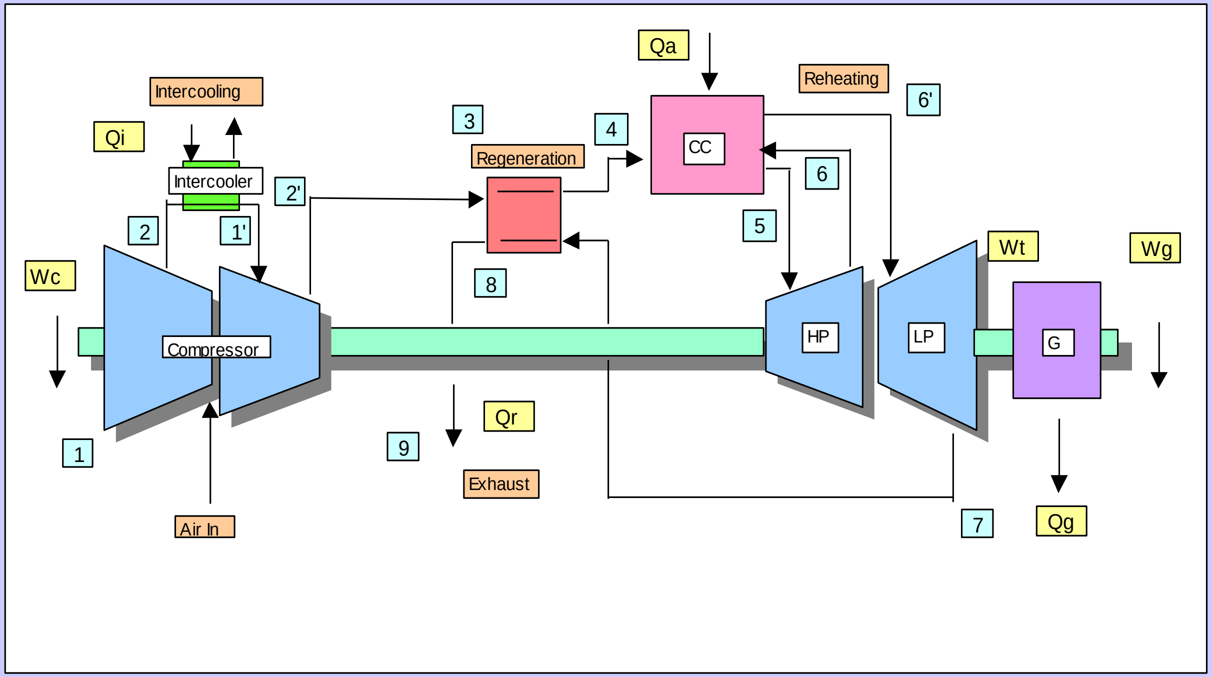
- The main effect of intercooling or reheating is to reduce the size and cost of the basic equipment by increasing the specific power output of the turbine.

- However, the lower cost of the basic smaller unit is offset by the added cost of an intercooler or additional combustor and a more complicated turbine design to reheat the gases.

- Intercooling with regeneration (recuperation) is more efficient than reheat with regeneration. Regenerators and intercoolers are also more susceptible to leakage – more downtime & costs.

Oil & Gas Advanced GT Cycles
Intercooled Aeroderivative (ICAD)

- **COMPOUND CYCLE –** consists of an intercooler, reheater and regenerator (no water or steam). Such a combination results in high thermal efficiencies over a wide range of pressure rations and yields high specific power outputs.



Oil & Gas Advanced GT Cycles
Efficiency Improvements in Combined Cycles

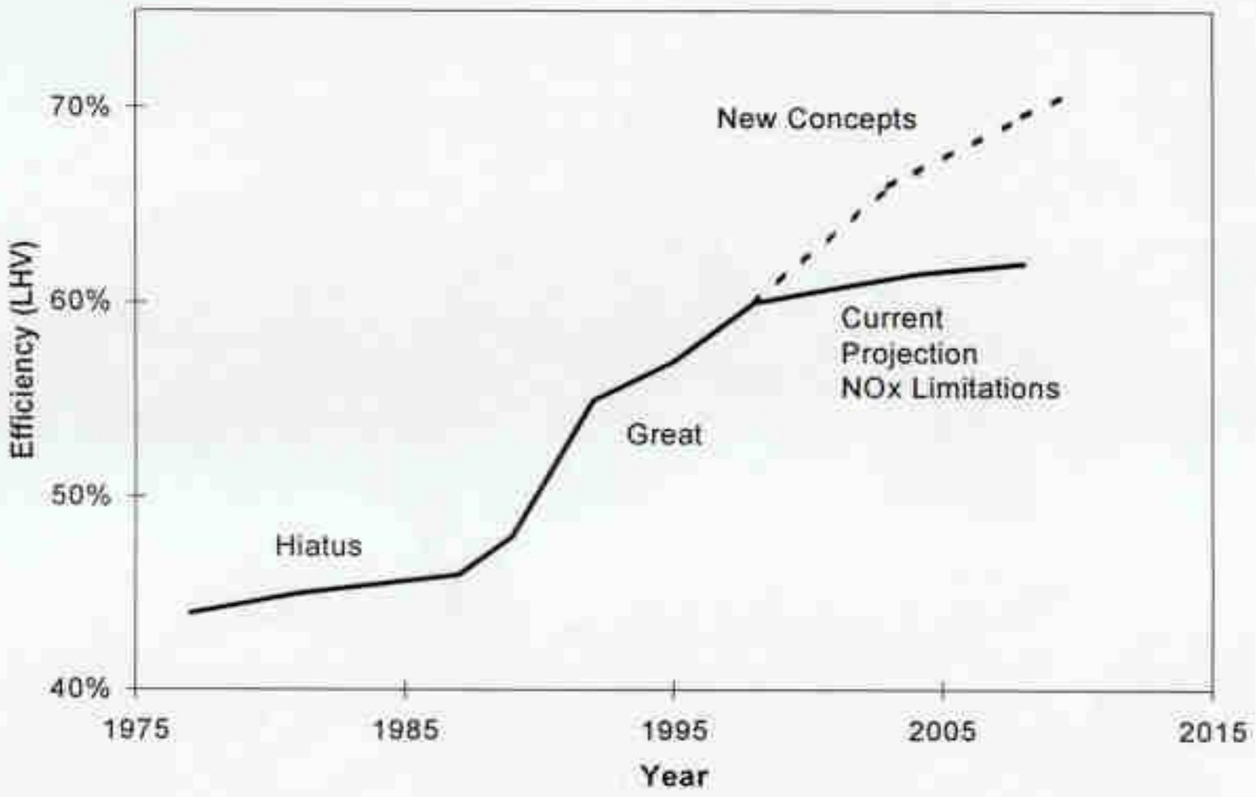
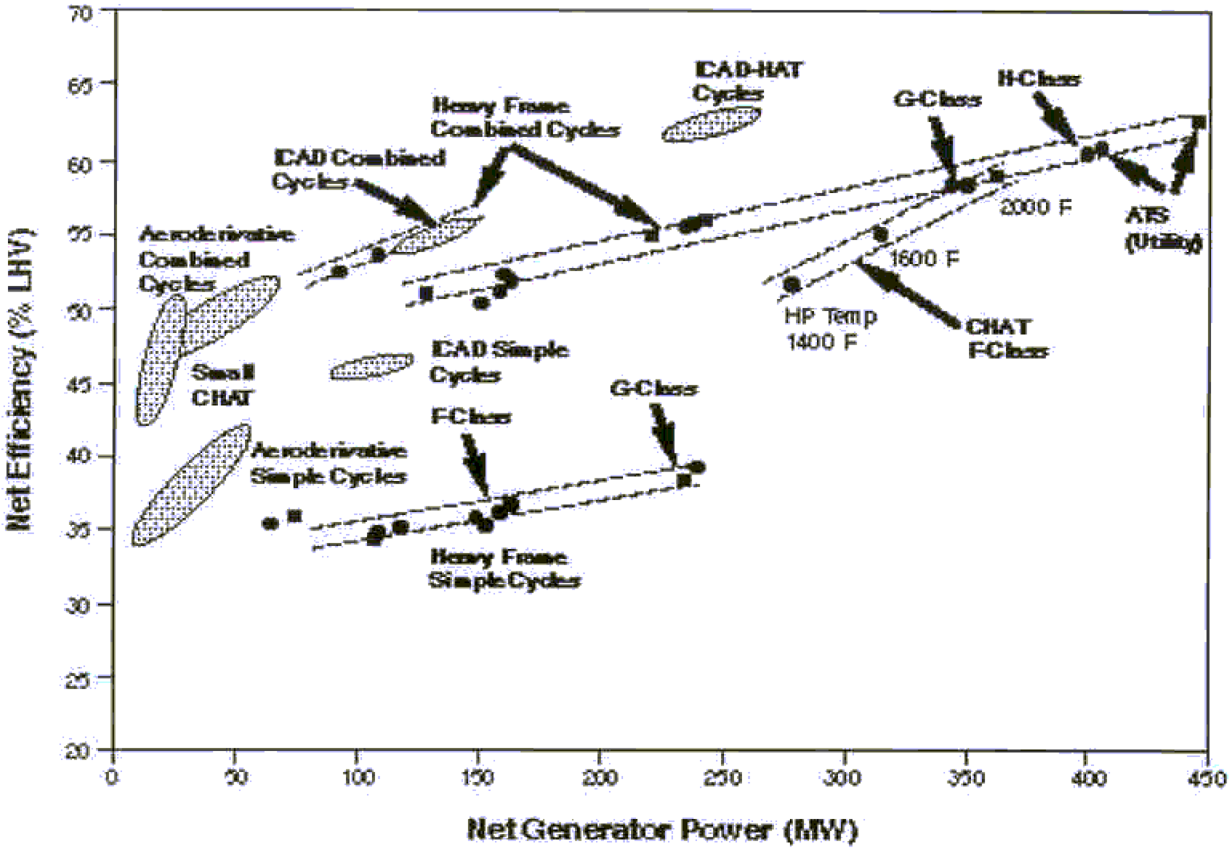


