Slag Removal/Char Recovery - separates dissolved gases from the raw gasifier slag. Also separates char from the slurry produced in gas cooling. Overhead gases and char are used to generate steam. Wet slag is sent to slag/ash disposal.

Slag/Ash Disposal - combines wet slag, bottom ash from steam generation and dusty liquor from flue gas cleanup. Dewatered slag/ash mixture is suitable for landfill disposal. Wastewater is used for preparation of coal slurry for coal gasification.

Sulfur Recovery - processes the acid gas stream produced during hydrogen sulfide removal, converting H_2S to elemental sulfur. Process technology employed is usually Claus (bypass type configuration).

Steam Production - uses char, purge and overhead gases, along with supplemental coal to provide plant steam/power requirements.

Flue Gas Clean-up - renders steam generation product gases environmentally acceptable for stack discharge to atmosphere.

IV. Gasification Technology

The gasification of coal began in the early 1850's when it was discovered that the gas could be burned more efficiently than solid coal and it was cleaner and easier to use. The technology developed fast and by the 1850's gas light for streets in London was commonplace. Between 1935 and 1960 there were close to 1,200 municipal "gasworks" serving larger towns and cities in the U.S. However the introduction of natural gas pipelines in the 1930's initiated the decline and almost disappearance of coal gasification in the U.S. With the increased cost of natural gas, interest in coal gasification has been renewed.

Numerous processes are now being developed to gasify coal, the most abundant hydrocarbon resource in the U. S., to low-, medium- and high-BTU gas. In the gasification process coal is reacted with a mixture of steam and air or steam and oxygen. With the former, a low-BTU gas is produced with a heating value between 100 to 200 BTU/scf.[15] This low BTU gas is made up of nitrogen, carbon monoxide, hydrogen, carbon dioxide and water.[22] This gas has a low BTU content because it contains a large portion of nitrogen (since air contains 80 percent nitrogen) which dilutes the energy content of the carbon monoxide and hydrogen produced. If the coal is mixed with steam and oxygen a medium BTU gas is produced consisting of carbon monoxide, hydrogen, carbon dioxide and methane, which has a heating value between 250 and 400 BTU/scf.[15] High BTU gas (or synthetic natural gas (SNG)) with a heating value of 970 BTU/scf can be produced from medium BTU gas by methanation or hydrogen removal.[29,30]

There are several factors such as thermal efficiency, reliability, capital investment, coal flexibility and product spectrum which are important and should be considered when comparing gasifiers. Table 2 shows some of these comparisons for different gasification systems. For instance thermal efficiency is important from a processing view. To achieve maximum efficiency a gasifier should have low oxygen and steam demands, low unburned carbon and heat losses, and should operate at high temperatures.[14] However, since some of these factors are not compatible with others, it is almost impossible to obtain a gasifier which optimizes each factor. For example high oxygen requirements (lower efficiency) are necessary to obtain high carbon conversions (higher efficiency) and to avoid large by-product formations (lower capital investment).[14] In addition, elevated pressures (high efficiency) produce more by-products[15] and interfere with reliability[14] but reduce raw gas compression requirements. Other desirable factors are high temperatures which reduce by-products and increase coal flexibility and capacity.[14] In general then, it is apparent that there is a trade off between efficiency and some of these other factors. The best gasifier will be that process unit which optimizes the majority of these factors while achieving the highest efficiency.

Before discussing the individual gasifier types it is helpful to examine the properties of coals used in the U.S. There are four properties of coal which are important in the process selection of gasifiers: 1) ash fusion temperature, 2) free swelling index (FSI), 3) moisture, and 4) sulfur content. The ash fusion temperature is that temperature at which the ash becomes fluid. FSI is a measure of a coal's tendency to agglomerate or cake when heated; the higher the FSI, the greater the agglomeration.

Eastern coals (predominantly bituminous) typically have low fusion temperatures (1990-2200°F), moderate to high FSI, low moisture (4-10 percent by weight as received) and high sulfur (3-5 weight percent). Western coals (mainly subbituminous) exhibit high fusion temperatures (2300-2400°F), low FSI, high moisture (28 weight percent) and low sulfur (0.3-0.5 weight percent). Lignite, which is found predominantly in North Dakota, has an even higher moisture content (35 weight percent) and a lower percentage of sulfur (0.2 weight percent).

