THE BRITISH GAS SLAGGING GASIFIER
- A SPRINGBOARD INTO SYNFUELS

Raymond B. Sharman
John A. Lacey
James E. Scott

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Raymond B. Sharman, F. Inst. Gas E., Member Inst.E.,
Director, International Consultancy Service,
British Gas Corporation

and

John A. Lacey, BSc., PhD., C.Eng., Member Inst.Chem.E.,
Assistant Director Midlands Research Station,
British Gas Corporation

and

James E. Scott, M.Inst.Gas E.,
General Manager, Westfield Development Centre
British Gas Corporation

1. SUMMARY

The most developed and widely used fixed bed pressure gasification systems are based on the Lurgi Gasification Process. The British Gas/Lurgi Slagging Gasifier results from the joining together of British Gas Corporation and Lurgi Company technology. The British Gas Slagging Gasification technology offers significant advantages over dry bottom Lurgi and other fixed bed gasification systems. It is also true to claim that the slagging gasifier has more advantages than disadvantages when compared with entrained flow gasifiers and these advantages are sufficient to give it an economic advantage in most process situations. There are other fixed bed, fluidised bed and entrained flow gasifiers under development[1] but these are not short to medium term options and only in the longer term will it become clear whether or not these developments offer sufficient economic advantage to compete with or displace the British Gas/Lurgi Slagging Gasifier. The processing of crude Slagging Gasifier gas and the multifarious uses of the resulting clean gas in the chemicals, power generation and fuel gas fields are described. The environmental impact of the process is also discussed and plans for commercialisation are considered.

2. INTRODUCTION

The fixed bed pressure coal gasifier is outstandingly represented by the Lurgi Gasifier, first operated successfully over forty years ago and without question a commercially proven process.[2]

The Lurgi process was first developed to gasify the extensive lignite deposits in what is now East Germany; but being separated from these, the Lurgi Company sought to gasify the weakly caking bituminous Ruhr coals. The technical feasibility of this was demonstrated in a pilot scale generator at Holten, which led to the opportunity for the commercial application of this technique to British coals at plants built and operated by British Gas at Coleshill and Westfield.[3] The fixed bed Lurgi gasifier has thus been applied to a wide range of coal feedstocks and has been the subject of continued improvements over the past four decades.

The efficiency and economics of the fixed bed Lurgi gasifier suffers from restrictions which are imposed by the use of excess steam to limit the reactor gasification zone temperatures. The zone temperature must be below the fusion point of the ash which means that the process is at its most efficient when gasifying reactive coals with a refractory ash, when optimum process oxygen consumptions and reasonably high steam decompositions are achieved. The reasons for this have been discussed in more depth by Hebden and Brooks.[4] Conversely, gasification of the unreactive high volatile bituminous coals, particularly those with low melting point ash, show much poorer performance in the Lurgi process, and efficiency falls away because of increasing quantities of undecomposed steam passing through the reactor. These factors set the economic horizon for the process and limit the range of coals that offer the opportunity to maximise efficiency and minimise costs of production.

It is thus clear an advantage to avoid the excess of steam by operating under slagging conditions, a fact which has been recognised for a considerable time[5]. Indeed, development along these lines was initiated by Lurgi itself in 1953, when, in collaboration with Ruhrgas, a special gasifier was erected at Holten. Unfortunately, this work had to be discontinued prematurely and before any significant progress was made. However, British Gas (or the Gas Council, as it then was) had always been interested in the possibility of slagging operating and, in 1955, the experimental gasifier was purchased from Lurgi company.

This gasifier was erected at British Gas' Midlands Research Station and was used[6] for some exploratory research into slagging gasification, using coke and operating only at modest pressures. As a result of this work the gasifier was extensively modified to provide for operation on coal at pressures up to 375 psig and outputs of 5 MMSCF/D of crude gas. Work on this gasifier between 1962 - 64 has been described by Hebden, Lacey and demonstrated slagging gasification of coal at pressures of 20 bar and at high loads, providing justification for its continued development to a commercial scale.

Because of the availability of North Sea Natural Gas and the conversion of Britain to utilize this fuel, the development was delayed, and it was not until a decade later, at Westfield, that development restarted.

3. DEVELOPMENT AT WESTFIELD

The transition of the Westfield site from a gas works to a Development Centre was initiated by the coal trials for the Amercian Gas Association carried out on the existing dry ash Lurgi reactors. These were followed by the methanation trials for the Continental Coal Development Corporation, a subsidiary of the Continental Oil Company. This work is described in detail elsewhere[8]. The restart of the development programme for the Slagging Gasifier was accelerated as a result of growing interest in the technology in the USA. This interest was principally from the US Gas and allied industries and was co-ordinated by Conoco and a programme was carried out, funded and sponsored by 15 US gas pipeline and oil companies over a period of three years. EPRI participated in this programme. The programme culminated in a successful 23 day test which demonstrated the commercial viability of the gasifier and confirmed its superior performance. This three year development also marked the beginning of formal co-operation between British Gas and Lurgi based on the combination of their respective technologies to result in the

British Gas/Lurgi Slagging Gasifier. Probably the most significant fact concerning this programme is that it was carried out on a commercial scale six feet diameter gasifier using 300-350 tons of coal per day.

This sponsored development programme was however overtaken by the setting up of the US Energy Research and Development Agency. As a result of this already successfully demonstrated project, the Continental Oil Company felt able with the support of BGC and Lurgi to respond to an invitation from the US Government for a proposal to build and operate a jointly funded 60 MMSCF/D SNG plant based on coal and utilising the new technology[9]. Their response was successful and Conoco with British Gas and Lurgi, using Foster Wheeler as the Engineering Contractor have been carrying out the first phase of the engineering of a demonstration plant based on the British Gas/Lurgi Slagging Gasifier. This phase, entirely US Government funded, involved a technical support programme carried out on the Slagging Gasifier at Westfield. During this programme Pittsburgh 8 and Ohio 9 coals, both having highly caking and swelling characteristics and having high sulphur contents, were gasified. The programme achieved all the objectives set for it and was successfully completed in August 1978[10].

This experimental work at Westfield since 1974 has already in 1980 dollars cost over US $60 million. British Gas commenced in 1978 a programme planned to last 20 years dedicated entirely to the development and demonstration of a range of processes to produce SNG. The current cost of this programme in 1980 dollars is estimated to be US $630 million. That part of the programme concerning the development of the Slagging Gasifier is currently under review and may be further enlarged to include full scale commercial demonstration during the 20 year programme. This may well increase the cost by a factor of three. The programme will involve continued operation of the 6' diameter shaft Westfield gasifier and construction, commissioning and operation of an 8' shaft prototype commercial Slagging Gasifier. Aspects of this programme are:

- (i) Performance testing of the Slagging Gasifier on a range of British Coals.
- (ii) Development of fine coal injection systems into the Slagging Gasifier.
- (iii) A long (three month) demonstration run on the Slagging Gasifier.
- (iv) The production and distribution of SNG from the Slagging Gasifier, via British Gas Corporation's HCM process.

Phase I of this programme has already been completed.

During this first Phase of the BGC programme, a three month interruption was made to accommodate a short but highly significant programme at Westfield, sponsored by EPRI. This three-run programme was aimed at demonstrating the potential of the Slagging Gasifier for electric power generation in a combined cycle plant using Pittsburgh 8 coal. The objectives of this programme were achieved with impressive authority, greatly increasing EPRI's confidence in the slagging gasification process and its use in the above mode, as the EPRI Press release at the end of the project in December 1979 indicated.