Figure 1. Efficiency Improvements in Combined Cycles

Oil & Gas Advanced GT Cycles Current & Projected Efficiencies



2. Current and Projected Technologies

Coal Pressurized Fluidized Bed Combustion (PFBC)

1st generation pressurized fluidized bed combustor uses a "bubbling-bed" technology. A relatively stationary fluidized bed is established in the boiler using low air velocities to fluidize the material, and a heat exchanger (boiler tube bundle) immersed in the bed to generate steam. Cyclone separators are used to remove particulate matter from the flue gas prior to entering a gas turbine, which is designed to accept a moderate amount of particulate matter (i.e., "ruggedized").

PHOTO:
FOSTER WHEELER CORP.

Coal Pressurized Fluidized Bed Combustion (2)

- Fluidized-bed combustion evolved from efforts to find a combustion process able to control pollutant emissions without external emission controls (such as scrubbers).

- The technology burns fuel at temperatures of 1,400 to 1,700 degrees F, well below the threshold where nitrogen oxides form (at approximately 2,500 degrees F, the nitrogen and oxygen atoms in the combustion air combine to form nitrogen oxide pollutants).

- Mixing action of the fluidized bed brings the flue gases into contact with a sulfur-absorbing chemical, such as limestone or dolomite. More than 95 percent of the sulfur pollutants in coal can be captured inside the boiler by the sorbent.

Coal **Pressurized Fluidized Bed Combustion (3)**

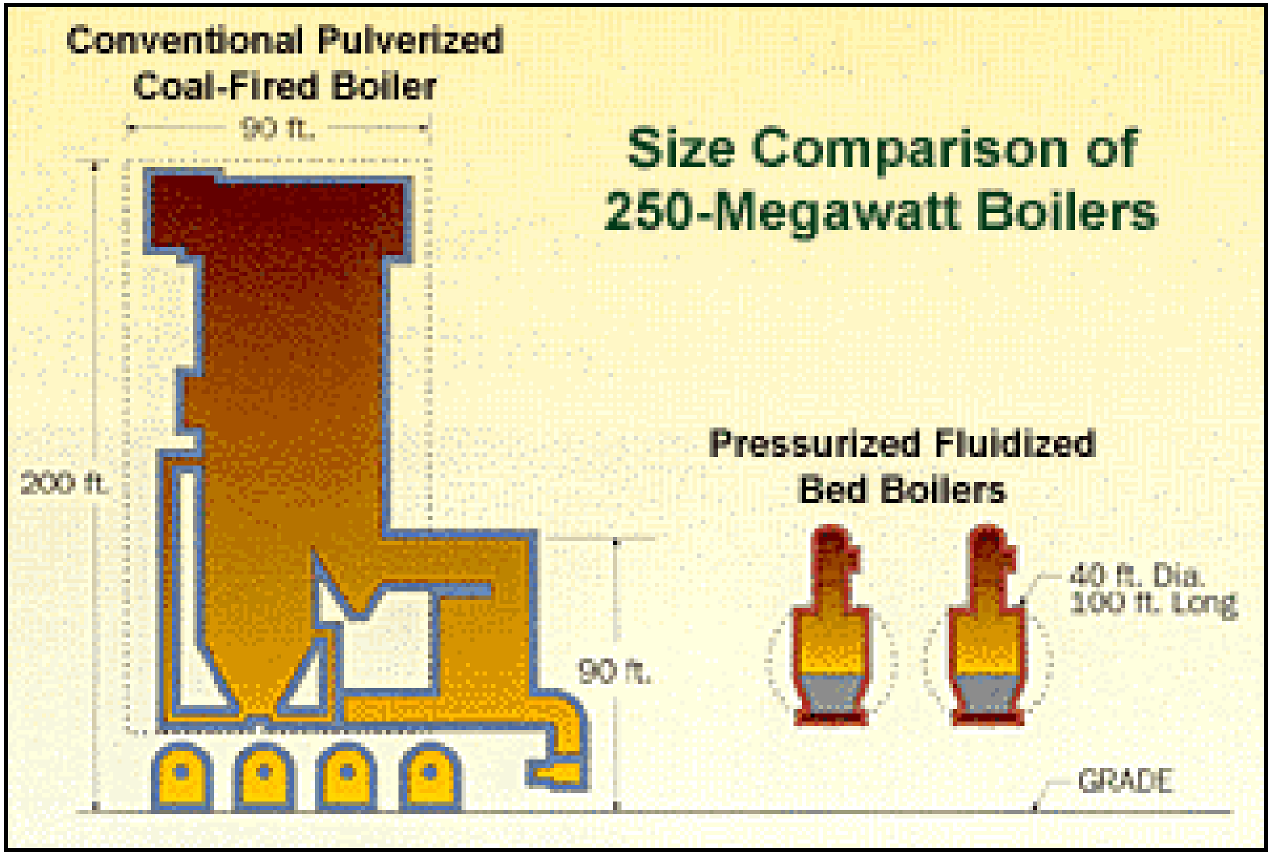
- Pressurized fluidized-bed combustion builds on earlier work in atmospheric fluidized-bed combustion technology. Atmospheric fluidized bed combustion is crossing over the commercial threshold, with most boiler manufacturers currently offering fluidized bed boilers as a standard package.

