2.0 EXECUTIVE SUMMARY

2.1 TECHNICAL COMPARISONS

Because of the wide range of technology types considered, comparisons of synthetic fuels technologies must be made within the technology areas of gasification and liquefaction. Even with this simplification, the range of application of these technologies is sufficiently broad to require further categorization within these areas. Technical comparisons across these groups can in general be difficult, misleading and of questionable utility (although economic comparisons are often valid). Therefore, it will be useful to consider low-, medium-, and high-Btu gasification systems separately. Portions of plant designs which bear similarities across these divisions will be pointed out, however. Each of the three gasification areas have examples of current and advanced technology types.

Coal liquefaction technologies may be categorized by those producing primarily synthetic crude oils and these oriented to methanol or other competing products (coal-oil mixtures).

The grouping of technologies is therefore:

Low-Btu Gasification	TAG No. 1	Wellman-Galusha (currently available)
	TAG No. 2	Combustion-Engineering (advanced technology)

Medium-Btu Gasification	TAG No. 3	Lurgi (currently available)
	TAG Nos. 4a 4b	Koppers-Totzek ? Texaco (advanced technology) See p 35
High-Btu Gasification	TAG No. 5	Lurgi-ANG (currently available)
	TAG Nos. 6a 6b 6c	IGY-Hygas IGT Exxon Catalytic BGC-Lurgi (advanced technology)
Coal Liquefaction for Production of Synthetic Petroleum Products	TAG No. 7	Fischer-Tropsch Indirect Liquefaction (currently available)
	TAG No. 8	Mobile Coal to Gasoline (advanced technology)
	TAG Nos. 9a 9b 9c	H-Coal EDS SRC-II Direct Liquefaction (advanced technology)
	TAG No. 12	Occidental Petroleum Pyrolysis (advanced technology)
Coal Liquefaction for Methanol Production or Other Products	TAG No. 10	ICI Coal to Methanol (currently available)
	TAG No. 11	Coal-Oil Mixtures (currently available)

2.1.1 Low-Btu Gasification

With respect to plant size, the Wellman-Galusha and Combustion Engineering gasification systems are not good candidates for comparison. The small throughput capacity of the Wellman-Galusha system generally relegates it to applications of fairly small capacity, such as cases of industrial boiler retrofit. The larger Combustion Engineering system would be best executed as part of an industrial park having a large demand for fuel gas and steam.

The fact the C-E gasifier produces gas of a fairly low heating value (113 Btu/SCF, the lowest of all gasifiers considered in this study) is a result of its two stage reaction system. A high temperature combustion zone provides heat for pyrolysis and gasification reactions which occur in the second stage. The necessity of high operating temperatures imposes a requirement for additional air, thus consuming more of the fuel which would otherwise appear as combustible fraction in the product gas. This energy is not wasted however, since it is ultimately recovered as steam. It is more a matter of emphasis rather than efficiency; the Wellman-Galusha system shifts more of the energy in the coal to gas heating value (143 Btu/SCF), a small part of which is methane, because of its lower operating temperature and countercurrent flow. Few industrial applications would find one gas acceptable and the other not.

A comparison of overall plant thermal efficiency shows 86 pecent for C-E versus 61 percent for Wellman-Galusha, which reflects one advantage offered by the advanced technology C-E design. Based on a comparable plant size; however, this difference would not be as great.

2.1.2 Medium-Btu Gasification

Three technologies are considered for this case; all are blown with oxygen to achieve the medium-range in heating value (as opposed to providing reaction heat with a circulating solid which is heated in a separate air blown bed). The Lurgi system has been in commercial use for some 40 years and hence represents the system of lowest technical risk. The Koppers-Totzek gasifier also has the advantage of considerable operating experience. Both systems are competitive in overall thermal efficiency, with the K-T system marginally higher. The Texaco system is an advanced gasifier showing higher overall thermal efficiency and many years of operating experience on heavy oils, but relatively little experience in coal gasification.