The first two aspects of the development programme at Westfield described briefly above represent a wealth of experience and improvement of the British/Gas Lurgi Slagging Gasifier. The achievement of over 5000 hours running and the gasification of nearly 60,000 tons of coal represents a considerable investment of confidence in the Slagging Gasifier, which is now described in detail in the next section (see Table 1).

TABLE 1

SUMMARY OF WESTFIELD SLAGGING GASIFIER PROJECTS

April 1975 - March 1981

Project	No. of Runs	Hours on Line	Fuel Gasified (tons)
Sponsors' Programme	27	1,508	19,444
DoE Programme	15	981	10,866
EPRI Trials	3	415	3,903
British Gas Programme	24	2,104	25,395
TOTALS	69	5,008	59,608

4. WESTFIELD SLAGGING GASIFIER

The Westfield Slagging Gasifier was built by converting one of the existing conventional Lurgi gasifiers to Slagging operation. Its main features are shown diagramatically in Figure 1. The original gasifier was lined to reduce its shaft diameter from 9' to 6' as the gasifier throughout previously served several Lurgi gasifiers. A second gas offtake was added, together with an associated downstream cooling system, to match the greater output. Following the installation of the slag tapping, hearth and tuyere equipment, and the elimination of the grate, the remainder of the Lurgi gasifier continues in use to serve its previous role. The fuel bed is now supported on the refractory hearth surrounded by a number of steam and oxygen inlets or 'tuyeres', with facilities for running off liquid slag via a tap hole into a chamber below where it is quenched in water. The quenched slag is discharged from the pressure system through a lock hopper.

The following are some of the salient features of the Slagging Gasifier:

4.1 Coal is fed to the gasifier via a lock hoppering system. This is a proven Lurgi system which is trouble free in operation. The Lurgi system is capable of handling the higher throughputs required by the Slagging Gasifier.

4.2 Fixed bed gasifiers are traditionally thought to require sized coal to promote good bed loading and heat exchange in the countercurrent flow regime. Thus, the requirements are often quoted as "lump coal, ½-2", with no fines". Westfield experience demonstrates that this is not so. During the EPRI trials, Pittsburgh 8 coal with up to 25% by weight less than ¼" was fed to the bed top without any significant change in gas analysis. Recent experience on the BGC programme at Westfield has shown that the above figure can be increased to 35%. The Slagging Gasifier also offers the potential of injecting fine coal directly into the reaction zone of the gasifier via the tuyeres, and this technique has been operated at Westfield. It is expected that this will lead to even greater potential fines intake into the slagging gasifier.

4.3 The fixed bed gasifier generates tar and oils which are carried out from the gasifier with the make gas. In the Slagging Gasifier they can be recycled to extinction through the tuyeres, as was demonstrated at Westfield during the EPRI trials. Tar plays a useful role in aiding the smooth operation of the gasifier by wetting the dust carried over from the top of the bed. The tar laden with dust is removed from the cooling systems, and recycled to the top of the fixed bed. As no carbon is taken out by the slag removal system the carbon gasification in the Slagging Gasifier is effectively 100%.

Another important function[2] of tarry compounds is to protect downstream heat exchangers and piping systems, which can be made of carbon steel. This equipment has operated successfully at Westfield for over 20 years and has proved to be very reliable.

4.4 It has been claimed that the fixed bed gasifiers do not work well with swelling coals. Statements such as this can still be seen[11] in the literature but are not true. In post-war years Lurgi have given much attention to the problem of stirrer design which has much benefitted the Westfield Slagging Gasifier. Substantial quantities of strongly caking and swelling coals such as Pittsburgh 8 and Ohio 9, as well as the equivalent strongly caling British coals have been gasified. A list of some coals put through the Westfield slagging gasifier is given in Table 2. No appreciable performance difference has been noted between weakly caking and strongly caking high volatile bituminous coals.

TABLE 2 COALS RUN THROUGH THE WESTFIELD SLAGGING GASIFIER

Coal	Manton	Rossington	Gedling	Ohio 9	Ohio 9
Source	England	England	England	USA	USA
Size	¼" – 1½" (with up to 35% under ¼")	¼" – 1½" (with up to 35% under ¼")	¼" – 1"	¼" – 1½" washed	¼" – 1½" unwashed
Moisture %	3.0	6.9	10.2	1.4	4.7
Ash %	7.3	4.3	5.8	12.0	20.8
VM %	31.9	33.3	31.5	39.7	32.3
FC %	57.8	55.5	52.5	46.9	42.2
Swelling	6½	1½	1	6	3½
Caking	G6	E	C	G4	G

Coal	Pittsburgh 8	Hucknall	Comrie	Killoch
Source	USA	England	Scotland	Scotland
Size	¼" – 1¼" (with up to 25% under ¼")	¼" – 1"	¼" – 1"	¼" – 1"
Moisture %	2.1	5.0	2.7	7.7
Ash %	11.5	5.1	6.3	4.5
VM %	36.1	35.4	32.1	33.8
FC %	50.3	54.5	58.9	54.0
Swelling	7	3½	2½	3½
Caking	G6	G	F	E

4.5 Performance data from the Slagging Gasifier is very consistent from coal to coal, as can be seen from some data collated in Table 3. This table shows the very low steam requirement of the Slagging Gasifier with its favourable, and almost constant oxygen demand, these factors being prime reasons for its very high thermal efficiency. Countercurrent operation and low steam requirements mean that the outlet temperature of the slagging gasifier is very low (even lower than that of the dry ash Lurgi and very much lower than that for the entrained flow gasifiers) and this means that complex heat recovery equipment is not required. The fact that almost all the process steam is decomposed within the gasifier gives two advantages. Firstly, it results in a very small yield of liquor and consequently reduced effluent treatment costs. Secondly, in contrast to a dry grate gasifier of the same diameter a much greater thermal output can be achieved. Furthermore the low CO_2 content of the crude gas minimises the CO_2 that is removed along with sulphur compounds during desulphurisation and so aids the subsequent processing of the off-gas.

These gasification characteristics result in considerable reductions in capital costs in the process areas of steam raising, oxygen production, gasification, effluent treatment and desulphurisation, while the high thermal efficiency of the gasifier gives lower operating costs because of lower coal feed requirements. The slagging gasifier operates with steam to oxygen ratios in the range 1 – 2 (v/v) in order to promote slagging conditions, and over this range the thermal efficiency of the

TABLE 3
Performance Data for British Gas/Lurgi Slagging and Lurgi Dry-Ash Gasifiers at Westfield