Coal gasifiers are classified according to the way coal is fed to them. The three main gasifier categories are the fixed or slow moving bed, the fluidized bed and the entrained bed. Tables 3 and 4 show a list of coal gasifiers by type and Table 5 summarizes the advantages and disadvantages of the three different types of gasifiers.

A. Fixed or Slow Moving Bed

Fixed or slow moving bed gasifiers consist of beds that carry or move the coal vertically downward through the zone where it is heated and decomposed. These gasifiers can be further divided

Table 2

Comparison of Gasification Systems

Name	Lurgi	BGC-Lurgi	Winkler	Koppers-Totzek	Texaco	Shell-Koppers
Bed Type	Fixed	Fixed	Fluid	Entrained	Entrained	Entrained
Commercial	Yes	Near	Yes	Yes	Near	Near
Coal Flexibility	Western	Western	Western	All	All	All
By-Product	Yes	Yes	No	No	No	No
Efficiency(%)	64	72	57	58	68-72	75
Capacity (STPD Coal)	500	1,250	1,000	850	2000	1,000

Table 3

Coal Gasifiers

	Pressure	Oxygen or Air	Agglomeration Prevention
FIXED OR SLOW MOVING BED			
		Dry Ash, Single Stage	
Gegas	To 500 psig	Air	Stirrer paddles
Lurgi	To 450 psig	Oxygen or air	Rotating blades
Merc	To 105 psig	Air	Spiraling stirrer
Riley-Morgan	40 in water	Air	Agitator in rotating bed
Wellman-Galusha	10 in. water	Air	Spiraling arms
Wilputte	atm	Air	Rotating arm
		Dry Ash, 2-Stage	
ATC/Wellman	atm	Air	None
FW/Stoic	atm		None
Ruhr-100	1,500 psig	Oxygen	Stirrer blades
Woodall-Duckham	40 in. water	Air or oxygen	None
		Slagging	
BGC/Lurgi	To 400 psig	Oxygen	Stirrer
Gferc	To 400 psig	Oxygen	Stirrer
FLUIDIZED BED			
Winkler	atm	Oxygen or air	
Rheinbraun	150 psig	Oxygen	
CO_2 acceptor	150 psig	Air	
Hygas	1,200 psig	Oxygen or air	
Synthane	1,000 psig	Oxygen	
Westinghouse	225 psig	Air	
U-gas	350 psig	Oxygen or air	
Cogas	10 psig	Air	
EDS (Exxon)	500 psig	None	
ENTRAINED FLOW			
		Single-Stage	
Bell HMF	to 225 psig	Air	
Koppers-Totzek	10-12 psig	Oxygen and steam	
Mountain fuel	to 150 psi	Oxygen and steam	
Shell-Koppers	to 450 psi	Oxygen or air	
Texaco	to 1,200 psig	Oxygen or air	
Bi-gas	To 1,500 psig	Syngas and steam	Oxygen and steam air
C-E	atm	Syn gas and air	Air and steam
Foster Wheeler	atm	Syn gas and steam	Air and steam
Peatgas	To 500 psig	Syngas	Oxygen and steam
Rockwell Int'l	To 1,500 psig	Hydrogen	Not known

Source: Institute of Gas Technology[29], Oil and Gas Journal, 7/16/81, pg. 57

Table 4

Coal Gasification Process Technology Status

Gasifier	Technology	Process Status	Location
Fixed Bed			
Lurgi, Dry Ash	1st Generation	Commercial	Worldwide
British Gas/Lurgi Slagging	2nd Generation	Semicommercial	Westfield, Scotland
Wellman Galusha	1st Generation	Commercial	14 operating in U.S. others outside U.S.
KilnGas	2nd Generation	Pilot (1971-)	Oak Creek, Wis.
Fluidized Bed			
Winkler	1st Generation	Commercial	Worldwide
U-GAS	2nd Generation	Pilot (1974-)	Chicago, IL
Westinghouse	2nd Generation	PDU (1975-)	Waltz Mill, PA
Entrained Flow			
Koppers-Totzek	1st Generation	Commercial	Worldwide
Texaco	2nd Generation	Pilot	Montebello, CA Mussel Shoals, Ala. & outside the U.S.
Combustion Engineering	2nd Generation	PDU (1974-)	Windsor, Conn.
Shell-Koppers	2nd Generation	Pilot	W. Germany

[15] Source: Oil & Gas Journal; June 29, 1981, pg. 106.