- Popularity of FBC is due largely to the technology's fuel flexibility - almost any combustible material, from coal to municipal waste, can be burned - and the capability of meeting sulfur dioxide and nitrogen oxide emission standards without the need for expensive add-on controls.

- An estimated 1000 megawatts of capacity installed worldwide now use pressurized fluidized bed to generate sufficient flue gas energy to drive a gas turbine and operate it in a combined-cycle.

Coal Pressurized Fluidized Bed Combustion (4)

- Pressurization effectively reduces the size of the fluidized bed boiler and raises efficiency from 47% to 50% compared to a huge conventional pulverized coal-fired boiler.



Coal Pressurized Circulating Fluidized Bed Combustion (PCFBC)

- A 2nd generation pressurized fluidized bed combustor, currently under development, uses "**circulating fluidized-bed**" technology and a number of efficiency enhancement measures.

- Circulating fluidized-bed technology has the potential to improve operational characteristics by using higher air flows to entrain and move the bed material, and recirculating nearly all the bed material with adjacent high-volume, hot cyclone separators.

- The relatively clean flue gas goes on to the heat exchanger. This approach theoretically simplifies feed design, extends the contact between sorbent and flue gas, reduces likelihood of heat exchanger tube erosion, and improves SO_2 capture and combustion efficiency.

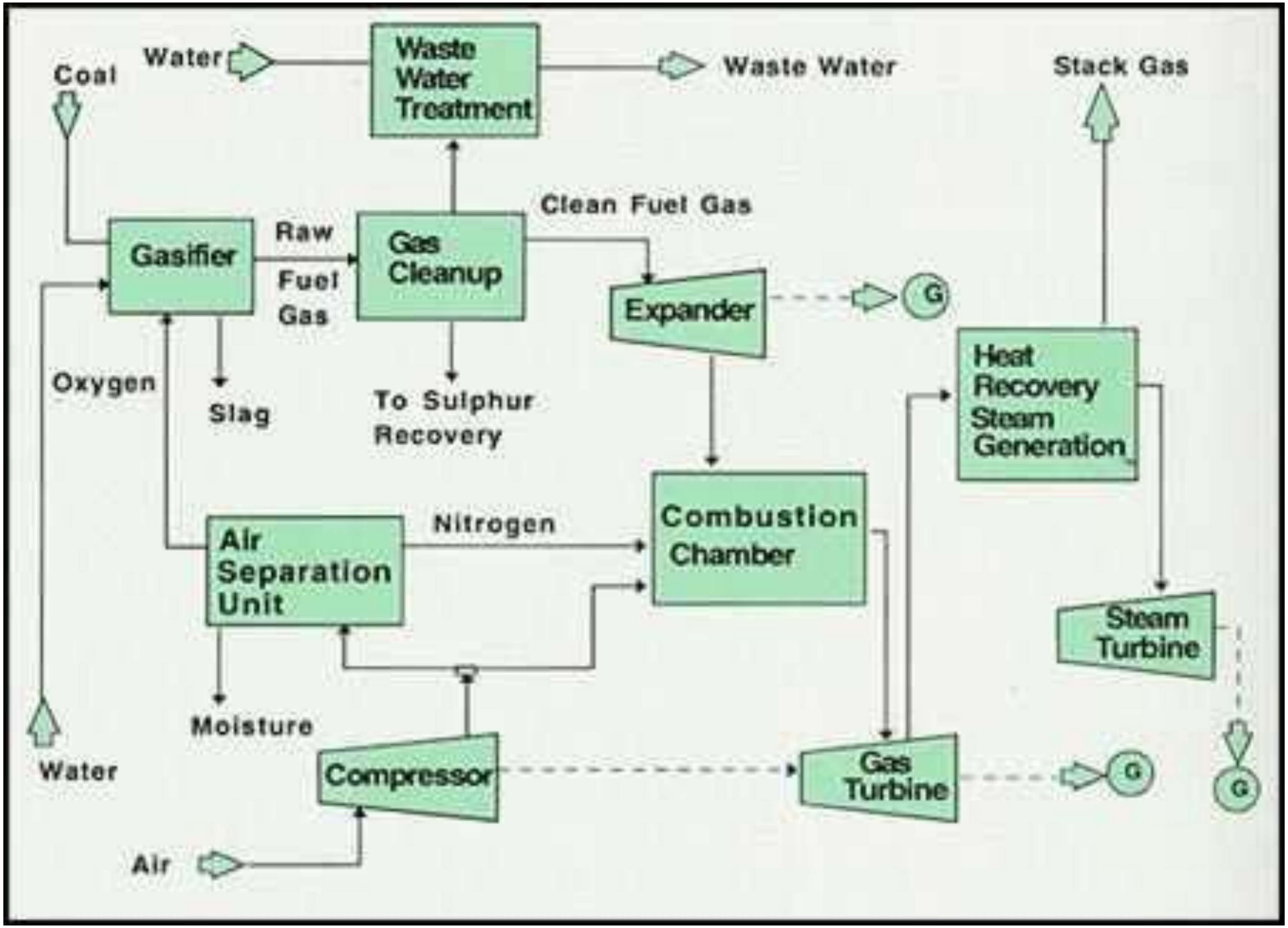
Coal Integrated Gasification Combined Cycle (IGCC)

- Major improvement of 2nd generation PFBC is the integration of a **coal gasifier** to produce a pressurized fuel gas that goes to a topping combustor and adds to the combustor's flue gas energy entering the GT, the more efficient unit of CCGT. The waste heat is recovered in the bottoming heat recovery steam generator.

