APPENDIX TO CHAPTER 5, A: STATUS OF PROCESS DEVELOPMENT

The status of development of coal conversion and oil shale retorting both in this country and abroad are reviewed at length in the literature (Rogers and Hill, 1979; National Coal Association, 1980; Fluor Engineers and Constructors, Inc., 1979a,b,c) .

The status of synfuel commercialization is summarized in the following tables:

- "Table A: Coal Gasification (Fluor Engineers and Constructors, Inc., 1979a) .
- Table B: Coal Liquefaction (Fluor Engineers and Constructors, Inc., 1979b) .
- Table C: Shale Oil Retorting (Fluor Engineers and Constructors, Inc., 1979c) .

These tables also review the major characteristics of these technologies. More details about the processes are given in Bentz, E.J., 1980.

ejb&a

TABLE A-1
COAL GASIFICATION - COMMERCIALLY PROVEN PROCESSES

NAME	DEVELOPERS AND SPONSORS	COMMERCIAL PLANTS	FUTURE PLANS FOR PROCESS	FEEDSTOCKS	PRODUCTS	TYPE OF REACTOR	OXIDANT	OPERATING PRESSURE	HEATING VALUE OF PROCESS GAS	PROCESS ADVANTAGES	PROCESS DISADVANTAGES	TYPICAL GASIFIER SECTION OUTLET COMPOSITION	PROPOSED GASIFIER REQUIREMENTS FOR A 250 MM SCFD COMMERCIAL PLANT	NOTES
KOPPERS-TOTZEK	Koppers Company, Inc.	Commercial – 16 plants since 1952	Engineering studies being performed now for industrial application	All ranks of coal, tar, pitch, coke, and other carbonaceous materials	Synthesis gas and sulfur	atmosphere flow	Oxygen	Atmos.	Medium/High	1) No by-products other than slag and sulfur 2) Wide range of feed 3) Quick turn down ratio 4) Feed can be changed	1) Low pressure – Atmos 2) Requires O_2 plant 3) Hi temp. gasifier operation 3000°F 4) High methanation req'mts for pipeline gas 5) High compression req'mts for pipeline gas	Mol % (H_2O FREE) CH_4 0 H_2 30 CO 60 CO_2 8 H_2S – N_2 –	Gasifier can handle 850 T/D coal each. 18-20 gasifiers required	
LURGI	Lurgi GmbH	To date has built 14 commercial plants utilizing their gasifiers	Presently engineering 8 plants for the U.S. and Canada	Flexible and capable of handling all types, except strongly caking coals	Fuel gas suitable for SNG, by-product oils, and sulfur	Moving Bed	Air Oxygen	Medium Medium	Low Medium/High	1) Only pressure gasifiers that have long term commercial operation	1) Requires O_2 plant, if SNG is the product 2) Requires compression of product gas 3) Requires sized coal	Mol % (H_2O FREE) CH_4 10 H_2 38 CO 24 CO_2 28 H_2S – N_2 –	Gasifier section would consist of 25-30 fixed bed reactors designed to operate at 400-450 PSI	Low BTU gas in air blown case
WELLMAN-GALUSHA	Wellman Engineering Co	Commercial – 28 plants in operation	Construction in progress for additional plants	Non-caking coals or coke	Low BTU gas, by-product oils, and sulfur	Moving-Bed	Air	Atmos.	Low	1) Small scale (suitable for individual plant installation)	1) Low pressure – Atmos 2) Requires sized coal 3) Low BTU gas must be used on or near site	Mol % (H_2O FREE) CH_4 3 H_2 15 CO 29 CO_2 3 H_2S N_2 50	Small scale operation – Not suitable	Pressurized operations are under pilot plant work
WINKLER	Winkler	Commercial – 16 plants in operation	Engineering studies in preparation for commercial units	Most ranks of coal can be used	Synthesis gas and sulfur	Fluid-Bed	Air Oxygen	Atmos Atmos.	Low Medium/High	1) H C Liquors can be added during 2) No tars or oils produced	1) Requires O_2 plant for Hi BTU gas 2) Low pressure – Atmos 3) Coal drying may be req'd 4) 70% of Ash Overhead 5) Reactor brick lined 6) High methanation req'mts as only 2% CH_4 produced 7) High compression req'd for pipeline gas req'mts	Mol % (H_2O FREE) CH_4 2 H_2 35 CO 48 CO_2 15 H_2S – N_2 –	10-20 gasifiers required	Low BTU gas in air blown case