Gasifier Type	Slagging				Dry Ash
COAL Origin	Frances Scotland	Rossington England	Ohio 9 USA	Pittsburgh 8 USA	Pittsburgh 8 USA
Size (ins)	¼-1	¼-1	¼-1	⅛-1¼	⅛-1¼
PROXIMATE ANALYSIS, (%w/w)					
Moisture	8.7	9.5	6.1	4.2	4.8
Ash	4.4	4.6	18.9	7.2	7.9
Volatile Matter	32.9	31.2	33.6	35.4	37.4
Fixed Carbon	54.0	54.7	41.4	53.2	50.3
ULTIMATE ANALYSIS (%w/w)					
Carbon	83.0	83.5	79.6	82.4	84.9
Hydrogen	5.5	4.9	6.1	5.3	5.8
Oxygen*	9.2	7.7	7.4	9.1	5.0
Nitrogen	1.4	1.7	1.2	1.5	1.6
Sulphur	0.5	1.7	5.6	1.6	2.6
Chlorine	0.4	0.5	0.2	0.1	0.0
B.S. Swelling No.	1½	1½	4½	7½	7½
Caking Index (Gray King)	B	E	G	G8	G8
OPERATING CONDITIONS					
Gasifier Pressure, (atm)	24	24	24	24	24
Steam/Oxygen ratio (v/v)	1.3	1.3	1.3	1.3	9.0
Outlet Gas Temperature (°F)	896	896	770	950	1220
CRUDE GAS COMPOSITION, (%v/v)					
H_2	28.6	27.2	28.7	28.9	38.8
CO	57.5	58.1	53.2	54.9	17.9
CH_4	6.7	6.8	6.9	7.1	8.4
C_2H_6	0.4	0.5	0.3	0.6	0.7
C_2H_4	0.2	0.2	0.2	0.2	0.3
N_2	4.2	3.9	4.0	4.4	2.4
CO_2	2.3	2.9	5.5	3.4	30.8
H_2S	0.1	0.4	1.2	0.5	0.7
HHV, (Btu/scf)	375	375	362	375	298
DERIVED DATA					
Coal Gasification Rate (lb/ft²h)	852	848	664	666	140
Steam Consumption, (lb/lb coal)	0.405	0.398	0.390	0.407	3.540
Oxygen Consumption, (lb/lb coal)	0.539	0.549	0.555	0.547	0.700
Liquor Production, (lb/lb coal)	0.20	0.21	0.16	0.21	2.24
Gasifier Thermal Output, (therms/ft²/h)	106	106	78	83	17
Gasifier Thermal Efficiency**, (%)	83.4	82.1	82.3	79.9	62.3

* Coal expressed 'moisture and ash free'

** Defined as total product gas thermal output (based on HHV, including tar, oil, naphtha) divided by corresponding thermal input of coal feedstock and the fuel equivalent of the steam and oxygen used.

gasifier is remarkably constant, with only slight effects upon product gas composition, as Figure 2 shows for a medium caking Rossington Coal.

4.6 Slag tapping from the Westfield Slagging Gasifier is carried out automatically and requires no operator attention. The molten slag is quenched in water and lock hoppered out of the system. As with the coal lock, the slag lock can be automated, although it is not at present at Westfield. British Gas consider the present systems employed at Westfield to be fully demonstrated and ready for commercial use and to be capable of extended trouble free operation.

4.7 The Slagging Gasifier also has important start up and shut down characteristics. Start up, that is going from an empty reactor to gas making is easily achieved in 4 hours using straight forward procedures. It can be shut down to hot standby in a matter of minutes, and retained in this condition for at least 48 hours and then restarted. It can be shut down and emptied, proprietary equipment repaired or replaced and returned to gas making in 7 days. It may be shut down and cooled but not emptied and restarted in a few hours. This latter case has yet to be demonstrated but there does not appear to be any reason why this should not prove to be the case. Obviously this requires a trained and experienced crew of operators. But operators are all that are required, not engineers and scientists other than the level of Management supervision that is normally found for example, in electricity utility power stations or an ammonia plant. These effects result from the presence in the gasifier of a relatively large quantity of hot fuel, leading to more stable and safer operation than with fluidised bed or entrained flow systems. For example the coal feed can be interupted and then restarted without interruption of gas making.

5. THE PROCESSING AND USES OF GAS FROM THE SLAGGING GASIFIER

5.1 Processing the Crude Gas

As has already been pointed out, the crude gas from the Slagging Gasifier contains tar and some entrained solids. It also contains a little steam mainly derived from the moisture content of the coal and the small amount of undecomposed reactant steam. Breakdown of the coal also yields phenols and chlorine, nitrogen and sulphur containing compounds. On cooling the gas the tar and steam condense to give a tar containing the solids and an aqueous liquor containing many of the other impurities. The tar can readily be recycled to extinction by either being pumped to the top of the bed or through the tuyeres. The aqueous liquor is processed by conventional solvent extraction (dephenolation), ammonia stripping and effluent treatment stages. The resulting phenols can be sold as valuable chemical feedstock or recycled to the gasifier. The anhydrous ammonia is of sales-grade. Some of the final aqueous stream can be added back to the gasifier via the tuyeres to replace some of the live steam added with the oxygen.

The cooled gas is then purified using any of several available processes of which Rectisol is the most tried and tested. In this process, hydrogen sulphide, carbonyl sulphide, ammonia, etc., are removed by contacting the gas with cooled methanol. The low CO_2 content of the Slagging Gasifier gas means that these established techniques for removing acid gases can be used without requiring a high selectivity to obtain an off-gas, with a relatively high concentration of H_2S, which is most suitable for conversion to sulphur by the Claus process.

The clean, dry H_2S-free gas, consisting essentially of CO, H_2, and CH_4, can now be considered ready for use, either directly as a fuel gas of calorific value around 360 Btu.sft.[13], for SNG manufacture, or for chemicals synthesis.

As far as the chemical industry is concerned, one of the main problems when natural gas begins to run short will be obtaining a replacement supply of synthesis gas (i.e. mixture of CO and H_2) most of which is presently produced by steam reforming of natural gas.

At present such synthesis gas is used throughout the world on a huge scale and possible chemical uses of the gas has been reviewed by Wender [12] and recently by Denny and Whan[13]. Many products can be manufactured from synthesis gas and Fig. 3 indicates the chemistry of its use. Other possibilities include production of oxygenated compounds such as ethylene glycol, but as yet, these are only in the exploratory stages.

All these applications operate at high pressure so that use of a high pressure gasification process reduces or, in some cases, eliminates the need for further compression of the intermediate gas. This is a major cost and energy consuming item when atmospheric pressure gasifiers are used. High pressures also aid the processing of the crude gas as described above.

5.2 Ammonia Production

At present the major end-use for synthesis gas is ammonia production. Currently about 70% of the world ammonia production is natural gas based. The salient steps in the route are high temperature methane reforming following by extensive CO-shift conversion. As purified slagging gasifier gas is rather like a partly reformed methane stream, it can directly replace both the natural gas used as process feedstock and that (about one-third) used as fuel[14]. Such retrofitting of existing plant has the minimum risk technically and economically and could be implemented rapidly if desired. A study by Humphreys & Glasgow Ltd., in which a comparison was made of five gasifier types for this kind of scheme showed that the Slagging Gasifier had the lowest coal rate (i.e. it was the most efficient) and just about the lowest capital cost.

For a new purpose-built coal-based ammonia plant the Slagging Gasifier gas would be passed directly to a CO-shift unit followed by CO_2 removal to adjust the gas composition to give a high hydrogen content. The relative capital costs and coal consumption for such schemes using four gasifier types is shown below, also based on Humphreys & Glasgow Ltd. (London) data[14].

	Relative Capital Cost	Relative Coal Consumption
British Gas/Lurgi	114	100
Texaco	100	117
Koppers-Totzek	138	154
Winkler	124	115

These figures show that the British Gas/Lurgi Slagging Gasifier and the Texaco coal gasification process are the most attractive, while the low pressure processes, Winkler and Koppers-Totzek, are least attractive. One of the reasons why the Slagging Gasifier route is more expensive than the Texaco route is the need to reform the methane present in the purge gas. If this could be separated from the other components and sold as SNG or even recycled to the gasifier, then the Slagging Gasifier option might come out even more attractively. A suitable way in which the methane could be removed is to adapt the cryogenic liquid nitrogen wash unit which frequently features in ammonia synthesis plant.