Gas production rates for the Lurgi system (in terms of SCF per ft^2 of reactor cross sectional area) are lower than that for the K-T or Texaco system. This fact combined with the high production rate of tars and other condensables in the Lurgi gasifier suggests a greater level of complexity is required in the overall plant design. However, due to lower operating temperatures for Lurgi, higher methane concentrations result, raising the heating value of the gas to over 300 Btu/SCF (compared to 280-290 for K-T and Texaco). Although this is not a great difference, it may be a factor in selection because of the influence of heating value on boiler derating. Most other applications would find any of the three gas compositions acceptable.

Ash disposal is another area of comparison. The Lurgi system operates at low temperatures to avoid slagging (melting) the ash, so that it may be removed from the gasifier through the rotating grate system. Gasifier steam consumption is very high since steam is used to control temperature. The entrained flow operation of K-T and Texaco results in very short reactor residence times, and therefore very high operating temperatures are required to achieve reaction rates which are sufficiently rapid to maintain good conversions. These high operating temperatures slag the ash which is then in a fused state for disposal. Leachate tests indicate that slagged ash (as opposed to the dry ash from the Lurgi system) may be more stable with respect to the introduction of hazardous wastes into groundwaters which may come into contact with the disposed ash.

2.1.3 High-Btu Gasification

The conventional approach to the preparation of high-Btu gas involves preparation of a medium-Btu synthesis gas which is then purified and catalytically reformed to methane and carbon dioxide. Suitable systems for medium-Btu gas generation are discussed in section 2.1.2 and TAGs 3, 4a and 4b. Pipeline quality gas is available for distribution following removal of the CO_2 from the methane-rich gas. This is the approach taken by the Lurgi-ANG design, which is based upon conventional Lurgi dry-ash gasification. One of the advanced technologies, BGC-Lurgi also uses this approach, where the prime difference lies in the use of a higher temperature, higher throughput slagging gasifier. The IGT-Hygas system also uses a methanation system, but the raw gas produced by the fluidized bed gasifier is considerably higher in methane and therefore requires less catalytic methanation. The Exxon catalytic gasification process uses a totally different approach, operating the gasifier at low temperatures which favor methane production, separating the methane cryogenically, and recycling the unreacted synthesis gas to the reactor. Each approach produces a gas of approximately 1000 Btu/SCF and which meets other specifications required of pipeline quality gas. The process design used in each case dictates process efficiency and desirability in specific applications.

The two Lurgi technologies are similar in overall design, but the advanced BGC system shows a higher efficiency (59%) than the conventional Lurgi (53%). Both are lower than Exxon and IGT (74 and 76 percent, respectively). The standard Lurgi process employs proven technology, as opposed to the BGC-Lurgi system which compensates with a higher efficiency rating (due to a lower gasifier steam consumption and greater flexibility). The reader should however bear in mind that the processes are based on different coal feedstocks. The slagging Lurgi system was chosen to process Eastern coals because its high gasification temperature promoted rapid gasification of this low-reactivity feedstock.

The IGT process shows the highest thermal efficiency, but is based on a complex reactor design which must be proven on a large scale before commercial acceptance can be guaranteed. The Exxon system relies heavily on added catalyst, which is necessary due to the slow reaction kinetics occurring at the low operating temperatures. The process would have to have a guaranteed supply of potassium based catalyst for the life of the plant. Even with the use of catalyst, reactor throughput is quite low, even lower than for the conventional Lurgi system. This dictates that more reactors will be required to meet a given production objective. The performance of the catalyst recovery system is essential to the economic operation of the process, since the potassium catalyst is a major operating expense item. Recovery of the catalyst can be hindered by insoluble potassium complexes formed by interaction of the catalyst with coal ash. Therefore, prediction of recovery performance may require a laboratory evaluation of this parameter for each coal type used.

2.1.4 Coal Liquefaction for Synthetic Crude

The widespread use of Lurgi technology is evident again in the Fischer-Tropsch process, which involves the production of a medium-Btu synthesis gas (such as discussed in section 2.1.2) followed by catalytic reforming to a broad spectrum of liquid and gaseous products. Somewhat similar is the Mobil process for synthetic gasoline production, which is based on methanol as a feedstock. This process can also be considered a form of indirect liquefaction, because the feedstock methanol is produced catalytically from a medium-Btu synthesis gas. The methanol is then catalytically reformed to naphtha-range hydrocarbons in Mobil's process. The selectivity for gasoline-type products is much higher in the Mobil process than in the Fischer-Tropsch approach, although the overall efficiency of conversion of coal to gasoline is only 50 percent for this process, as compared to 71 percent conversion (total for all products) in the case of Fischer-Tropsch. However, this is offset by the fact that the naphtha/gasoline products produced by Mobil are much higher value than the products produced by the Fischer-Tropsch approach. The efficiency of the Mobil process could be enhanced by the use of a more efficient gasifier (rather than dry-ash Lurgi).