TABLE A-1 (continued)

COAL GASIFICATION - PROCESSES READY FOR DEMONSTRATION

NAME	DEVELOPERS AND SPONSORS	PILOT PLANTS	FUTURE PLANS FOR PROCESS	FEEDSTOCKS	PRODUCTS	TYPE OF REACTOR	OXIDANT	OPERATING PRESSURE	HEATING VALUE OF PROCESS GAS	PROCESS ADVANTAGES	PROCESS DISADVANTAGES	TYPICAL GASIFIER SECTION OUTLET COMPOSITION	NOTES
BGC/LURGI SLAGGING	Being developed by British Gas Council and Lurgi under the sponsorship of 16 American Companies	A Lurgi gasifier at Westfield was converted to slagging operation	Design of 3800 TPD plant for Noble County, Ohio is underway	Most coals – except high ash, high moisture coals	Fuel gas suitable for SNG and sulfur	Moving-Bed	Oxygen	Medium	Medium/ igh	1) High efficiency 2) High gas output 3) Lower steam requirements than conventional Lurgi	1) Requires O_2 plant 2) Requires compression of product gas if pipeline gas is required 3) Requires sized coal	Mol % (H_2O FREE) CH_4 8 H_2 28 CO 60 CO_2 3 H_2S – N_2 1	The slagging gasifier should have at least three times the output of a standard Lurgi gasifier
[illegible]-KOPPERS	Shell [illegible] Research	Pilot plant in Amsterdam, the Netherlands. Capacity 6 TPD. Operating since 1978	[illegible] on 150 TPD plant Harburg, Germany early 1977	All coals	Synthesis gas and sulfur	Entrained-Flow	Oxygen	Low	Medium	1) Requires no pretreatment of feed 2) No by-products other than slag and sulfur 3) Gasifier is entrained flow	1) Requires O_2 plant 2) Requires compression of product gas if pipeline gas is required	Mol % (H_2O FREE CH_4 1 H_2 30 CO 67 CO_2 1 H_2S 1 N_2 –	Pressurized system increasing capacity and reduces compression requirements over conventional Koppers-Totzek
TEXACO	Being developed by Texaco Development Corp.	M [illegible] Capacity	Texaco and SCE to [illegible] 650MW power station in Cantonwater, CA.	All coals	Synthesis gas and sulfur	Entrained-Flow	Air Oxygen	Medium Medium	Low Medium/High	1) Requires no pretreatment of feed 2) Gasifier is entrained flow 3) No by-product char 4) Slurry feed system	1) Requires O_2 plant 2) Requires compression of product gas if pipeline gas is required	Mol % (H_2O FREE) CH_4 1 H_2 45 CO 45 CO_2 8 H_2S – N_2 –	used [illegible] ide ran operance

TABLE A-1 (continued)