- An advanced IGCC power plant, incorporating high temperature gas cleaning and GT with high firing temperatures, could achieve a power generation efficiency of 50% (LHV) within the next 10 to 15 years.

- This increase of efficiency will consequently result in a lower CO_2 emission i.e 660 g/kWh. Such an IGCC power plant will also have 50% lower emissions of NO_x and SO_2.

A Texaco based IGCC power plant



A Texaco based IGCC power plant:
Mass & Energy Balances (Net Efficiency = 42%)

MASS BALANCE			
Input	**kg/s**	**Output**	**kg/s**
Coal	47	Stack Gas	1,028
Water (coal slurry)	18	Waste Water	26
Air	990	To Sulfur Recovery	4
Water (venturi scr.)	10	ASU Condensates	1
		Ash	6
Total Input	1,065	Total Output	1,065

ENERGY BALANCE				
Input	**MW**	**Output**	**MW**	**%**
Coal (LHV)	1,206	Expander	10	0.8
		Gas Turbine	289	24.0
		Steam Turbine	272	22.6
		Plant Consumption	68	5.6
		Net Output	503	41.7
		Heat Losses	703	58.3
Total Input	1,206	Total Output	1,206	100.0

A Texaco based IGCC power plant: Emissions

Emissions from Texaco based, 500 MW, state of the art IGCC Power Plant

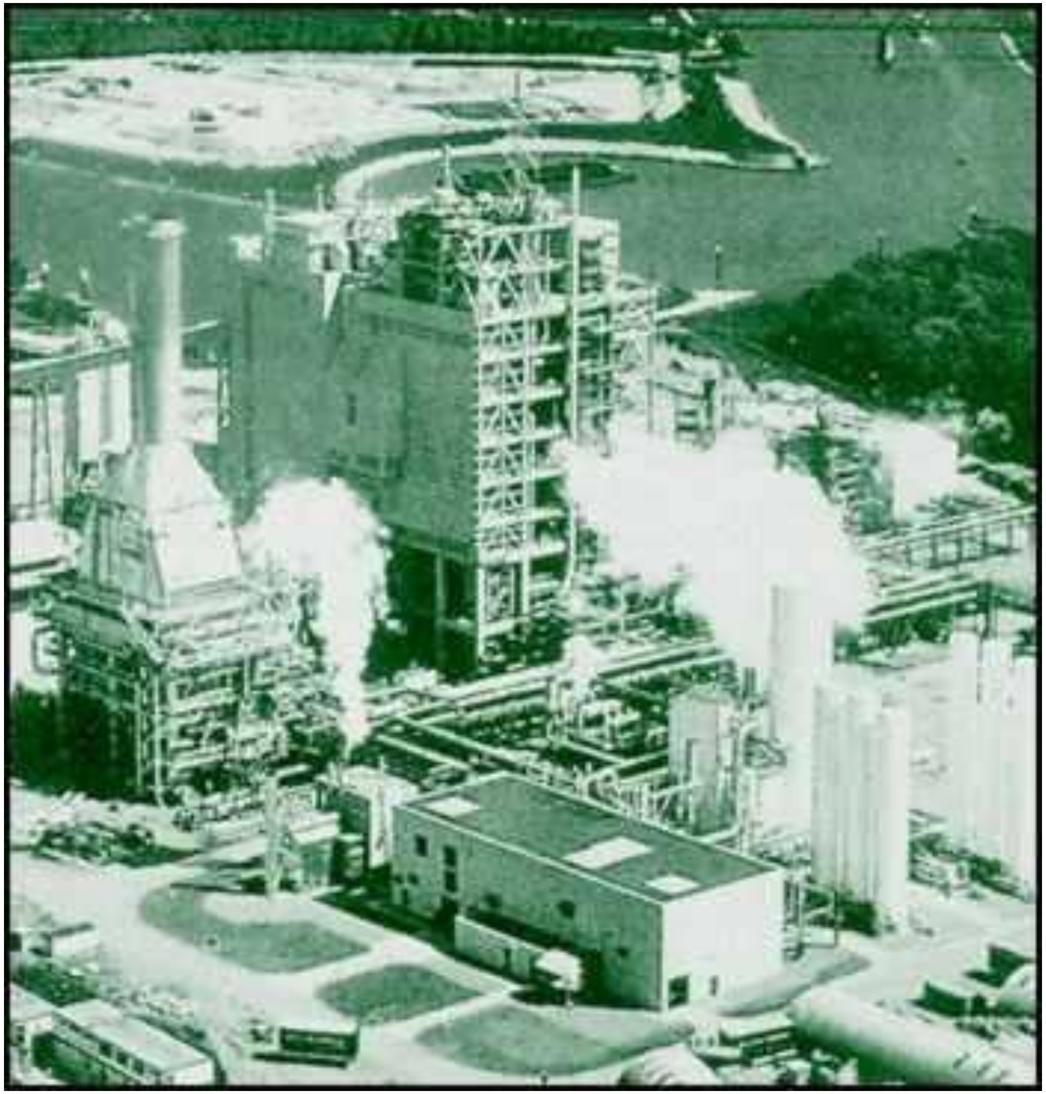
Emission	**Units**		**Units**		**MT/year**
Particulates	mg/kWh	< 6	mg/Nm3	< 1	< 25
SO2	mg/kWh	66	mg/Nm3	12	47
NOX	mg/kWh	250 - 450	mg/Nm3	44 - 80	937 - 1,686
CO2	g/kWh	794	g/Nm3	141	2,975

A Texaco based IGCC power plant: Investment & Cost of Power

Investments of a Texaco based, 500 MW, state of the art IGCC, 85% Load Factor			
Gasification	**million $**	**Combined Cycle**	**million $**
Coal Treatment	19	Gas Turbines	86
Gasifier &	108	Waste Heat Boiler &	127
Sulfur Cooler		Steam Turbines	
Syngas Purifying &	68	Storage & Transport	32
Sulfur Recovery		Support Systems	37
Wastge Water Treatment	10	Common Supplies	65
O2 Production	88		
Total Gasification	293	Total Combined Cycle	347