Table 5

Gasifier Characteristics

Fixed Bed Gasifier	Fluidized Bed Gasifier	Entrained Bed Gasifier
Advantages		
Extensive practical experience	Uniform temperature and compositions throughout fluidized zone	Highest capacity per unit volume
High carbon conversion efficiency	Excellent solid-gas contact	Produces inert slagged ash with low carbon content
Low temperature operation	No internal moving parts	Product gas free of tars and phenols
Large fuel inventory provides safety, reliability and stability	Can handle wide variety of coals Large fuel inventory provides safety, reliability, and stability	Handles all types of coal No moving parts and has simple geometry
Limitations		
Sized Coal required	Distributor plate design is critical	Less developed than fixed bed
Coal fines must disposed of or handled separately	Requires dry coal for feeding	Critical design areas include combustor nozzles and heat recovery in presence of molten slag
Product gas contains tars and heavier hydrocarbons		Smallest fuel inventory; requires advanced control techniques to ensure safe reliable operation
Lowest capacity due to limited gas-flow rates	Removal of fines required to prevent elutriation or flow instability	
Internal moving parts with higher degree of mechanical complexity	Fluidization requirements sensitive to coal characteristics	
Caking coal technology not commercially proven		

Source: Oil and Gas Journal, June 29, 1981, pg. 101.[15]

into two types which describe the flow of air in them: updraft and downdraft.

The simplest air gasifier is the updraft or countercurrent gasifier which introduces air at the bottom of the furnace where it first comes into contact with the hottest temperatures of the reactor. Since the combustion gases immediately enter a zone of excess char, any carbon dioxide or water present is reduced to carbon monoxide and hydrogen by the excess carbon. In addition to producing the desired products, carbon monoxide and hydrogen, these hot gases contain large amounts of tars, phenols, cresols and other oxygen containing organic compounds. As the gas rises its temperature decreases as heat is transferred from the hot gas to the cooler incoming coal. This low temperature hinders the oxidation of the coal and is the major cause of the by-products produced.[22]

One of the problems caused by these by-products (chemicals, oils and tars), is that they condense in the cooler regions, causing maintenance problems. In addition, these components contribute to the majority of environmental problems associated with fixed bed gasification systems.[18]

The downdraft gasifer is specifically designed to eliminate the tars and oils associated with the updraft gasifer. Tars and oils are formed near the middle of the bed (where air is injected) and carried by the airflow through a relatively large hot zone in which they have time to further decompose or be cracked to simpler gases or char. One of the important results of this cracking is that an effect called "flame stabilization" occurs which maintains the temperature range between 800°C to 1000°C. When the temperature rises, endothermic reactions predominate, causing the gas to cool; when the temperature drops, the exothermic reactions predominate, thus heating the gas.[22]

The tars and oils are reduced to less than 10 percent of the amount produced in updraft gasifiers thereby making gas clean-up easier and less expensive. Since the gas velocities are low in both updraft and downdraft gasifiers, the ash settles through the grate so that very little is carried with the gas.[22]

One example of a moving bed gasifier is the Lurgi gasifier which is commercially available through Lurgi Kohle and Mineraloeltechnik. In the Lurgi process, coal is fed into the gasifier via automatically operated coal locks. As the bed of coal moves from the top to the bottom of the gasifier it comes in contact with a counter-current hot gaseous mixture of oxygen and steam introduced at the bottom which successively dries, devolatilizes and gasifies the coal. The partial oxidation of the coal with oxygen supplies the necessary heat for the coal gasification while the addition of steam prevents the temperature from rising above the ash fusion (or melting) point. The ash left after gasification is removed by a rotating grate at the bottom of the gasifier.