COAL GASIFICATION - PROCESSES READY FOR COMMERCIAL DEVELOPMENT

NAME	DEVELOPERS AND SPONSORS	PILOT PLANTS	FUTURE PLANS FOR PROCESS	FEEDSTOCKS	PRODUCTS	TYPE OF REACTOR	OXIDANT	OPERATING PRESSURE	HEATING VALUE OF PROCESS GAS	PROCESS ADVANTAGES	PROCESS DISADVANTAGES	TYPICAL GASIFIER SECTION OUTLET COMPOSITION	NOTES
BCR	Bituminous Coal Research with DOE funding	1 2 TPD in operation at Monroeville, Pennsylvania			Low BTU gas and sulfur	Fluid Bed	Air	Medium	Low	1) No residual char 2) Does not require O_2 plant	1) Coal requires pretreatment 2) Requires particulate and sulfur removal	N A	
BI-GAS	Being developed by Bituminous Coal Research, Inc with financing from ERDA and AGA	Pilot plant in Homer City, Pa , capacity 120 TPD, operating since 1976	None until P P tests have been run and evaluated	All coals	Fuel gas suitable for SNG and sulfur	Entrained Flow	Air Oxygen	High High	Low Medium/High	1) Requires no pretreatment of feed 2) Gasifier is entrained flow 3) Does not produce char by-product 4) Slurry feed system	1) Requires O_2 plant	Mol % (H_2O FREE) CH_4 17 H_2 24 CO 44 CO_2 14 H_2S 1 N_2 -	The gasifier may also be operated on air rather than oxygen at moderate system pressures producing a low BTU gas
B&W	Being developed by B&W with financing from EPRI	5 TPD pilot plant under construction, Alliance, Ohio		All coals	Synthesis gas and sulfur	Entrained Flow	Air Oxygen	Low Low	Low Medium/High	1) Requires no pretreatment of feed 2) Gasifier is entrained flow 3) No by-product char	1) Requires O_2 plant 2) Requires compression of product gas	Mol % (H_2O FREE) CH_4 - H_2 30 CO 58 CO_2 9 H_2S 1 N_2 1	Operation with air will produce a low BTU gas Moderate sized (17 TPH) plant was operated successfully in 1950's
C E	Being developed by Combustion Engineering with financing from EPRI	120 TPD pilot plant under construction, Windsor, Conn.	Detailed design of a 5 TPH unit underway	All coals	Low BTU gas and sulfur	[illegible]	Oxygen	Atmos.	Low Medium/High	1) Does not require O_2 plant 2) Requires no pretreatment of feed 3) No by-product char 4) Gasifier is entrained flow	1) Atmospheric pressure 2) Requires compression of product gas 3) Low BTU gas - must be used on or near site	Mol % (H_2O FREE) CH_4 - H_2 12 CO 23 CO_2 5 H_2S - [illegible] 60	Operation with oxygen will produce an intermediate BTU gas, which can be upgraded to pipeline gas
[illegible] ALLEGHENY	Being developed by Conoco Coal Development Company with financing from DOE and AGA	A 48 TPD pilot plant, located in Rapid City, S D	[illegible] plant underway	[illegible] mites and possibly sub bituminous	Fuel gas suitable for SNG and sulfur					1) Does not require O_2 plant 2) Does not produce char by-product 3) Requires no pretreatment of feed	1) Good only for highly reactive lignite and sub-bituminous coals 2) Requires compression of product gas 3) Requires sulfur removal on flue and synthesis gas streams 4) Large number of fluidized beds may present a control problem.	Mol % (H_2O FREE) CH_4 21 H_2 54 CO 18 CO_2 7 H_2S - N_2 -	
COGAS	Joint venture of Consolidated Natural Gas, FMC Corp , Panhandle Eastern Pipeline, and Tennessee Gas Pipeline	Successful pilot plant operation at 100 TPD Located at Leatherhead, England	Planning integration of coal pyrolysis and and char gasification	By-product char from pyrolysis	Synthesis gas and sulfur					1) Does not require O_2 plant	1) Requires compression of product gas 2) Requires sulfur removal on flue and synthesis gas streams	Mol % (H_2O FREE) CH_4 1 H_2 53 CO 24 CO_2 20 H_2S - N_2 2	Could possibly gasify by-product char from any gasification process
FOSTER-WHEELER	Foster Wheeler with support from DOE	400 TPD pilot plant at Sioux Falls, S D. scheduled for completion late 1977	-	Most coals	Low [illegible] gas and sulfur	[illegible]ined [illegible]ow	[illegible]	Medium	Low	1) Requires no pretreatment of feed 2) Gasifier is entrained flow 3) No by-product char	1) Requires sized and dryed coal 2) Requires particulate and sulfur removal	N A	
GEGAS	Being developed by G E with joint funding by G E and EPRI	18 TPD pilot plant onstream since 1976		All coals - except strongly coking	Low BTU gas, tar, and sulfur	Moving Bed	Air Oxygen	Medium Medium	Low Medium/High	1) Does not require O_2 plant 2) Does not produce char by-product	1) Requires compression of product gas 2) Low BTU gas - must be used on or near site		Innovations involving coal extrusion feed systems and membrane acid gas removal systems are being developed. Operation with oxygen will produce an intermediate BTU gas, which can be upgraded to pipeline gas