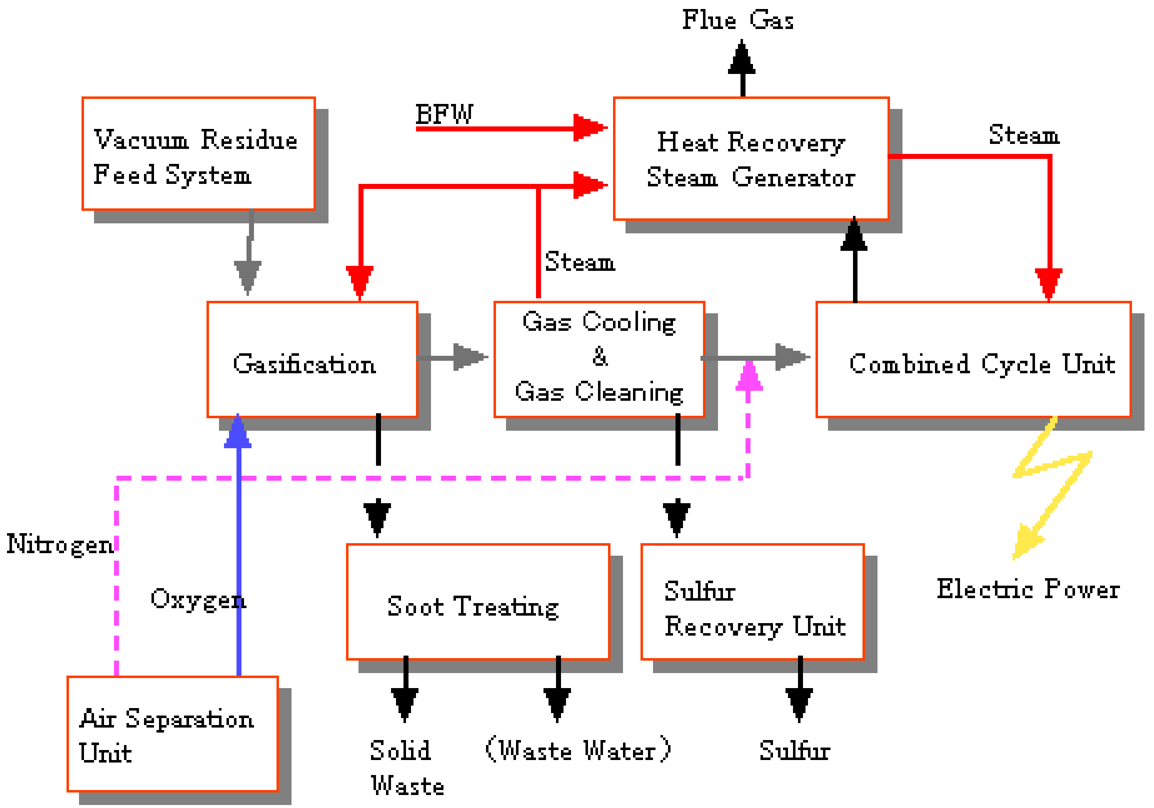
Total Investment	**million $**	**Power Production Cost**	**million $/yr**
Total Gasification	293	Fuel Cost	87.4
Total Combined Cycle	347	O & M Costs	41.6
Bare Cost (BC)	640	Capital Costs	90.3
EPC, 5% of BC	32	Total Costs	219.3
Capital Investment (CI)	672	Net Production, GWh/yr	3,745.3
Fees, 2% of CI	13	Power Cost, $/kWh	0.059
Land & Site, 5% of CI	34	cents/kWh	5.9
Contingencies, 10% of CI	67	mills/kWh	59
Total Plant Cost	786	Real Rate of Return used	10%
Allowance for funds during construction	177	Sensitivity:	
Total Capital Requirement	963	At 5 % rate of return:	
Overnight Cost, $ per kW net	1,915	mills/kWh	49

The first European commercial scale, IGCC power plant at Buggenum, The Netherlands



Where the GT is fired on a gas fuel derived from the gasification of liquid or solid carbonaceous materials, the cycle is known as an Integrated Gasification Combined Cycle (IGCC). An IGCC can convert "difficult" liquid and solid fuels to electricity at high efficiencies and with low emissions.

IGCC for fossil fuel, such as vacuum residue, heavy oil, petroleum coke, coal and Orimulsion



IGCC BLOCK FLOW

Coal Integrated Gasification Humid Air Turbine (IGHAT)

- In conventional gas turbines, more than a third of the power generated in the expander is absorbed to compress the working fluid. This loss of exergy is increased by the requirement for an excess air flow to allow cooling of the turbine components.

- Humid air turbines (HAT) allow for lowering this inconvenient disadvantage in two ways:

  - First, they use intercoolers on a multistage compressor, therefore reducing the power requirement of compression and producing low temperature heat.

  - Secondly, moisture is added to the compressed air (20-40%). Low grade heat is used to produce hot water. This heat is recovered from the compressor intercooler, aftercooler and turbine exhaust.

Coal Integrated Gasification Humid Air Turbine (2)

- When HAT is integrated with a coal gasifier (IGHAT), there is a large amount of heat available from the gasifier and other processes (including air separation plant for oxygen blown gasifiers).

- The hot water is brought into contact with the compressed air in a counter current saturator. Humid air leaving the saturator may have a moisture content of 20% (natural gas HAT) and 40% (IGHAT).

- This is a key stage of the HAT cycle, since the saturator is a multistage column and this heat exchange approaches reversibility. The humid air is further heated against the hot turbine exhaust in the recuperator.

Coal Integrated Gasification Humid Air Turbine (3)

- The variable boiling point working fluid of steam and air avoids the large temperature divergence between the water and turbine exhaust in a gas turbine combined cycle.

- Thus, the moisture addition increases the work output from the turbine, while the intercooling reduces the compressor work requirement.

- This combines to increase the net power output. The IGHAT cycle can achieve efficiencies higher than those of conventional combined cycles, and is especially adapted for base-load electricity production.

- An additional feature of this cycle is that, given the high moisture content of the exhaust gas, it is particularly well-suited for district heating. Biomass can also be used in the IGHAT.

Coal Brayton Cycle Direct Coal-Fired Combustion: DCF, DCFCC (Combined Cycle)

- The research on direct coal firing (DCF) in gas turbines has been carried out for over forty years. The initial difficulties were related to the severe effects of coal ash on turbine blade path components (corrosion, erosion and deposition).

- Latter-day effort on DCF has concentrated on developing high pressure (12-16 bar) slagging coal combustors which allow removal of ash as a liquid prior to entering the turbine.

- The hot gas clean up must take place above the ash melting temperature (1400-1600ºC) and high pressure (at least 18 bar). This high temperature provides additional gains in exergy with respect to other advanced coal cycles, such PFBC or IGCC. The molten ashes accumulate on the edge of the slagging chamber by a centrifugal effect.

Coal Brayton Cycle Direct Coal-Fired Combustion: DCF, DCFCC (2)

- DCFCC (combined cycle) is not yet a proven technology, its state of development being still in the laboratory phase.
- Apart from the slagging combustion system and the liquid ash and contaminants removal, however, all other components of DCFCC (gas turbine, steam cycle, etc.) are commercially available technologies.
- A study carried out by Westinghouse/Gilbert-Commonwealth Inc. in 1990 investigated the economics of DCF gas turbines fitted with slagging combustion technology.
- The study concluded that the cost of electricity from this plant type could be 11-18% cheaper than a comparable 220 MW_e pulverised coal boiler fitted with FGD.