As shown in Table 3, the Lurgi "dry-ash" fixed bed gasifier is a first generation unit which has been commercially proven and is used worldwide.[14,15] The Sasol I plant in South Africa which has been operating for over 25 years utilizes the Lurgi gasifier (and also the Fischer-Tropsch synthesis unit) to produce 10,000 barrels per day of fuel. (It and Sasol II are the only existing commercial-size coal-liquefaction plants in the world.) The Dunn Nakota project, which is hoping to produce 85,000 barrels per day of methanol by 1987 via Lurgi gasification, could be the largest commercial-scale coal gasification process built in the U.S.[31] The main disadvantages of the Lurgi gasifier are that it 1) has problems with the caking eastern coals, 2) produces byproducts, 3) has high steam requirements and 4) has a low capacity per volume of gasifier (i.e., high capital cost).

The BGC/Lurgi slagging gasifier is a second generation reactor which is now being tested in Scotland by Lurgi and British Gas Corp with support from 13 U.S. companies and DOE.[30] In this gasifier, coal is fed into the top of the unit by a distribution system. As the coal descends in a moving bed, it is successively dried, devolatized and gasified. At the bottom of the gasifier oxygen and steam are fed and slag is withdrawn. The operating pressure is 300-350 psig with a gas temperature of 800-1100°F and an ash temperature over 2000°F so the slag can be removed in a molten form.[1] Because it does operate in the slagging mode it can tolerate a higher throughput of coal and oxygen without entraining coal dust in the product gas.[16]

The latest papers describe this technology as near commercial.[14,15] Its improvements over the older Lurgi dry-ash gasifier are a higher efficiency and a reduction in steam use. However, it still has problems with caking eastern coals and still produces by-products.

B. <u>Fluidized Beds</u>

Over the last 60 years fluidized beds have been developed to provide uniform temperatures and efficient contact between gases and solids. This is accomplished by blowing gas upward through a bed of solid coal so rapidly that the bed becomes suspended and churns as if it were a fluid. Fluidized reactors are more compact because they have a higher throughput (due to higher reaction rates), but the higher velocity of the gas carries out ash and char with it that must be removed by cleaning the product gas. The fluid bed often contains limestone to react with and remove the sulfur from the coal. Fluidized bed reactors have a considerably faster heating rate than moving bed gasifiers and, therefore, the reactor temperature must be held below the softening or initial deformation temperature of the coal ash which is typically well below 1040°C. However, at this temperature many undesirable by-products are stable and the churning of the bed enables materials at all stages of decomposition to be found throughout the bed. Because of this contact, tars and oils have a tendency to escape from the heating zone before they can be fully decomposed. This removal and disposal of these by-products can pose a number of environmental problems for the fluidized reactor. Claims that they can produce very low tars and char with recirculation still remain to be proven.[22] Since typical operating temperatures are low with respect to the ash melting temperature of coals, the fluid-bed gasifier also has problems with eastern coals.

The Winkler fluid-bed gasifier is a first generation unit which is commercially proven and used around the world.[15] According to DM International over 70 Winkler gasifier have been built.[8] The two main disadvantages with the Winkler are that it operates at atmospheric pressure (large volume per throughput) and that it has a tendency to clog when using eastern coals. A pressurized modification of the Winkler is now under development which should improve its efficiency.[8,14]

In the two designs of lignite gasification that will be reviewed in this study, modified Winkler gasifiers have been used. In both cases the modified Winkler operates at a higher pressure (65 psig) than the established Winkler which operates at atmospheric pressure (14.7 psig). The lignite is dried from 35 percent moisture to 8 percent and is then continuously fed by a pressure lock and screw conveyor system into the Winkler gasifier where it is maintained as a fluid bed at 65 psig. Steam is injected near the bottom of the reactor to fluidize the coal and to cool the larger ash particles discharging from the gasifier bottom while steam and oxygen are injected at several points within the bed to gasify the coal. Since the gasifier operates at high temperatures (1800-1900°F), tars, oils, gaseous hydrocarbons and carbon present are converted to carbon oxides and hydrogen. Only a small percentage of methane is left in the raw gas product. In the fluidized bed, heavier particles such as ash fall down through the bed into the char discharge, while lighter particles are carried out of the bed by the product gas. In the Winkler gasifier approximately 70 percent of the total char is entrained in the hot product gases leaving the top of the reactor.