5.3 Methanol production

Methanol is already an important chemical with many uses. Many have speculated that the methanol market will increase rapidly in future years as new uses develop, these being as a clean liquid fuel in its own right, as an intermediate for gasolene production (e.g. Mobil process) and perhaps as a feedstock for propylene plants[15]. Chemical uses demand a high product purity (99.5 + %) but fuel-grade methanol need consist of only about 98%, CH_3OH, the balance being water and higher alcohols, and so can be made with more simple plant.

Methanol synthesis catalysts are highly sensitive to sulphur and so the feed gas must be extensively purified and a chemical guard, say of zinc oxide, will be mandatory. Basically the synthesis gas should comprise hydrogen and carbon monoxide at a molar ratio of 2, so slagging gasifier gas with a much higher CO content must be extensively shifted. The purge gas rate from the synthesis loop will have to be sufficient to prevent a build-up of the nitrogen and methane which are present in the purified Slagging Gasifier gas. This gas can be used as fuel in the plant or passed to an adjoining methane synthesis plant to produce SNG as a co-product.

An alternative route is to feed the purified Slagging Gasifier gas to a reforming/CO-shift stage similar to that found on a natural gas fuelled methanol plant.

A study by EPRI[16] has shown that the British Gas/Lurgi process had the lowest capital and operating costs of the four processes evaluated (Table 4).

5.4 Fischer-Tropsch Synthesis

Although the original Fischer-Tropsch process for producing higher hydrocarbons from CO and H_2 was first announced over 45 years ago, it has undergone various stages of development in the USA and especially in South Africa where large quantities of vehicle fuels and oxygenated chemicals are produced by this route. There both fixed bed and circulating bed F-T reactor systems are in use, each yielding different product distributions. The reactant again needs to be hydrogen rich with a CO/H_2 ratio of about 2 so the highly purified gas from the slagging gasifier needs to be subjected to the CO shift reaction.

The CO/H_2 ratios used in the full-scale F-T reactors at Sasol are 1,7 and 2.8 respectively. The purge gas from the Fischer-Tropsch reactor can be used for SNG production or fractionated to give a methane-rich gas and a hydrogen-rich gas suitable for an ammonia synthesis unit. Additionally some of the purge gas can be reformed catalytically or with oxygen to give a gas that can be returned to the synthesis reactor.

TABLE 4
ECONOMICS OF COAL DERIVED METHANOL

Total Levelised	Overall Capital %	Cost ($MM)	Efficiency MMbtu(HHV)
Foster Wheeler	1723	5.18	55.5
British Gas/Lurgi	1580	5.00	57.7
Koppers-Totzek	2342	6.75	52.4
Texaco	1925	5.70	58.2

Early 1977 Dollars
90% Operating Factor
$1.02/MMBtu Coal Cost
315,000 MMBtu/D Methanol Product

TABLE 5

ECONOMICS OF COAL DERIVED FUEL GAS

Technology	Total Capital	Cost MMBtu (HHV)	System Cold Efficiency
British Gas/Lurgi - O_2	392	2.79	81
Lurgi - Air	583	4.23	70
Lurgi - O_2	705	5.08	68
'U' Gas - Air	475	3.16	80
'U' Gas - O_2	460	2.93	85
Combustion Engineering - Air	398	2.70	77
Combustion Engineering - O_2	390	2.97	78

Mid 1976 Dollars
70% operating load factor
$1.00/MMBtu Coal Cost
10,000 TPD Illinois 6 coal

TABLE 6
Capital Costs and Efficiencies for Power Generation Systems

Process	Capital Cost $ million (mid 1976)	Overall System Efficiency Coal to Power (%) [1]
British Gas/Lurgi Slagging	553	40.6
Foster Wheeler	575	40.5
Texaco	638	38.7
Combustion Engineering	728	38.1
Lurgi	705	35.0
Coal fired plus stack gas desulphurisation	629	34.4

5.5 SNG production

SNG can be made at high thermal efficiency from slagging gasifier gas, partly because nearly half of the methane in the SNG is made in the gasifier. ~~The remainder is produced from the CO and H_2 in the gas by~~ reaction with steam over an active nickel catalyst. British Gas has developed an upgrading route, called the HCM (High Carbon Monoxide) process[17] that has been specifically tailored to take advantage of the particular composition of Slagging Gasifier gas (high CO content and low CO_2 and steam contents). In this way the high efficiency of the gasifier is not dissipated in the following stages and an overall coal-to-SNG efficiency of about 70% is possible. The combination of Slagging Gasifier and HCM also offers a relatively low capital cost. Details of the route have been presented [18]. Figure 4 gives the block diagram of the overall flow sheet and Figure 5 that for the methane synthesis section. The process steam for the reaction is generated in a saturator using low grade heat from the cooling trains and this leads to the high thermal efficiency. This process has been proved on a pilot scale and will be demonstrated on a commercial scale at Westfield.

As has been mentioned in earlier sections SNG is often an attractive co-product along with ammonia, methanol or Fischer-Tropsch liquids as this increases the overall efficiency of the total complex. The problem is that the output of the two products cannot be independently varied, but schemes of this type are under consideration.

5.6 Medium BTU Gas

The gas from the Slagging Gasifier, after removal of tar and aqueous liquor is suitable for use as a medium Btu fuel gas once it has passed through a desulphurisation stage such as Rectisol. It may not be necessary to remove all the sulphur compounds and some slip of the more difficult to remove carbonyl sulphide, COS, may be economically desirable. Removal of H_2S to quite low levels will probably be mandatory. If the gas is to be transmitted through pipelines the presence of some sulphur compounds to odorise the gas may be needed. The economics of producing fuel gas from coal were studied by EPRI and Table 5 summarises their results[19] and [20]. These show that the Slagging Gasifier produced the cheapest gas from the oxygen blown processes.

5.7 Power Generation

The direct use of coal for power generation has technical and particularly environmental drawbacks, such as the difficult desulphurisation of the coal or the stack gases to reduce atmospheric pollution. It is more attractive to gasify the coal and then to remove sulphur (mainly in the form of hydrogen sulphide) from the crude product gas. Removal of sulphur dioxide from stack gases has several drawbacks. Also, by allowing the use of advanced power generation cycles, gaseous fuels can be used more efficiently than the initial feedstock, giving improved thermal efficiency for power generation. Thus electricity generation using combined cycles, that is using an optimised combination of gas and steam turbines to drive altenators, (Fig.6) can result in an overall efficiency, including gasification, of above 40%. This compares with less than 35% for conventional steam cycle power plants fitted with stack gas clean-up devices.

The use of oxygen-blown gasifiers is not essential in this application, but can be economically desirable as it reduces the cost of the compression, gasification and gas purification stages. The low CO_2 content of the Slagging Gasifier is an advantage in the combined cycle. Little CO_2 is removed with the H_2S and the capital and operating costs of the sulphur recovery plant are minimised. Processes with higher CO_2 contents will also lose pressure energy during acid gas removal, which would otherwise be recovered in the gas turbine expander.

The evaluation of combined cycle schemes has been undertaken by EPRI for five different gasifiers[21] based on the simplified flow sheet shown in Figure 6. Their estimates of both plant capital costs and power generation efficiency are summarised in Table 6, which includes a conventional coal fired case, employing flue gas desulphurisation, for comparison. It clearly shows the advantage of the British Gas/Lurgi Slagging Gasifier. Some key parameters for a large combined cycle facility using the British Gas/Lurgi Slagging Gasifier are given in Table 7.