Coal Brayton Cycle Direct Coal-Fired Diesel

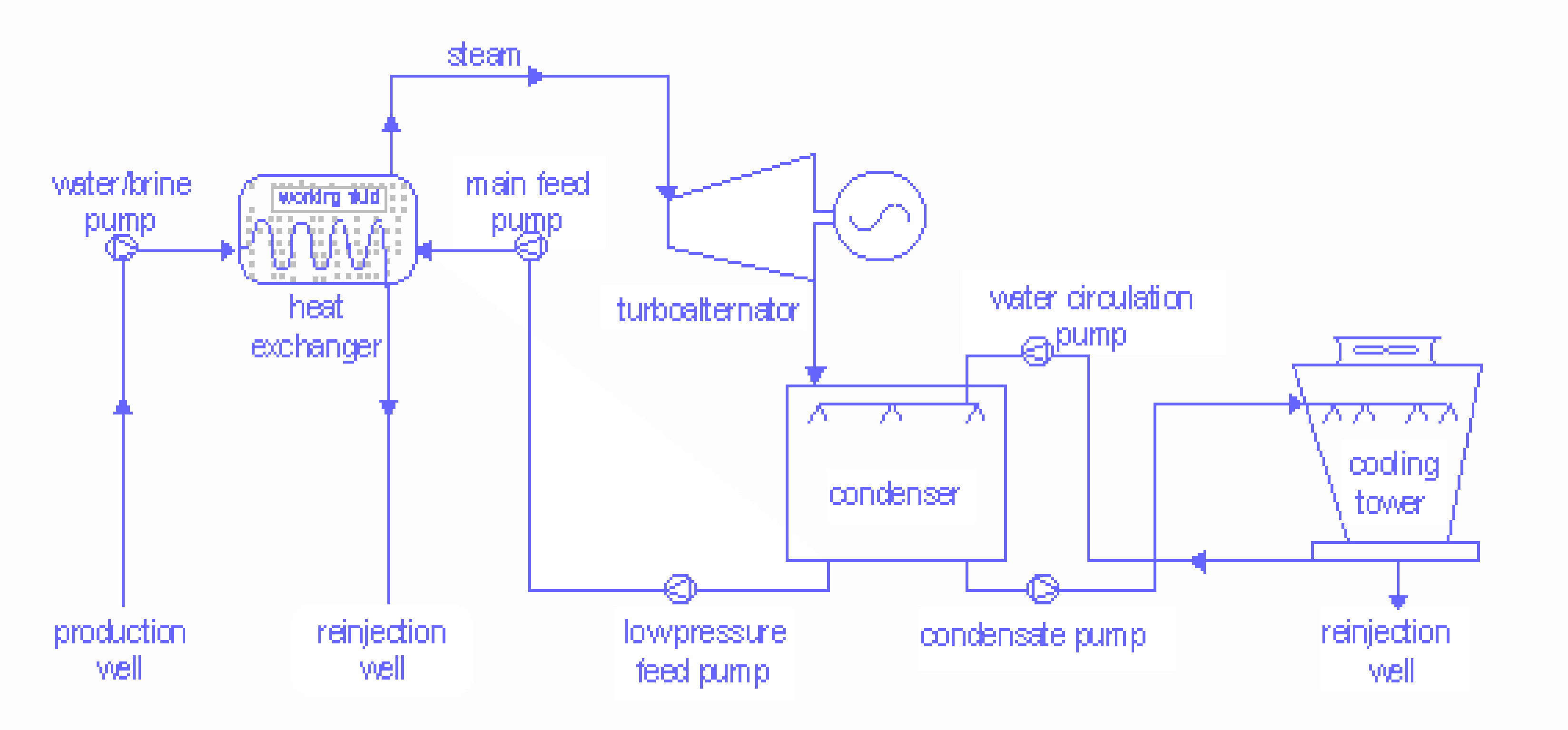
- Fuels such as orimulsion or refinery bottoms can yield substantial cost savings for large diesel engines.
- The technology challenge is how to use these abrasive fuels when injecting coal water slurry directly into a diesel engine cylinder.
- The technology is still under study.

Geothermal Liquid Dominated Binary Plant Kalina Cycle

- This plant is estimated to be up to 40-50% more efficient than existing standard binary Rankine cycle geothermal power plants.
- The **Kalina cycle** uses an ammonia-water mixture(85-15 % by weight) as the working fluid and takes advantage of regenerative heating.
- Binary plants are usually sized in 10 MW modules.
- The ammonia-water mixture has a low boiling point, therefore, the excess heat coming from the turbine's exhaust can be used to vaporize a substantial portion of the working fluid.
- The Kalina cycle would therefore transfer substantially less heat to the environment. An efficiency improvement would also mean that more electricity is being produced per pound of brine.

Geothermal Liquid Dominated Binary Plant Kalina Cycle (2)

Schematic diagram of a binary cycle plant



Geothermal Liquid Dominated Binary Plant Kalina Cycle (3)

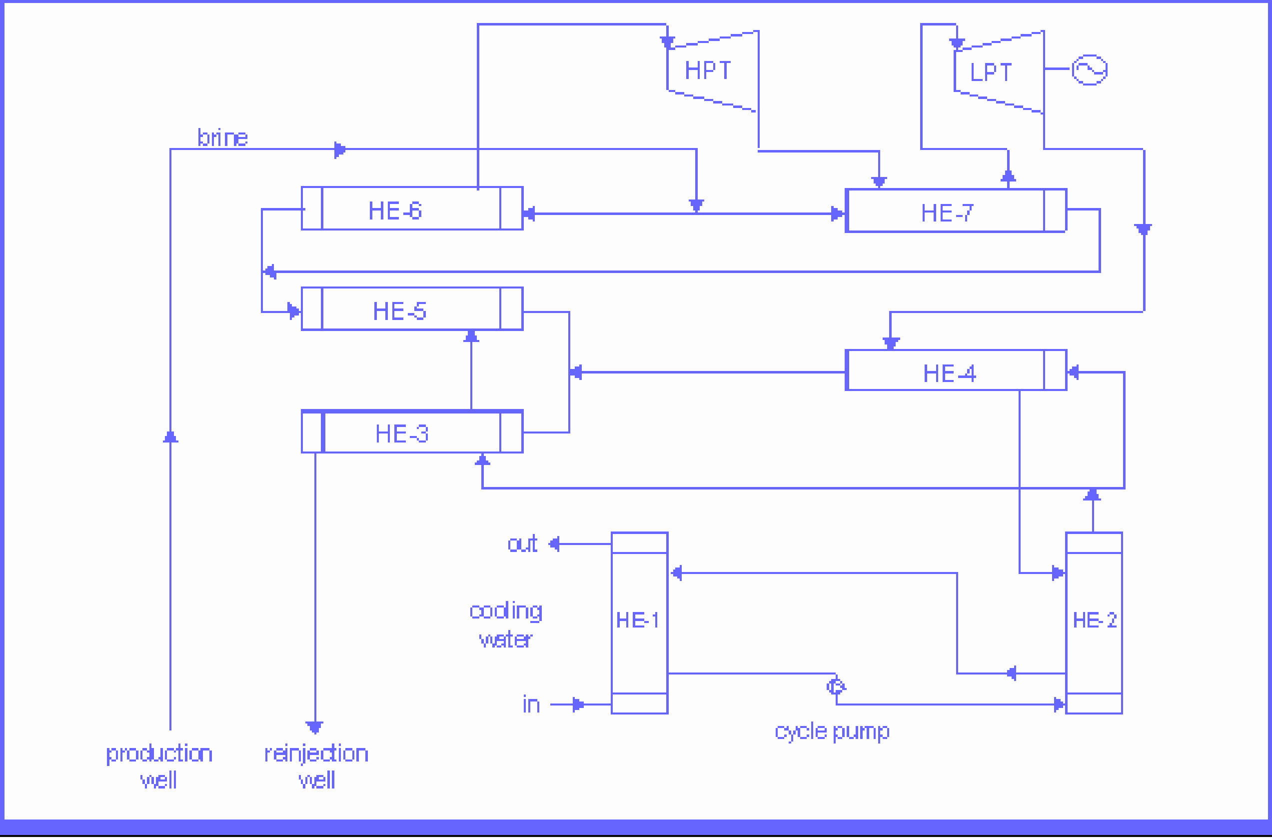
- The hot brine from the geothermal well is used firstly to both superheat and reheat the working fluid and then to evaporate and preheat it before being reinjected into the ground.