TABLE A-1 (continued)

COAL GASIFICATION - PROCESSES READY FOR COMMERCIAL DEVELOPMENT

NAME	DEVELOPERS AND SPONSORS	PILOT PLANTS	FUTURE PLANS FOR PROCESS	FEEDSTOCKS	PRODUCTS	TYPE OF REACTOR	OXIDANT	OPERATING PRESSURE	HEATING VALUE OF PROCESS GAS	PROCESS ADVANTAGES	PROCESS DISADVANTAGES	TYPICAL GASIFIER SECTION OUTLET COMPOSITION	NOTES
HYDRANE	Being developed at Pittsburgh Energy Research Center by ERDA	Bench scale 10 lb/hr integrated unit	Scale up to 24 TPD pilot unit is planned	All coals	High BTU gas, char, and sulfur	Fluid Bed	Oxygen	High	High	1) No pretreatment of coal required 2) No oxygen introduced into the gasifier 3) Minimum methanation required 4) High thermal efficiency	1) Dilute phase reaction coupled with fluid bed reactor may be difficult to control and operate 2) By product char produced	Mol % (H_2O FREE) CH_4 33 H_2 23 CO 4 CO_2 H_2S N_2	
HYGAS	Being developed by Institute of Gas Technology with financing from ERDA and AGA	Pilot Plant, Chicago, Ill., capacity 75 TPD operating since 1972	Preliminary engineering design for 80 MM SCFD plant	Illinois high volatile bituminous and Montana lignite (two extremes) As slurry in recycle oil	Fuel gas suitable for SNG, char, sulfur and by-product oil					1) Slurry feed system 2) Operates at high pressure does not require compression	1) Requires O_2 plant 2) Produces by product oil 3) Requires pretreatment of some coals	Mol % (H_2O FREE) CH_4 19 H_2 30 CO 24 CO_2 26 H_2S 1 N_2	Work on the electrothermal variation has been discontinued
ROCKGAS	Being developed by Rockwell International Corp with financing from DOE	Bench scale gasifier	Design and construction of a 5 TPH plant is planned	Coal, coke, or fuel oil	Low BTU gas and sulfur					1) Wide range of feedstocks 2) Sulfur removed in the melt	1) Corrosion caused by the sodium carbonate melt 2) Low BTU gas must be used on or near site	Mol % (H_2O FREE) CH_4 2 H_2 12 CO 25 CO_2 4 H_2S N_2 57	With modification a synthesis gas can be produced which can be upgraded to pipeline gas
SYNTHANE	Being developed at Pittsburgh Energy Research Center by DOE	Pilot plant, Bruceton, PA., capacity 72 TPD Operating since 1976	Testing and evaluation of pilot plant	Supposedly flexible and capable of handling all types	Fuel gas suitable for SNG, char, and sulfur					1) Operates at high pressure	1) Requires O_2 plant 2) By-product char produced	Mol % (H_2O FREE) CH_4 25 H_2 28 CO 17 CO_2 29 H_2S 1	Substitution of air for oxygen to the gasifier will produce a low BTU raw gas
U GAS	Institute of Gas Technology		Planning a demonstration gasifier to fuel a 50-100 MW power generation plant	All coals	Low BTU gas and sulfur					1) Does not require O_2 plant 2) Does not produce char by-product	1) Requires pretreatment (Caking coals) 2) Requires sized coal 3) Low BTU must be used on or near site	Mol % (H_2O FREE CH_4 H_2 13 CO 12 CO_2 14 H_2S	Operation with oxygen will produce an intermediate BTU gas, which can be upgraded to pipeline gas
UNION CARBIDE/ BATTELLE	Developed by Union Carbide - financed by DOE and AGA	25 TPD pilot plant in construction at West Jefferson, Ohio		All coals	Synthesis gas and sulfur					1) Does not require O_2 plant 2) No char produced	1) Requires two fluidized beds 2) Hi temp gasifier operation above 1800°F 3) Requires compression of product gas	Mol % (H_2O FREE CH_4 H_2 59 CO 37 CO_2 3 H_2S 1 N_2	May also be used to supply hydrogen for other processes
...STINGHOUSE	Being developed by Westinghouse Research under a cost-shared partnership of DOE and five companies	1,200 lb/hr process development unit at Waltz Mill, Pa.	Scale up the gasifier to 5 TPH is planned	All coals	Low BTU gas and sulfur					1) Does not require O_2 plant 2) Does not produce char by-product	1) Low BTU gas - must be used on or near site	Mol % (H_2O FREE CH_4 3 H_2 15 CO 19 CO_2 9 H_2S N_2 54	The overall program is directed toward the operation of a combined cycle power plant utilizing a 55 to 60 tons of coal per hour commercial sized gasifier system