When used for power generation in a combined power cycle, a coal gasifier must respond quickly to the fluctuating fuel demands of the gas turbine over the full operating range. In 1979 EPRI awarded British Gas a contract to carry out trials on the British Gas/Lurgi Slagging Gasifier at its Westfield Development Centre with the aims of confirming the suitability of the Slagging Gasifier for use with combined cycle power generation systems. Following an initial run on Rossington Coal, a high caking, high sulphur Eastern USA coal (Pittsburgh 8) was chosen for the tests, which were particularly orientated towards establishing the ability of the gasifier to respond quickly to load changes and to run steadily at a variety of loads. These objectives were successfully achieved, with the gasifier's ability to respond to load changes more than matching the set requirements. The gasifier ran stably at all loads used between 30% and 100% of full load and could change rapidly from one load to another within this range. The gasifier can also be readily put on hot standby, from which it can return to full working load in ten minutes, if required. Some of these results are summarised in Figure 7. There were no significant gasifier transients during load changes and the gas composition remained substantially constant at all loadings.

As an aid to gasifier output stability a system of controlling the product gas flow instead of gasifier outlet pressure was devised for the Westfield Gasifier. This system is simple and very effective.

The controlling of the output characteristic together with the constant heating value and load change characteristic enables constant and relatively precise control of the gasifier 'heat' output and simplified matching of imposed load demand.

TABLE 7

Some key parameters of a large combined cycle facility using the British Gas /Lurgi Slagging Gasifier

Total net power output (MW)	1200
Coal feed rate (moisture free) (tons/hour)	400
Gasifier pressure (psig)	320
HHV of crude gas (dry), (Btu/scf)	379
Gas turbine inlet temperature (°F)	2400
Gas turbine pressure ratio	17:1
Gas turbine exhaust temperature (°F)	1130
Steam conditions (psig/°F/°F)	1450/900/1000
Steam turbine power output (MW)	385
Overall system efficiency based on coal HHV (%)	40.6

6. THE ENVIRONMENTAL IMPACT OF SLAGGING GASIFICATION

The provision of feed-stock by siting gasification plants at mine mouth will identify the plant with the existing problems that arise from mining coal. This will be particularly evident when both plant site and mine are greenfield projects. Both operations will have an impact on the local community and fauna. These effects can be significantly reduced, and become acceptable, both in terms of criteria imposed by legislation and resistance from popular reaction arising, as it often does, from reluctance to accept change. This reaction to change is far from being an insignificant problem and requires good management and committed public relations exercises. But with care, time, and expenditure of money, these problems can be solved.

Some aspects of the factors that need to be considered can be briefly mentioned here in connection with an integrated Slagging Gasification plant making medium Btu gas from Eastern USA coal in accordance with the flow sheet shown in Figure 8. The acid gas removal stage of a plant, using 5000 tons of coal containing 3.9% of sulphur, produces gases containing 195 tons/day of sulphur - mostly hydrogen sulphide but also some carbonyl sulphide, traces of carbon disulphide and organic compounds. The treatment of these gases, which also contain carbon dioxide and traces of hydrocarbons, do not present any engineering or technical difficulty as the required technology is already available.

Nitrogen will be produced in large quantities in the air separation plant (about 9000 tons/day),and that which is surplus to plant requirements would need to be discharged in a safe manner, probably via a stack.

The high pressure plant itself is so designed that it should not give rise to any significant releases of odorous or hazardous substances to the atmosphere except for small quantities released during maintenance under careful supervision. Monitoring around the British Gas/Lurgi Slagging Gasifier has shown that the level of polycyclic aromatic hydrocarbons was much lower than in urban atmospheres. This is contrary to certain statements that have appeared recently and is consistent with British Gas experience in coal gasification on these kinds of plants for almost twenty years.

The effluent produced from the gasification of coal with steam and oxygen will contain most, if not all, of the substances found in traditional coke oven or coal based town gas works effluents although the relative quantities will vary. Methods of treating liquor which contain phenols and ammonia are well known and effluents from the Lurgi Gasifier have been successfully dealt with in the past. The Slagging Gasifier will produce less effluent per ton of coal gasified although the resulting liquor will be more concentrated. The initial stages of treatment could either be carried out on site and the rest at a water authority works or the whole treatment could be undertaken on site. A study on effluents from the Slagging Gasifier has recently been carried out by British Gas in a project sponsored by the International Energy Authority. The object was to determine whether or not the concentrated liquors from a Slagging Gasifier were amenable to microbiological treatment. The result showed that the use of dephenolation, microbiological treatment, liming, and activated carbon clean up provided an acceptable effulent.

Some thought is being given to the fact that the combination of treatments mentioned above does not reduce the salt concentration of the final effluent. If the discharge of treated effluent was to fresh water the salinity might need to be controlled.

There is increasing interest in the pathways of trace metals in the environment and those arising from coal are no exception. Work is still continuing on the levels which might be significant. As far as effluents are concerned, most toxic metals are likely to be in the tenths to hundredths of one part per million in final treated effluent.

There are other potential sources of effluent. The slag quench water is innocuous and contains even lower levels of trace metals than those in ash quench water from dry ash reactors. Depending on the process units used on site there may be chemical solutions which require periodic disposal.

The main solid materials which are taken off site are:- about 550 tons/day of slag frit from a 8.4% ash coal, about 195 tons/day of sulphur from a 3.9% sulphur coal and the sludge from the effluent treatment plant which has been estimated at 2 - 3 tons/day.

The slag frit is a clean black glassy granular material which separates completely from the quench water and is easily handled. It has several potential uses examples of which are use as a road fill or as a component of construction materials; there may be other potential uses but these have not yet been fully evaluated. Because of its glassy character the long-term leaching of the frit are negligable. Some or all of the material may be marketed but any disposal to landfill should present no environmental problems.

The sulphur taken out by the Claus process is of high quality and it should be saleable. Should demand be low, the sulphur can be stored in solid form until required.

The sludge from the treatment of effluent is likely to contain concentrated trace elements. It may therefore be more desirable to dispose of it as waste rather than find an outlet through agricultural use. The sludge may also have substantial quantities of lime associated with it if this material is used in clean up procedures. About 25 - 30 tons of phenols and 30 - 35 tons of naphtha would be produced daily and sold as by-product, although these can be eliminated by gasification when reinjected into the gasifier.

The residual types and quantities of materials that must be discharged from the slagging gasifier are summarised in Table 8.

TABLE 8

Types and quantities of material required to be discharged from a 5000 ton/day plant.

Slag	550 tons/day
Sulphur	195 tons/day
Sludge	2-3 tons/day
Nitrogen	9000 tons/day
Waste water	1100 tons day
Ammonia	22 tons/day
Flue gas	4000-5000 tons/day

There are likely to be many sources of noise - coal handling, coal charging, compressors, vents, high pressure gas flow, turbines, pumps, etc. The coal handling and charging will not be any noisier than present day methods used at power stations and new developments in design and operation may lead to reduced noise levels in future. British Gas already has considerable experience of the design and operation of noise control equipment at compressor stations, pressure reduction stations and other installations. It has also developed successfully vent silencers which would find application on these plants. In planning the site and equipment, care must be taken to avoid noise nuisance.