- The working fluid, in superheated condition, is expanded through the H.P.turbine stages and then reheated before entering the L.P.turbine stage. After the second expansion, the saturated vapour moves through a recuperative boiler before being condensed in a water cooled condenser.

- The two recuperative heat exchangers (HE-4 and HE-2) provide approximately 38% of the total heat transferred to the working fluid, thus improving net brine effectiveness (higher kWh/kg brine). Standard steam turbines are used because ammonia and water are similar (M.W. of 17 and 18).

Geothermal Liquid Dominated Binary Plant Kalina Cycle (4)

Schematic diagram of a Kalina cycle plant (with regenerative heating)



Municipal Solid Waste **RDF Co-Firing (e.g. 20% coal)**

- Municipal solid waste (MSW) is one of three major waste-to-energy technologies (the others are anaerobic digestion and biomass).
- MSW can be directly combusted in waste-to-energy facilities: (1) as a fuel with minimal processing, known as mass burn; (2) it can undergo moderate to extensive processing before being directly combusted as refuse-derived fuel (RDF); (3) or it can be gasified using pyrolysis or thermal gasification techniques.
- Each of these technologies presents the opportunity for both electricity production as well as an alternative to landfilling or composting the MSW.

Municipal Solid Waste RDF Co-Firing (2)

- In contrast with many other energy technologies that require fuel to be purchased, MSW facilities are paid by the fuel suppliers to take the fuel (known as a "tipping fee").

- The tipping fee is comparable to the fee charged to dispose of garbage at a landfill.

- Refuse-derived fuel (RDF) typically consists of pelletized or fluff MSW that is the by-product of a resource recovery operation. Processing removes ferrous materials, glass, grit, and other materials that are not combustible. The remaining material is then sold as RDF. Both the RDF processing facility and the RDF combustion facility are located near each other, if not on the same site.

Municipal Solid Waste RDF Co-Firing (3)

- The RDF can then be used in one of several configurations: (1) dedicated RDF boilers designed with traveling grate spreader-stokers; (2) co-firing of RDF with coal or oil in a multi-fuel boiler; and (3) dedicated RDF fluidized-bed boiler.

- In 1998, a 10.5 MW commercial RDF facility in the City of Commerce, California, was operated by the Los Angeles County Sanitation District.

- RDF is now a successful technology in a number of locations where dedicated boilers were selected rather than attempting to co-fire with other fuels. Currently there are 26 RDF plants working in the US processing some 27,000 tpd of RDF (Kiser & Zannes, 2000).

Municipal Solid Waste RDF Co-Firing (4)