Also included in this category are three advanced direct liquefaction technologies; H-Coal, Exxon Donor Solvent, and SRC-II. All three processes achieve conversion of coal to liquid products by the use of a process generated solvent oil which aids in hydrogenation of the coal feedstock, and all utilize distillation in conjunction with other separation techniques to recover recycle solvent and produce the array of products.

The Exxon system is unique in its use of an externally hydrogenated donor solvent. The H-Coal system employs a catalytic reactor which promotes liquefaction, solvent hydrogenation and product upgrading simultaneously. The SRC-II process employs neither a donor solvent or catalyst, but relies on thermal degradation of the feedstock in a recycle solvent.

The Occidental Petroleum Pyrolysis process also fits in this category because of its production of liquid products. In addition, char and gas are also produced. Occidental claims that the choice of pyrolysis chemistry, which is not as endothermic as either indirect or direct liquefaction techniques, is primarily responsible for the extremely high energy efficiency (>90%) claimed for their process. The simplicity of the process is also a factor in process efficiency, but the yield of liquid products is lower (because of the char and gas products), and hence a lower product value applies overall.

2.1.5 Coal Liquefaction for Other Products

This category includes methanol production and coal-oil mixtures. Coal-oil mixture technology is not a true liquefaction process since it is concerned with only the

Table 2-1

Production Cost Comparisons for Synthetic Fuels Technologies

	Coal Type	Total Plant Investment, $/MM Btu-Yr.	Net Operating Cost, $/MM Btu-Yr.	Unit Energy Cost $/MM Btu Non-Fuel Cost	Unit Energy Cost $/MM Btu Total^a
Low-Btu Gasification					
Wellman-Galusha	Subbituminous	9.06	0.76	3.70	6.16
Combustion Engineering	Illinois No. 6	5.02	0.44	2.37	4.27
Medium-Btu Gasification					
Dry-Ash Lurgi	Illinois No. 6	12.50	0.77	4.91	7.07
Koppers-Totzek	Subbituminous	10.59	0.72	4.31	6.55
Texaco	Bituminous	7.76	0.76	3.20	5.45
High-Btu Gasification					
Lurgi-ANG	Lignite	25.70	0.75	10.23	13.00
IGT Hygas	Illinois No. 6	13.64	0.50	4.70	7.06
Exxon Catalytic	Illinois No. 6	10.41	1.47	8.09	10.14
BGC-Lurgi	Illinois No. 6	15.35	0.83	6.27	8.01
Liquefaction for Synthetic Petroleum Products					
Fischer-Tropsch	Eastern U.S.	15.70	0.94	6.22	8.41
Mobil Coal to Gasoline	Wyodak	25.06	1.93	11.92	14.93
H-Coal	Illinois No. 6	19.25	1.11	5.51	7.70
Exxon Donor Solvent	Illinois No. 6	17.56	1.29	7.59	9.96
SRC-II	Powhatan W.Va.	8.90	0.50	3.72	5.02
Occidental Petroleum Pyrolysis	Wyodak	5.94	0.42	2.75	4.32
Liquefaction for Other Products					
ICI Coal to Methanol	Wyodak	16.91	1.33	7.07	10.20

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^a Total product cost includes $1.50/MM Btu for coal cost physical preparation of coal-oil slurries, and hence defies comparison to true liquefaction technologies on thermal efficiency and other bases.

The production of methanol by the ICI process is based on conventional Lurgi dry-ash coal gasification technology, followed by commercially available catalytic reforming systems for methanol production. This process is the basis for the Mobil coal to gasoline process design examined in TAG No. 8, and the ICI process efficiency of 64 percent (based upon Wyodak coal) is a prime component in determining the overall efficiency in the Mobil coal to gasoline process. In addition to methanol, an equivalent quantity (in terms of Btu content) is produced as SNG (pipeline quality gas), which gives some indication of the overall efficiency of converting feed carbon to methanol. Small amounts of diesel oils, naphthas and crude phenols are also produced.

