APPENDIX A

PLANT STEAM COAL REQUIREMENTS

Dry-Ash Lurgi System

This Appendix shows the method used to compute the quantity of total plant coal that must be sent to a coal-fired steam plant to provide steam for oxygen production, gasifier steam and downstream unit requirements. The example shown is for Illinois #6 coal.

For the Dry-Ash Lurgi, in addition to fine coal firing, the gasifier tars, oils and phenols are sent for steam production.

The plant coal split requirement for this case is shown below.

PRODUCTION OF TARS, OILS & PHENOLS FOR DRY-ASH LURGI
(Btu/Lb of Coal Gasified)

		DAF		As-Received	
	MBtu/lb	lb/lb	MBtu/lb	lb/lb	MBtu/lb
Tars	15.7	.038	0.597	.031	.4867
Oils	16.7	.0035	0.058	.0028	.047
Phenols	7.8	.0057	0.044	.0045	.035
Totals			0.700		.569

Total plant coal = 2,317 M #/hr
LHV (as-received) = 10,951 Btu/lb
Lbs O_2/lb as-received coal = 0.454
Lbs steam/lb as-received coal = 1.98
Lbs steam = (.98 + 1.78(1) x 0.454) G.C. + 596(2)
where G.C. = Gasifier Coal
Lbs steam = 2,788 G.C. + 596
S.C. + G.C. = 2,317 where S.C. = Steam Coal
Steam Btu = 1,550 x lb steam
Steam Coal Btu's = 1,550 x steam - (569 x G.C.)
= S.C. x 10,986
∴ 1,550 x lb steam - (569 G.C.) = (2,317 - G.C.) 10,986
∴ 1,550 (2.7888 G.C. + 596) - 569 G.C. = (2,317 - G.C.) 10,986
∴ 4,321 G.C. + 923,800 - 569 G.C. = 25,454,562 - 10,986 G.C.
∴ 14,738 G.C. = 24.526 x 10^6
∴ G.C. = 1,664 M lbs/hr
∴ S.C. = 653 M lbs/hr

BGC-Lurgi System

For the BGC-Lurgi, only the oils and phenols are sent to the steam plant, the tars are recycled to the gasifier. The plant coal split requirement for the BGC gasifier case is shown below.

PRODUCTION OF OILS & PHENOLS FOR BGC-LURGI
(Btu/Lb of Coal Gasified)

		DAF	As-Received	
	MBtu/lb	lb/lb	lb/lb	MBtu/lb
Oils	16.7	.021	.017	283
Phenols	7.8	.0058	.0047	37
Total				320

Total coal (as-received) = 2,317 M lbs/hr
LHV of as-received coal = 10,986 Btu/lb
Lbs O_2/lb as-received coal = 0.498
Lbs steam/lb as-received coal = 0.354
Lbs steam = (1.78[1] x 0.498 + 0.354) G.C. + 596[2]
= 1.24 G.C. + 596
S.C. + G.C. = 2,317
1,550 x steam - 320 G.C. = S.C. x 10,986
∴ 1,550 (1.24 G.C. + 596) - 320 G.C. = (2,317 - G.C.) 10,986
∴ 12,589 G.C. = 24.531 x 10^6
∴ G.C. = 1,949 M Btu/hr
∴ S.C. = 368 M lbs/hr

(1) Assumed that 1.78 lb steam required to produce 1 lb of oxygen.
(2) Plant steam needs in excess of gasifier requirement.

APPENDIX B

SHIFT ANALYSIS

In the MRDC report,[3] a portion of the raw gas stream was shifted to an H_2/CO ratio of 10:1. The portion shifted is sufficiently large to produce the required ratio of 2.54:1 for the Synthol reactor when the shifted stream is recombined with the unshifted stream.

The same procedure is used in the analyses of the Lurgi dry-ash fixed-bed gasifier for this report.