ILLUSTRATION: APWA, 1961

Batch-Type Incinerator Design

Traveling Gate Incinerator Design

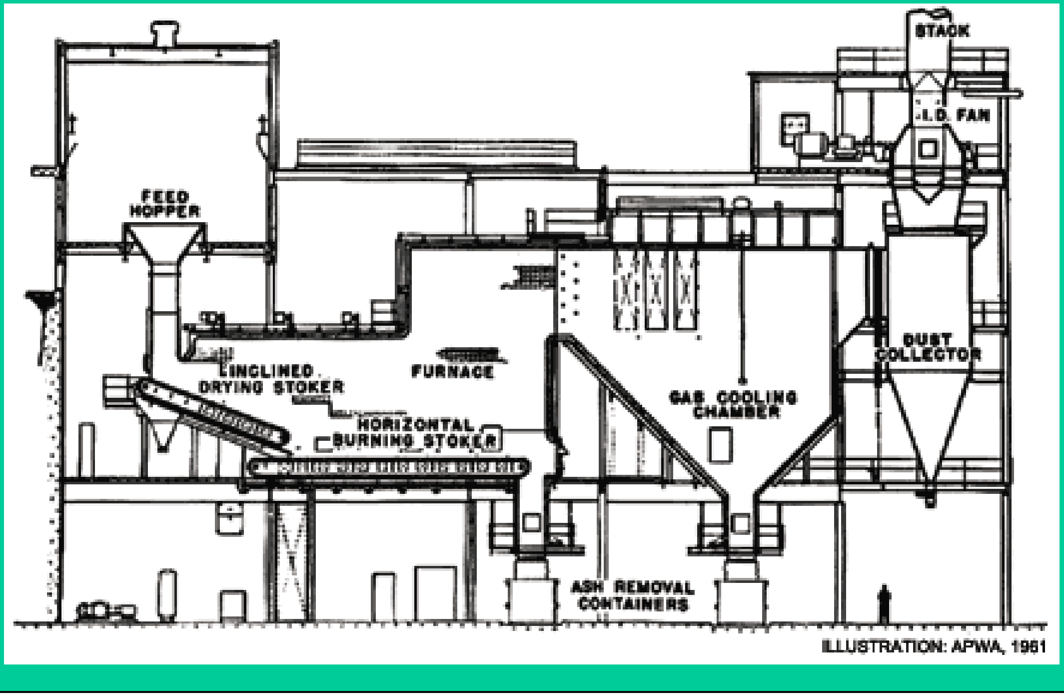


ILLUSTRATION: APWA, 1961

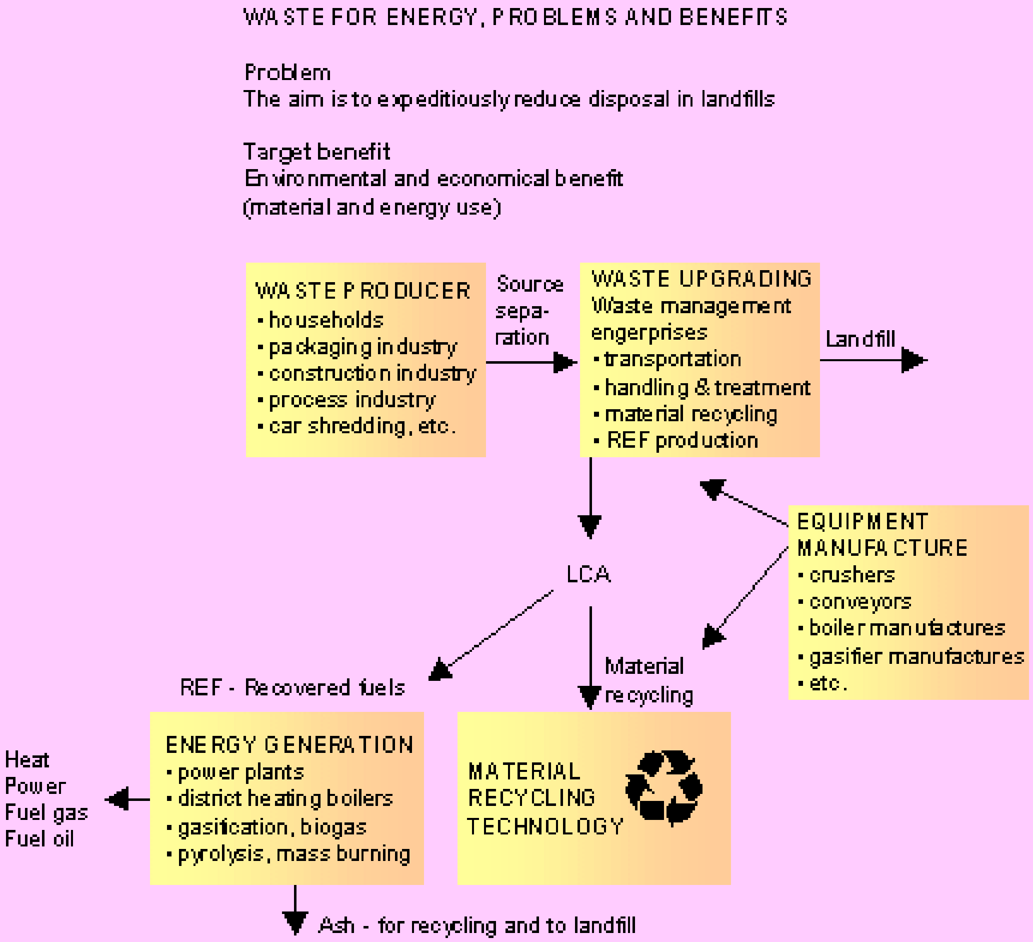
Municipal Solid Waste Gasification (Pyrolysis/Thermal)

- **Pyrolysis** is the thermal decomposition of organic material at elevated temperatures in the absence of gases such as air or oxygen. The process, which requires heat, produces a mixture of combustible gases (primarily methane, complex hydrocarbons, hydrogen and carbon monoxide), liquids and solid residues.

- **Thermal gasification** of MSW is different from pyrolysis in that the thermal decomposition takes place in the presence of a limited amount of oxygen or air. The producer gas which is generated can then be used in either boilers or cleaned up and used in combustion turbine/generators.

- The primary area of research is the scrubbing of the producer gas of tars and particulates at high temperatures in order to protect combustion equipment and still maintain efficiency.

Waste-to-Energy Problems and Benefits



WASTE FOR ENERGY, PROBLEMS AND BENEFITS

Problem
The aim is to expeditiously reduce disposal in landfills

Target benefit
Environmental and economical benefit
(material and energy use)

WASTE PRODUCER
- households
- packaging industry
- construction industry
- process industry
- car shredding, etc.

Source separation

WASTE UPGRADING
Waste management engerprises
- transportation
- handling & treatment
- material recycling
- REF production

Landfill

EQUIPMENT MANUFACTURE
- crushers
- conveyors
- boiler manufactures
- gasifier manufactures
- etc.

LCA

REF - Recovered fuels

Material recycling

ENERGY GENERATION
- power plants
- district heating boilers
- gasification, biogas
- pyrolysis, mass burning

MATERIAL RECYCLING TECHNOLOGY

Heat
Power
Fuel gas
Fuel oil

Ash - for recycling and to landfill

Cogeneration Stirling Engines

- Stirling engines have been around for a long time, but only in small quantities and specialized applications. Therefore, performance data on Stirling engines is difficult to obtain.

- STM Power (formerly Stirling Thermal Motors) has a 25 *kW* unit with current electrical efficiency of approximately 30%, though the goal is to increase this efficiency to greater than 34% with more development.

- Other companies report electrical efficiencies in the range of 25 to 30%. Overall, the electrical efficiency of current Stirling engines is in the range of 12 to 30%.

Cogeneration Stirling Engines (2)

- The heat from your ST-5 powered electricity generating system can be recovered and used in a number of ways for space and domestic water heating.

- Electricity is generated by attaching a 4kW AC alternator to the ST-5. The engine has been sized to provide up to 3.5 kW of electricity, enough to take the surge loads of induction motors used in washing machines and other domestic appliances. One option would be to run the engine for 4 to 6 hours a day, during which period high and intermediate draw appliances - washing machine, freezers and power tools - can be used. At the same time, a bank of batteries can be charged to provide electricity for domestic lighting and other small load equipment when the engine is not operating.

Cogeneration Stirling Engines (3)

25-kW Dish-Stirling System (Boeing)- Hydrogen/Helium

10-kW Solar Dish-Stirling System

Cogeneration Fuel Cell Cogenerators

- Fuel cell cogenerators are an environmentally friendly, safe, efficient and highly reliable source of electricity.

- Operate without the usual infrastructure that all utilities use to distribute electricity.

- Being able to supply an uninterrupted flow of electricity, without power lines and free from outages caused by storms and other acts of nature is a big plus for utilities, especially when serving customers in rural and remote locations.

- The fuel cell systems store hydrogen as a compressed gas or, at lower pressures in metal hydride powders, or is derived from conventional fuels such as natural gas or propane. Oxygen is drawn from the air.

Cogeneration Fuel Cell Cogenerators (2)

NOT YET COMMERCIALLY AVAILABLE POWER GENERATION TECHNOLOGIES

Discussed Previously in Solar, Ocean & Fuel Cells

- *Solar Thermal Electric* Central Receivers
- *Solar Thermal Electric* Parabolic Dishes
- *Solar Photovoltaic* Utility-Scale Systems (e.g. IHCPV)
- *Ocean Energy* Tidal Energy
- *Fuel Cells* Phosphoric Acid (PAFC)
- *Fuel Cells* Proton Exchange Membrane (PEMFC)
  - Direct Methanol
- *Fuel Cells* Molten Carbonate (MCFC)
- *Fuel Cells* Solid Oxide (SOFC)
  - SOFC-GT Hybrid