This modified Winkler is still being tested and therefore it cannot be considered to be commercially proven. However, since Davy McKee believes that this design contains equipment similar to other high pressure units, they feel that the gasifier is feasible and are therefore prepared to offer commercial guarantees.

C. Entrained Bed

The entrained bed gasifier, which dates back to the 1950's, is the most recently developed gasifier. In the entrained bed gasifier fine particles of coal are suspended in a stream of oxygen which moves rapidly into and through the decomposition zone. The entrained bed gasifier is typically operated at a temperature above the melting point of the coal ash. At this temperature, which is typically 1260–1316°C, the gasification reaction rates are much faster and many of the undesirable by-products associated with the fixed bed and the fluid bed systems are unstable and are destroyed. When the entrained bed gasifier is operated at pressures substantially above atmospheric, high throughput and high single pass conversion can be obtained. One drawback is that the feedstock must be reduced to a relatively small size which would add to the total preparation cost. However, there is a tradeoff since the smaller particles are more efficiently gasified.

These gasifiers are also called "slagging" because they remove the ash in a molten, slag form. One of the big advantages of entrained bed gasifiers is that they can utilize any type of coal. As shown in Table 4, Koppers-Totzek, Texaco and Shell-Koppers are all entrained-bed gasifiers.

In the Koppers-Totzek gasifier pulverized coal is horizontally injected with steam and oxygen into the reactor which is essentially operating at atmospheric pressure. The gasification temperature is around 2700°F. At this high temperature, the ash is in a molten slag form which drops into a quench tank and is removed.[1]

The Koppers-Totzek gasifier is a first generation technology which, like the Winkler and Lurgi, has had extensive commercial experience and therefore is considered proven and available technology.[20,14,15]. Five of the 24 proposed projects submitted to the Synthetic Fuels Corporation plan to use Koppers-Totzek gasifiers which would seem to confirm its reliability. It will handle all types of coal but does require large raw gas compressors since it operates at atmospheric pressure.

The Texaco gasifier is a coal-slurry fed, high-capacity gasifier which handles all types of coals and produces very little by-product. The slurry which is composed of pulverized coal and water is pumped with oxygen into the top of the high-pressure (600–700 psig) gasifier and fired downwards. The product gas is withdrawn through a side nozzle at a temperature around 2500°F. The molten slag is removed through a slag hopper beneath the quench chamber.[1]

Since the coal is fed in a water slurry the coal does not have to be dried. This can be a big advantage over gasifiers (predominantly for western coals) which use part of their coal to dry the rest of the feedstock. Drying is expensive, it reduces efficiency and it raises operating costs.

The high operating pressure is also an advantage since the synthesis gas must be fed at even higher pressures to the methanol unit. Although the operating cost for high pressure may be higher, it more than makes up for the high cost of compressors needed with low pressure gasifiers.

However, in order to have good efficiency the solid content of the slurry feed must be high, 50-60 percent. When lignite is slurried with water, the highest untreated solid concentration is about 43 percent because lignite naturally contains up to 35 percent moisture. If the lignite is pretreated, the moisture content can be lowered to more efficient levels.[9] The drawback is that pretreatment is an added cost to production, (although not too large).

Another disadvantage of the Texaco process is that it requires more oxygen than most of the other processes.

Although the Texaco gasifier has not yet been used on a commercial scale it has been extensively tested at a pilot plant in Montebello, California[1] and at three demonstration plants: the Ruhrchemie/Ruhrkohle plant in Oberhausen, West Germany; 2) Tennessee Valley Authority's ammonia-from-coal plant in Muscle Shoals, Alabama; and 3) an air blown gasification plant at a chemical facility in the USA.[17] Texaco appears to be the leading second generation technology and being planned for two projects already underway: Tennessee Eastman's project in Kingsport, Tennessee to produce acetic anhydride and other chemicals from methanol made from coal, and Southern California's Cool-Water power generation station in Daggett, California.[15]