The following illustrates the computation necessary to calculate the total number of moles of raw gas requiring to be shifted:

Let A M moles/hr = Total raw gas stream flow
B M moles/hr = M moles/hr of H_2
C = M moles/hr of CO
Required H_2/CO ratio = X

$$\text{Moles of CO remaining after shift} = \frac{B+C}{1+X} = C^1$$

$$\therefore \text{Moles requiring shift} = C-C^1$$

The amount of synthesis gas which must be shifted to an H_2/CO ratio of 10:1 to produce an overall H_2/CO ratio of X when combined with the unshifted stream is:

$$\text{Synthesis gas to shift} = \frac{C - C^1}{\frac{10}{11} - \frac{B/C}{1+B/C}}$$

$$\therefore \text{Total raw gas stream requiring shift} = \text{Synthesis gas to shift} \times \frac{A}{B+C}$$

APPENDIX C

COMPUTATION OF ENTRAINED GASIFIERS PRODUCT GAS OUTPUT

Texaco

Gas computation data for Texaco gasification were obtained from Reference 12. Use of this data resulted in a coal/slurry concentration of 74 to 26 for the Illinois #6 coal used in this report. This slurry concentration was adjusted to be 63/35 in the following manner:

Slurry Composition	74/26 lbs/hr	Delta lbs/hr	63/35 lbs/hr
Coal (DAF)	1,869,000	0	1,869,000
Oxygen	1,781,458	122,208	1.903,666
Inerts	35,299	2,422	37,721
Steam	0		
Water	807,770	439,754	1,247,524
Ash	210,817	0	210,817
Coal Moisture	237,014	0	237,014
CO (lb moles)	99,520	-7,630	91,890
CO_2 (lb moles)	20,420	+7,630	28,050

Heat energy required to raise the increased water to gasification temperature is given by:

439,756 (200°F water ⟶ 2360°F steam at 600 psi) = 929.66 MMBtu

This heat energy is provided by combustion of carbon monoxide to form carbon dioxide. 7.63×10^3 lb moles of CO are required to produce this heat. Oxygen requirement for this combustion is 122.21×10^3 lb moles.

APPENDIX D

GASOLINE COST COMPUTATIONS
SYNTHOL SYNTHESIS

Gasifier Type	Mode	Coal	Plant Construction Cost 1977 $	Plant Output MMBtu/hr HHV(1)	Cost per MMBtu/hr of Output				Gasoline Cost per Gallon			
					Capital Recovery	Plant O&M(2)	Coal Cost	Total	1977 $ Thermal Basis(3)	1977 $ Market Basis(4)	1980 $(5) Thermal Basis(3)	1980 $(5) Market Basis(4)
Dry Ash Lurgi	M	Wyoming	1,186.1	[illegible]738	5.45	1.61	.72	7.78	.93	1.33	1.24	1.76
Dry Ash Lurgi	AL	Wyoming	1,382.7	[illegible]713	8.49	2.50	.96	11.95	1.43	1.51	1.90	2.00
BGC Lurgi	M	Wyoming	1,104.3	11,955	4.81	1.42	.68	6.91	.83	.92	1.10	1.22
BGC Lurgi	AL	Wyoming	1,289.4	9,444	7.05	2.08	.86	9.99	1.19	1.24	1.58	1.65
Westinghouse	M	Wyoming	1,163.1	11,805	5.09	1.50	.69	7.27	.87	1.03	1.16	1.37
Westinghouse	AL	Wyoming	1,325.4	9,388	7.29	2.15	.86	10.30	1.23	1.28	1.63	1.70
Texaco	M	Wyoming	1,167.1	11,254	5.36	1.58	.77	7.71	.92	1.05	1.22	1.39
Texaco	AL	Wyoming	1,289.0	9,577	6.95	2.05	.91	9.91	1.18	1.23	1.57	1.64
Shell-Koppers	M	Wyoming	1,231.4	12,333	5.16	1.52	.70	7.38	.88	.98	1.17	1.30
Shell-Koppers	AL	Wyoming	1,347.2	10,499	6.62	1.95	.83	9.41	1.13	1.16	1.50	1.55

(1) Does not include by-product sulfur and ammonia.

(2) O&M cost are net of by-product recovery costs.

(3) All products sold for same cost per MMBtu.

(4) Products priced per relative price schedule given in Figure 3-14.

(5) 1980 prices are determined by escalating 1977 capital costs by 1.26 and O&M costs by 1.39. (Nielsen Index.)