7. PLAN FOR COMMERCIALISATION

In March 1975 British Gas entered into an agreement with Lurgi for the development of the British Gas/Lurgi Slagging Gasifier, and this has recently been updated. Under these agreements British Gas is the licensor of the process and also provides the detailed engineering and procurement of its proprietary equipment relating to the bottom half of the gasifier. Lurgi is responsible for the detailed engineering and procurement of its proprietary equipment relating to the top of the gasifier, but British Gas puts together and supplies the complete package.

The ERDA contracts referred to in Section 3 were signed in May 1977 and included a licence to Conoco granted by British Gas. Phase I of this contract, the design of the demonstration plant, was estimated to last 22 months and included the Technical Support Program also described in Section 3.

Unfortunately the project has been subject to various slow downs and delays so that Phase I will not be completed before June 1981, and the US Department of Energy has still not selected the process to enable the construction phase to proceed in 1981 despite the successful completion of the Technical Support Programme in 1978. Thus it remains uncertain whether the plant will be built because of the various political, environmental, regulatory and financing problems which face all coal gasification projects in the USA at the present time.

British Gas policy is to have ready a fully developed and proven process for the manufacture of SNG from coal for the time when natural gas from the North Sea is no longer sufficient to match the requirement for natural gas in the premium market. The uncertainty in the prospects for the Conoco project meant that British Gas decided that it must itself carry the project forward and it is now in the middle of a programme at Westfield which will include the construction of a larger gasifier of 8ft nominal diameter which will gasify 600 - 800 tons/day, and the carrying out of a three month run during which the gas will be treated by the HCM route to make SNG. This programme should be completed in 1982 and will confirm the commercial status of gasifiers of this size, which are smaller than that proposed for the Conoco demonstration plant which will gasify 1000 tons/day. British Gas is now prepared to grant licences for plants utilizing Slagging Gasifiers of sizes up to 8ft diameter and will provide full commercial guarantees.

British Gas is supporting Florida Power Corporation in a Feasibility Study for the integration of a Slagging Gasifier with combustion turbines and exhaust heat recovery steam generators to repower existing condensing steam turbine generators at the Higgins Plant in Pinellas County, Florida. This study will last twelve months and is expected to be followed by detailed engineering and construction of the facility.

A number of other feasibility studies are under consideration and these should lead to the construction of additional gasifiers. British Gas considers that, in view of the results obtained at Westfield and the ongoing programme, there is no technical objection to ordering plants at the present time based on 8ft diameter gasifiers.

8. CONCLUSIONS

The British Gas/Lurgi Slagging Gasifier is at an advanced stage of development and can now be regarded as ready for commercial exploitation. It is particularly suitable for high volatile, unreactive, bituminous coals and can find wide application in the areas of ammonia, methanol and Fischer-Tropsch synthesis, SNG manufacture, combined cycle power generation and medium Btu and reducing gas production.

There is a strong possibility that the first commercial plants will be constructed in the USA. However, there is considerable interest in other parts of the world, including Europe, which will not be far behind the USA.

Finally, the authors wish to express their thanks to the British Gas Corporation for permission to present this paper. They also wish to express their appreciation to those colleagues at the Midlands Research Station, the Westfield Development Centre and in the International Consultancy Service who gave such excellent and willing support.

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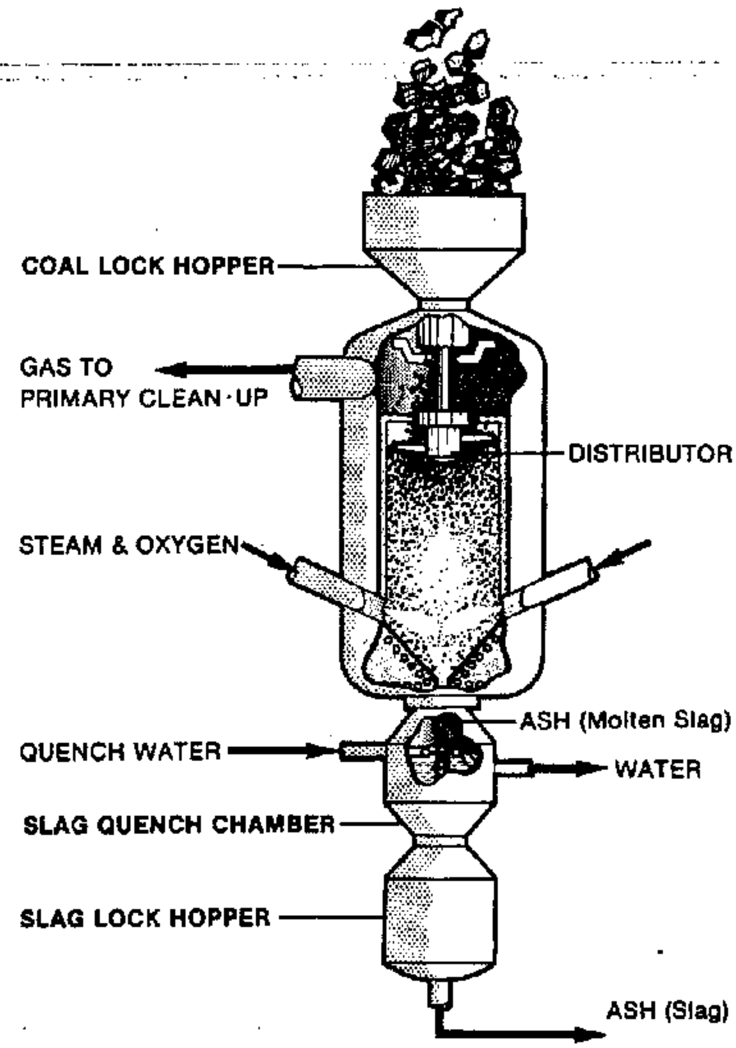