The reader should remember that comparisons drawn between different technologies are best used in reference to specific applications where coal type and end use requirements are the same. Under these circumstances, the differences due to superior process design, product slate or other advantages will become most apparent. Conclusions reached under any other circumstances are of limited accuracy and must be carefully used to avoid the introduction of any unjustified bias.

2.2 ECONOMIC COMPARISONS

Within the categories discussed above in section 2.1, according to the guidelines followed for the economic analyses, the results of production cost estimate are summaried in Table 2-1.

Numbers in the table generally reflect the effects of plant complexity and thermal efficiency. However, other variables can have a strong influence which must be included to assure valid comparisons. Comparisons are best made when making an analysis of a particular application of known size, coal type and end use.

With this in mind, Table 2-1 suggests several factors of significance. For low-Btu gasification, higher unit capital and operating costs for the Wellman-Galusha system are evident in the gas cost figures. Some of this difference is due to the variation in size, the Combustion Engineering system having the advantage of larger scale economics. Due to the difference in coal type, the best comparison is found in the non-fuel gas cost. Some technology advantage appears to apply in the C-E case.

In the medium-Btu gas case, the dry-ash Lurgi system shows the worst cost performance. The Koppers-Totzek system, although using a lower quality coal, shows an advantage for its entrained flow, slagging design. The advanced technology Texaco system shows a clear advantage in capital and product costs, but interestingly, not in operating costs. This is probably due to the fact that processing requirements downstream of the gasification section are similar in all three cases. All plants were assumed to be the same size.

The high-Btu gas cases were all sized to produce 250 million standard cubic feet per day, and all were examined assuming an Illinois No. 6 feed coal except the Lurgi-ANG system which operates on lignite (the lowest grade of coal). As expected for technology reasons, the Lurgi gas cost is considerably higher than its advanced technology competitors, although some of this difference may have been caused by the lower quality feedstock (particularly for the total gas cost). Lowest capital and operating costs were obtained for the HYGAS system which posted correspondingly low gas costs. The Exxon catalytic gasification system shows the effect of costly catalyst recovery and gas separation steps in its high capital cost, and the effect of a large catalyst consumption rate is evident in the operating costs (highest unit operating cost of the gasification technologies). The BGC-Lurgi case shows the effect on cost of the advanced technology slagging gasifier and attendant plant design over the dry-ash Lurgi system.

Because of the wide variation in product slate and feedstock composition for the coal liquefaction technologies, comparisons are particularly difficult. The Fischer-Tropsch (the only currently available technology) produces the lowest value products of this group, only a fraction of which is suitable for upgrading to motor fuels. Its product costs, although not high for the group, are actually quite high when this effect is considered, and reflect the performance of this older technology. The complexity of converting coal to gas, followed by reforming to methanol, followed by reforming to gasoline is responsible for the high capital and operating costs for the Mobil system (although the Mobil technology is only a small part of the overall process). These costs are reflected in higher product costs, but these products (gasoline) would also command higher prices in the marketplace. The H-coal technology shows slightly lower product costs than the EDS process. Both however are higher than the SRC-II process, which uses a straightforward thermal approach to direct liquefaction, rather than one based on catalytic reactions or donor solvent hydrogenation. The lowest costs of the entire group are shown by the Occidental Petroleum Pyrolysis process, which reflects its high thermal efficiency and simple design. However, the ORC process produces large amounts of lower value products (such as char and gas, which have a lower market value. The ICI coal to methanol process is used as the basis for the Mobil synthetic gasoline system, and is based on the inefficient dry-ash Lurgi technology. Improvements in overall costs for both the ICI and Mobil systems could be expected by changing to a different gasification technology. The product costs for the ICI system appear to be somewhat high, although the methanol produced is a fairly high value commodity. The effect of the ICI system on Mobil costs can be seen by comparing the respective numbers for these processes. Again, the reader is cautioned to recognize that the accuracy of these comparisons is limited by many factors, some of which have been mentioned. Comparisons should be made for qualititative purposes only.