APPENDIX D (Continued)

GASOLINE COST COMPUTATIONS
SYNTHOL SYNTHESIS

Gasifier Type	Mode	Coal	Plant Construction Cost 1977 $	Plant Output MMBtu/hr HHV[1]	Cost per MMBtu/hr of Output				Gasoline Cost per Gallon			
									1977 $		1980 $[5]	
					Capital Recovery	Plant O&M[2]	Coal Cost	Total	Thermal Basis[3]	Market Basis[4]	Thermal Basis[3]	Market Basis[4]
Dry Ash Lurgi[6]	M	Ill #6	1,464.5	12,047	6.28	1.85	1.96	10.09	1.21	2.14	1.58	2.78
Dry Ash Lurgi[6]	AL	Ill #6	1,670.5	9,114	9.46	2.79	2.59	14.85	1.78	2.32	1.91	3.01
Dry Ash Lurgi[7]	M	Ill #6	1,393.3	15,303	4.70	1.39	1.54	7.63	.91	1.33	1.19	1.73
Dry Ash Lurgi[7]	AL	Ill #6	1,674.9	11,245	7.69	2.27	2.10	12.06	1.44	1.52	1.88	1.95
BGC Lurgi	M	Ill #6	1,335.2	14,344	4.81	1.42	1.68	7.90	.95	1.20	1.24	1.56
BGC Lurgi	AL	Ill #6	1,542.2	11,461	6.95	2.05	2.10	11.10	1.33	1.39	1.73	1.81
Westinghouse	M	Ill #6	1,319.6	15,846	4.30	1.27	1.49	7.06	.84	.97	1.10	1.26
Westinghouse	AL	Ill #6	1,523.6	12,562	6.22	1.85	1.88	9.99	1.19	1.24	1.56	1.61
Texaco	M	Ill #6	1,401.8	14,548	4.98	1.47	1.62	8.07	.96	1.13	1.26	1.47
Texaco	AL	Ill #6	1,536.1	12,368	6.41	1.89	1.91	10.21	1.22	1.27	1.59	1.66
Shell-Koppers	M	Ill #6	1,400.0	15,813	4.57	1.35	1.49	7.41	.89	.99	1.16	1.29
Shell Koppers	AL	Ill #6	1,541.4	13,461	5.91	1.74	1.75	9.41	1.13	1.16	1.47	1.51

(1) Does not include by-product sulfur and ammonia.

(2) O&M cost are net of by-product recovery costs.

(3) All products sold for same cost per MMBtu.

(4) Products prices per relative price schedule given in Figure 3-14.

(5) 1980 prices are determined by escalating 1977 capital costs by 1.26 and O&M costs by 1.38. (Nielson Index.)

(6) Calculated from Westfield gasifier trials, Reference 2.

(7) Calculated from Fluor data, Reference 6.

APPENDIX D (Continued)

GASOLINE COST COMPUTATIONS
KOLBEL SYNTHESIS

Gasifier Type	Mode	Coal	Plant Construction Cost 1977 $	Plant Output MMBtu/hr HHV(1)	Cost per MMBtu/hr of Output				Gasoline Cost per Gallon			
									1977 $		1980 $(5)	
					Capital Recovery	Plant O&M(2)	Coal Cost	Total	Thermal Basis(3)	Market Basis(4)	Thermal Basis(3)	Market Basis(4)
BGC Lurgi	M	Wyoming	1,067.9	11,909	4.63	1.37	.68	6.68	.80	.84	1.06	1.12
BGC Lurgi	AL	Wyoming	1,180.4	10,377	5.87	1.73	.78	8.39	1.00	1.03	1.33	1.44
Westinghouse	M	Wyoming	1,125.4	11,618	5.00	1.48	.70	7.17	.86	.93	1.14	1.24
Westinghouse	AL	Wyoming	1,212.4	10,175	6.15	1.82	.80	8.76	1.05	1.08	1.39	1.36
Texaco	AL	Wyoming	1,176.1	10,583	5.74	1.69	.82	8.25	.99	1.01	1.32	1.34
Shell-Koppers	M	Wyoming	1,163.8	12,077	4.98	1.47	.72	7.16	.86	.89	1.14	1.18
Shell-Koppers	AL	Wyoming	1,193.5	11,568	5.33	1.57	.75	7.65	.92	.94	1.22	1.25

(1) Does not include by-product sulfur and ammonia.

(2) O&M cost are net of by-product recovery costs.

(3) All products sold for same cost per MMBtu.

(4) Products priced per relative price schedule given in Figure 3-16.

(5) 1980 prices are determined by escalating 1977 capital costs by 1.26 and O&M costs by 1.38. (Nielson Index.)