Figure 1
BRITISH GAS/LURGI SLAGGING GASIFIER

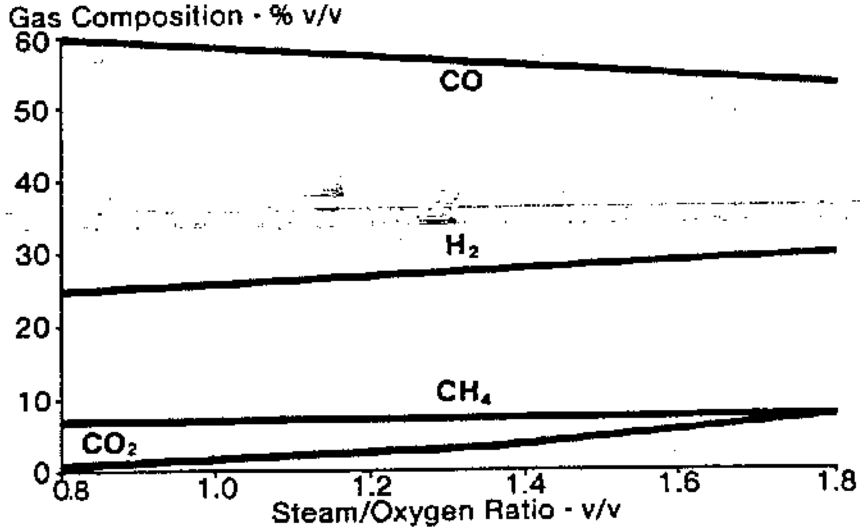

Figure 2
INFLUENCE OF STEAM TO OXYGEN
RATIO ON GASIFIER PERFORMANCE

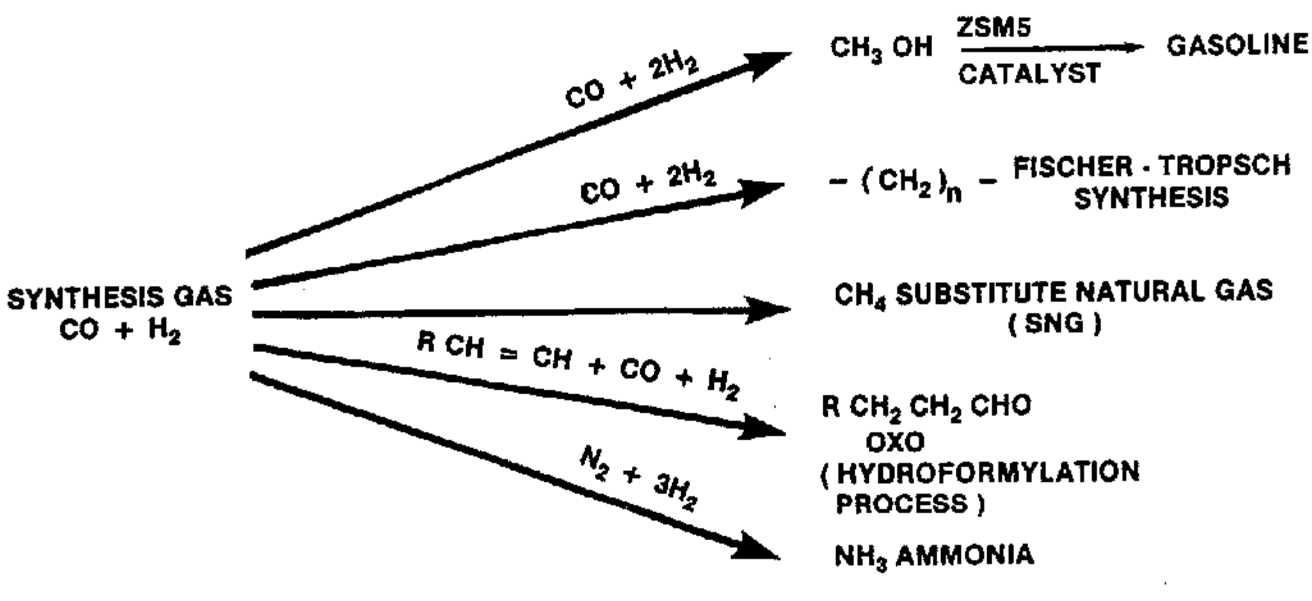

Figure 3
APPLICATIONS OF SYNTHESIS GAS

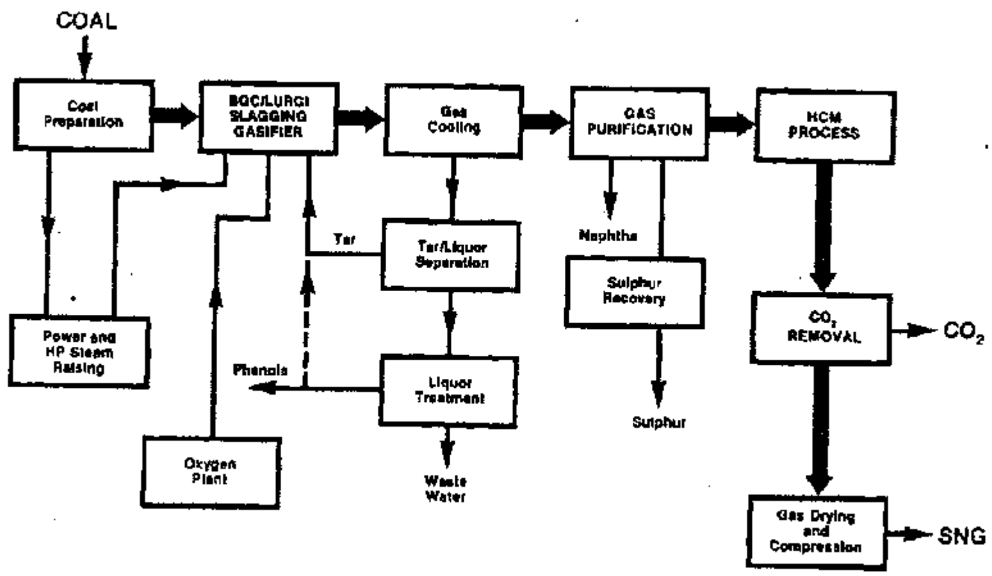

Figure 4
SLAGGING GASIFICATION ROUTE TO SNG USING THE HCM PROCESS