The Shell-Koppers gasifier is very similar to the Texaco gasifier in that it can also use any coal and produces very little byproduct. However, it is likely that the process will not be commercialized for a couple of years since only limited data is available on a 150 ton per day demonstration plant.[14]

One of the gasifiers that was used in the design studies to be reviewed later was a Foster-Wheeler entrained bed gasifier. This gasifier unit consists of two stages. In the second which is an entrained gasifier operating at 300-400 psig and 1700°F, transport gas from stage one and pulverized raw coal are introduced yielding slag and the product gas. The char which is removed from the product gas is then sent with steam and oxygen to the first stage producing the transport gas which is recycled to the second stage.[1] As of 1977 the Foster-Wheeler gasifier was in the early stages of pilot plant development.[1]

The gasifier used by Badger was a version of an entrained bed gasifier.[4] According to Badger this gasifier is operated in an oxygen-blown mode with a molten slag-bath at the bottom. The gasifier has a total of 14 feed nozzles; 6 for coal and lime, 6 for oxygen and steam, and 2 for recycled char. The nozzles, which are distributed around the periphery of the vessel, fire tangentially and at a 45 degree angle toward the surface of the slag to make it rotate. Dense-phase pulverized coal and lime are pneumatically fed into the lower section of the gasifier which operates at 500 psig. The lime is a fluxing agent which is added to obtain a slag viscosity of 10 poise. The oxygen and superheated steam are added as gasifying agents. The coal, which is partially pyrolized in the reaction, is gasified at 3000°F.

The advantages that are claimed in the literature for this gasifier are that it can handle any type of coal and that the raw gas is free of tar and high boiling hydrocarbons. When Badger compared dry and wet (slurry) feeding they found that dry feeding was economically superior to the slurry feed because the slurry feed required 29 percent higher coal feed and a 73 percent higher oxygen feed for a given synthesis gas, and therefore methanol, rate. Badger also found that a steam-oxygen gasification medium produces the highest thermal efficiencies ([4] pg. 64,65).

According to Badger "this single shaft high pressure slag-bath gasifier is based on published information for entrainment and other types of gasifiers and for the Rummel/Otto Gasifier which is proven at atmospheric pressure. It is a new concept and further development work may be necessary. Similar gasification principles have been studied and pilot plant tests have been conducted at lower pressures. Mechanical problems are recognized and are believed to be solvable".[4]

Until recently, industry has been very sluggish in its progress to reimplement coal gasifiers in the U.S. However, the increasing cost of natural gas has sparked a new interest in coal gasification and the majority of the coal or shale-based synthetic fuel projects currently being planned use coal gasification.[31] Table 6 lists some of the current projects which are now planned or proposed.

One example is the previously-mentioned Cool Water combined-cycle power-generation demonstration plant, to be located in Daggett, California. It will gasify 1000 tons per day of coal to produce 100 MW of electricity. According to a recent article in <u>Chemical Engineering Progress</u>, the facility, which will use the "proven" Texaco Coal Gasification Process, is to begin construction in July 1981 and be ready for start-up before the end of 1983.[32]

V. Synthesis Technology

The purpose of this section is to review available indirect liquefaction processes with the emphasis being placed on commercial feasibility, process description (reactor configuration, operating conditions, etc.), product quality, and a comparison of technological advantages and limitations. The processes that have been reviewed include seven methanol synthesis technologies (ICI,

Table 6

Coal to Methanol Projects

Project Name	Plant Size (Barrels Methanol/day)	Construction Date	On Stream Date
1. Great Plains Coal Gasification Project Mercer County, ND	125	July 1980	1984
2. Coal-to-Methanol-to Acetic Anhydride Tennessee Eastman Kingsport, TN	4,200	1980	1983
3. *Beluga Methanol Project, Granite Point, AK	54,000	1982-1983	1987
4. Grants Project **(ETCO), Grants, NM	3,608	1982	1984-1985
5. Mapco Synfuels Carmi, IL	35,000	1982	1987
6. Peat-to-Methanol **(ETCO), Creswell, NC	3,714	1982	1984
7. Keystone Project Cambria and Somerset Counties, PA	100,000	1983	1986
8. Dunn Nokota Lignite-to-Methanol Dunn County, ND	85,000	1983	1987
9. Chokecherry **(ETCO), Moffat County, CO	3,608	1982	1984-1985

* Feedstock is 60 percent natural gas, 40 percent coal

** Energy Transition Corporation (ETCO)

Source: EPA [8]

Lurgi, Haldor Topsoe, Mitsubishi Gas Chemical, Vulcan-Cincinnati, Wentworth Brothers' and Chem Systems) and two gasoline/petroleum synthesis technologies (Mobils' Methanol-to-Gasoline and Fischer-Tropsch).