APPENDIX D (Concluded)

GASOLINE COST COMPUTATIONS
KOLBEL SYNTHESIS

Gasifier Type	Mode	Coal	Plant Construction Cost 1977 $	Plant Output MMBtu/hr HHV(1)	Cost per MMBtu/hr of Output				Gasoline Cost per Gallon			
									1977 $		1980 $(5)	
					Capital Recovery	Plant O&M(2)	Coal Cost	Total	Thermal Basis(3)	Market Basis(4)	Thermal Basis(3)	Market Basis(4)
BGC Lurgi	M	Ill #6	1,279.0	14,126	4.68	1.38	1.70	7.76	.93	1.05	1.24	1.40
BGC Lurgi	AL	Ill #6	1,392.3	12,376	5.81	1.71	1.94	9.47	1.13	1.16	1.51	1.55
Westinghouse	M	Ill #6	1,267.1	15,598	4.19	1.24	1.51	6.95	.83	.89	1.11	1.19
Westinghouse	AL	Ill #6	1,377.7	13,60[illegible]	5.23	1.54	1.74	8.51	1.02	1.05	1.36	1.40
Texaco	M	Ill #6	1,349.2	14,249	4.89	1.44	1.66	7.99	.96	1.01	1.28	1.35
Texaco	AL	Ill #6	1,385.2	13,625	5.25	1.55	1.73	8.53	1.02	1.05	1.36	1.40
Shell-Koppers	M	Ill #6	1,318.5	15,486	4.40	1.30	1.52	7.22	.86	.90	1.15	1.20
Shell-Koppers	AL	Ill #6	1,355.7	14,834	4.72	1.39	1.59	7.70	.92	.94	1.23	1.25

(1) Does not include by-product sulfur and ammonia.

(2) O&M cost are net of by-product recovery costs.

(3) All products sold for same cost per MMBtu.

(4) Products priced per relative price schedule given in Figure 3-14.

(5) 1980 prices are determined by escalating 1977 capital costs by 1.26 and O&M costs by 1.38. (Nielsom Index.)

REFERENCES

1. D. Gray, M. Lytton, M. Neuworth, G. Tomlinson, "The Impact of Developing Technology on Indirect Liquefaction." MTR 80W326, The MITRE Corporation, McLean, Virginia, November 1980. (NTIS #DOE/ET/10280-T1T2.)

2. "Trials of American Coals in a Lurgi Gasifier at Westfield, Scotland." Energy Research and Development Administration, Report FE-105, November 1974.

3. Max Schreiner, "Research Guidance Studies to Assess Gasoline from Coal by Methanol-to-Gasoline and SASOL-Type Fischer-Tropsch Technologies," final report, Mobil Research and Development Corporation, FE-2447-13, August 1978.

4. J.D. Holmgren, C.E. Seglem, L.A. Salvador, M.W. Dyos, "Coal Gasification/Combined Cycle System is Ready for Commercialization," Modern Power Systems, Vol 1, No. 3, 44, March 1981.

5. Private communication from Westinghouse Synthetic Fuels Division.

6. "Economies of Air vs. Oxygen Pressure Gasification of Coal," EPRI Report 239-1, Phase 1. Report prepared by Fluor Engineers and Contractors, Inc. NTIS Report PB-242-595, January 1975.

7. "Phase I: The Pipeline Gas Demonstration Plant Design and Evaluation of Commercial Plant," Continental Oil Company, FE-2542-10, Vol 3.

8. G.F.I. Roberts, D. Hebden, C.T. Brooks, J.D. Sudbury, "The Application of Slagging Gasification to the Production of SNG from Coal," 14th Congres Mondial du Gaz, Toronto, 1979.

9. R.C. Corey, "Measurement and Significance of the Flow Properties of Coal-Ash Slag," United States Bureau of Mines Bulletin 618, 1964.

10. Elliott, Martin A. (Editor), "Chemistry of Coal Utilization. Second Supplementary Volume." John Wiley & Sons, 1981. Chapter 21, "Coal Ash--Its Effect on Combustion Systems," W.T. Reid, page 1440.

11. H. Kolbel and M. Ralek, "The Fischer-Tropsch Synthesis in the Liquid Phase," Catalysis Reviews, Vol 21, No. 2. 1980.

REFERENCES (Concluded)

12. "Economic Studies of Coal Gasification Combined Cycle System for Electric Power Generation," EPRI AF-642, Final Report, January 1978.

13. E.V. Vogt and M.J. van der Burgt, "Status of the Shell-Koppers Process," CEP, March 1980, 65.