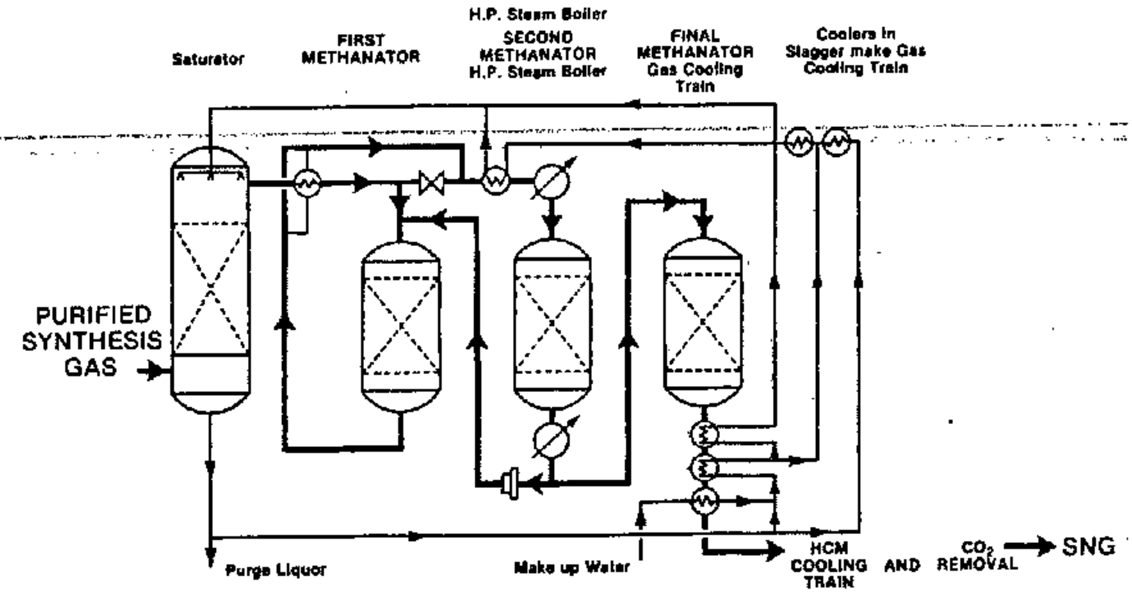

Figure 5
THE HCM METHANE SYNTHESIS PROCESS

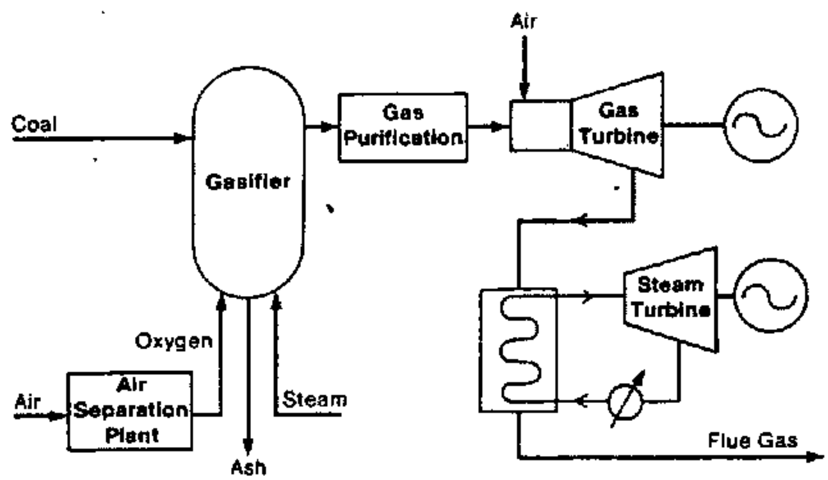

Figure 6
COAL GASIFICATION WITH
COMBINED CYCLE POWER GENERATION

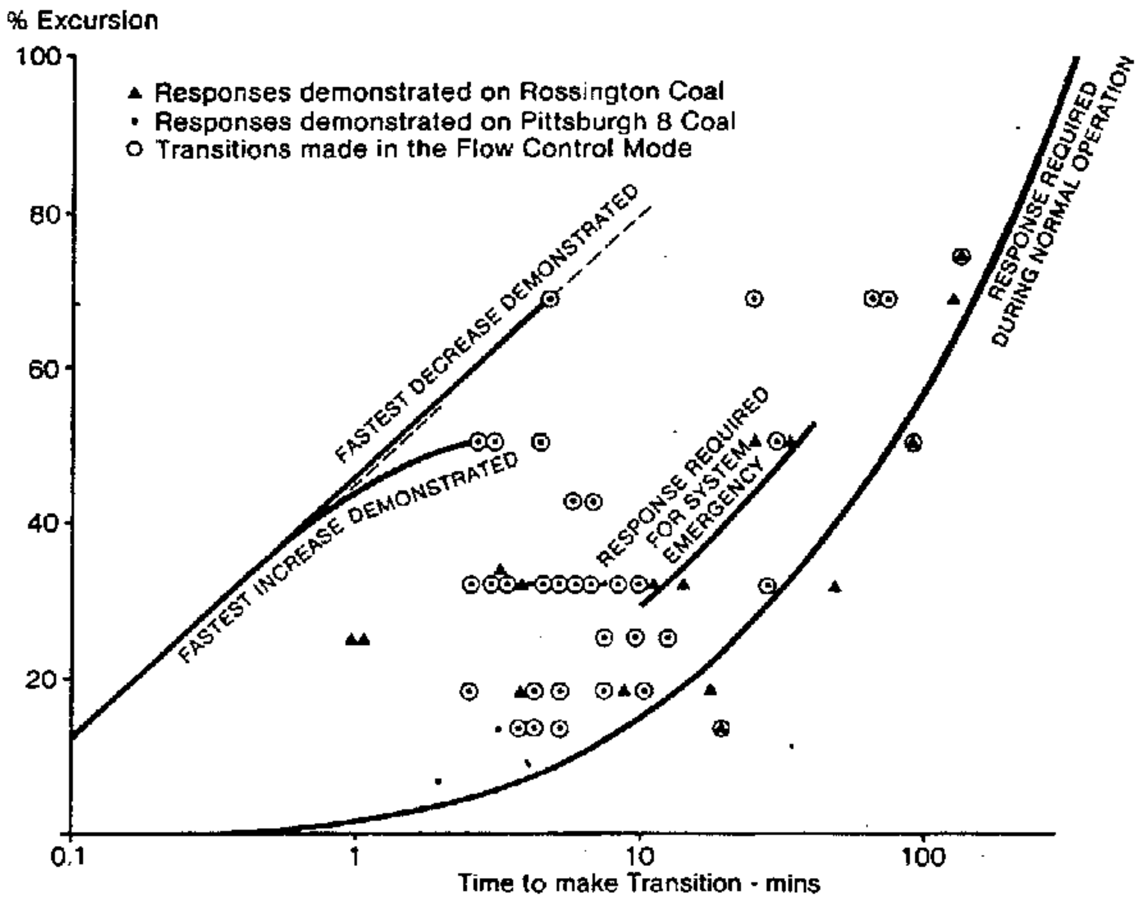

Figure 7
BRITISH GAS/LURGI SLAGGING GASIFIER
DEMONSTRATED RESPONSES TO LOAD CHANGE

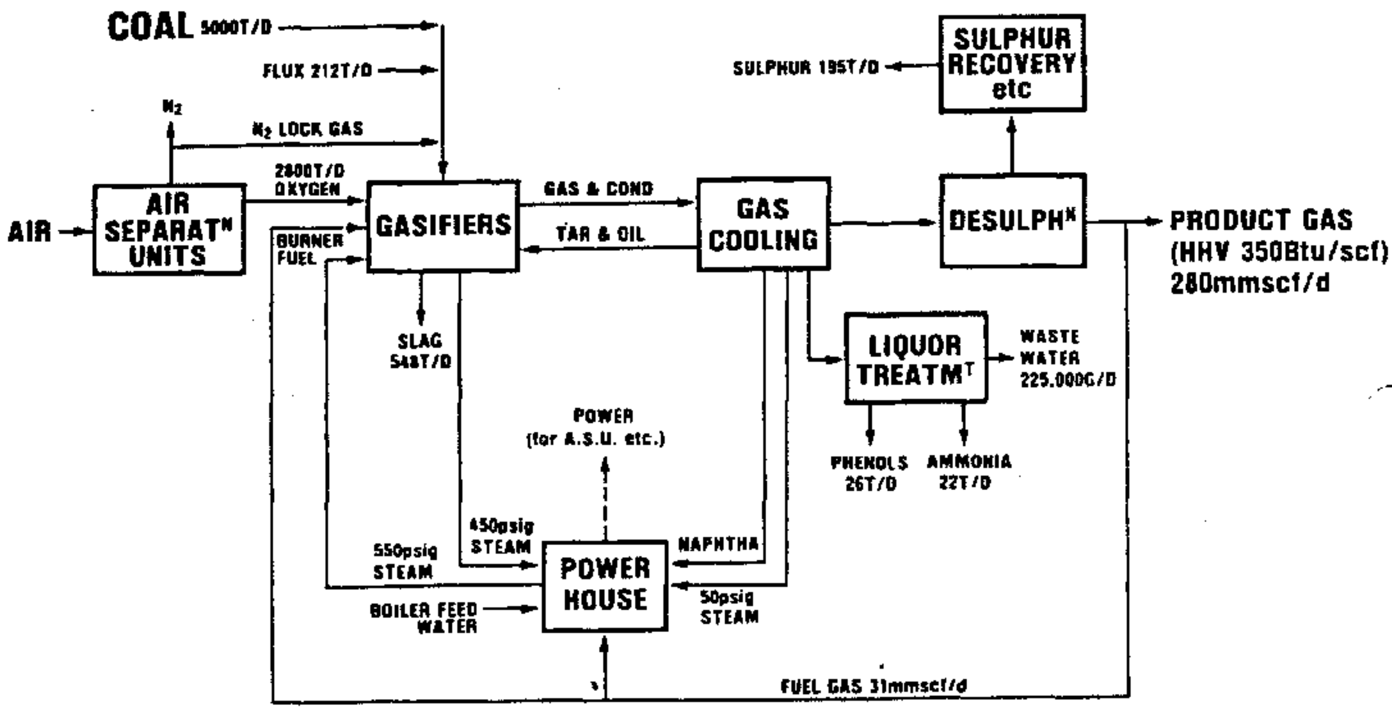

Figure 8
EASTERN U.S.A. COAL