The results of this section are briefly summarized in Table 7. Of the seven methanol synthesis processes that were examined, the ICI, Lurgi, Haldor Topsoe, Mitsubishi Gas Chemical and Vulcan-Cincinnati technologies have several commercial scale processes in operation today. The Wentworth Brothers' methyl fuel process is adapted from proven technologies and may be close to commercialization.[13] The Chem Systems process is not commercially feasible at this time since it is only at the pilot plant stage. The latest report on the Mobil MTG process[19, 3/80] was that the 4 barrel per day (BPD) pilot plant was the biggest operating unit to date, but that plans for 100 BPD and 13,000 BPD plants were proceeding. Mobil states that MTG is ready for commercialization[19], but at this time the MTG process is not commercially proven. The Fischer-Tropsch process, which has been operating for 25 years in South Africa, is unquestionably proven.

From a process point of view the high pressure methanol synthesis technologies (Vulcan-Cincinnati and Wentworth Bros.) are better suited for large scale production plants whereas the low pressure methanol synthesis technologies (ICI, Lurgi, Haldor Topsoe, Mitsubishi and Chem Systems which operate between 30 and 130 atm) can be used with any size plant.[13] This is because the high pressure plants have high throughputs which tend to compensate for the higher cost for compression, especially for very large plants. Although individual efficiencies have not been reported for the methanol synthesis processes it is probable that many of the technologies have comparable efficiencies since they are highly developed and very competitive. Two big factors that affect efficiency are the extent of heat recovery and the percent conversion of carbon monoxide and hydrogen to methanol per pass in the converter. Of the methanol technologies listed most have a conversion per pass of about 5 percent (e.g., ICI) while the Chem Systems process claims up to 20 percent.[13] Concerning heat recovery Lurgi claims to be more efficient than ICI because it uses a heat exchanger type reactor versus the quench type used by ICI.[1] Since Chem Systems uses a liquid phase process it should get an even higher recovery of heat than Lurgi. Over the past ten years ICI and Lurgi (more recently) have dominated the methanol synthesis market.[1,25] Since these two processes are so competitive it would seem logical that their economics would be the same, and compared to other commercial processes, be comparable if not less expensive.

Parsons has stated that the Chem Systems process shows a slightly higher thermal efficiency and slightly lower capital cost than Lurgi and ICI synthesis; however, they believe room for improvement over these synthesis units is small.[1] A comparison

Table 7

Methanol Synthesis Processes

Vendor	Catalyst	Pressure (atm)	Temperature (°C)	Reactor Type	Cooling
ICI*	Cu/Zn/Al	50–100	220–290	Single fixed-bed	Multiple gas quench
Lurgi*	Supported Cu	30–50	235–280	Tube in shell	Steam generation
Topsoe*	Cu/Zn/Cr	50–100	220–350	Radial flow	Boiler-feed-water heating
Vulcan-Cincinnati	Zn/Cr	300–350	300–400	Multiple bed	Cold-shot quench, plus external gas cooling
Mitsubishi Gas Chemical*	Cu/Zn/Cr	50–130	240–310	–	Multiple gas quench
Wentworth Bros.*	Multi-Catalyst	up to 400	200–400	–	–
Chem Systems	Cu/Zn	34–68	215–250	Liquid entrained and liquid fluidized	Recirculated inert hydrocarbon liquid
Mobil MTG	Zeolite	2.7	330–400	Fixed or fluid	
Fischer-Tropsch*	Cobalt or Iron	0–25	200–325	Fixed and fluid with cooling tubes	Steam generation

* Proven on a commercial scale.