TABLE A-2
COAL LIQUEFACTION — PYROLYSIS PROCESS

	DS GPS	FEEDSTOCK	HE... SOURCE	...OR SYSTEM	CONVERSION CONDITIONS	PRODUCT YIELDS	REMARKS	PILOT PLANT	PLANS FOR PROCESS	PROCESS ADVANTAGES	PROCESS DISADVANTAGES
LURGI-RHEINKAS	Lurgi Ruhrgas	Lignite Sub-bituminous Bituminous	Hot char recycle	Mechanical Mi...	mospher ssure 00°	000 .../ton char BBL/ton tar	...ondu... U S shale but not on U S coal	.000 ... per day commercial plant operating on European brown coal		Commercially proven	1 Mechanical mixing 2 Product char handling
CO...	MC Corporation	... Sub-bituminous Bituminous	No. flue gas	Multiple fluid beds	...to psig 550-1800°F	1,000 LB/ton char 1 BBL/ton oil 8000 SCF/ton gas (276 BTU/SCF)		Successfully piloted in 36 TPD plant, design of commercial plant completed	Installation of 2200 TPD plant in combination with COGAS Process — Perry County, Illinois		1 Limited to low sulfur coals 2 Caking coals require pretreatment
TOSCOAL	The Oil Shale Corporation	Sub-bituminous	Hot ceramic ball recycle	Rotary vessel	Atmospheric 800-870°F	1000 LB/ton char 0 3 0 6 BBL/ton oil 1700 SCF/ton gas (600-660 BTU/SCF)	Primary purpose is upgrading heating value of sub-bituminous coal	Process has been demonstrated in a 25 TPD pilot plant			1 Unfavorable product mix 2 Mechanically complex
OCCIDENTAL	Occidental Research and Development Corporation	Lignite Sub-bituminous Bituminous	Hot char recycle	Entrained bed	Atmospheric 1100°F	1150 LB/ton char 1 0 1 5 BBL/ton liquid 3000 SCF/ton gas (700 BTU/SCF)	Short residence time, rapid heat up rate of feed, has highest liquid yields of pyrolysis processes	36 TPD pilot plant in operation	Technique to desulfurize char Design of 260 T/D pilot plant underway	1 Relatively high liquid yields 2 Straight forward processing scheme	1 High sulfur char
CLEAN-COKE	U S Steel Corporation	High volatile Bituminous	Hot gas recycle	Fluid bed	PYROLYSIS 90 100 psig 1200 1400°F HYDROTREATING 3000-4000 psig 400°F	700 LB/ton coke pellets < 1 0 BBL/ton oil 1 MM BTU fuel gas/ton	Developed primarily for upgrading high sulfur caking coals to low sulfur metallurgical grade coke	600 LB/D carbonizer and hydrogenator in operation 400 LB/D coke pelletizer in operation	Design a 250 T/D demonstration plant		1 High pressure slurry feed system 2 Integrated operations have not been done

TABLE A-2′ (continued)

COAL LMMJEFACTION – **HYDROGENATION** PROCESSES

NAME	DEVELOPER	FEEDSTOCKS	REACTOR SYSTEM	CONVERSION CONDITIONS	TYPICAL PRODUCTS YIELDS	HYDROGEN CONSUMPTION	REMARKS	PILOT PLANT	FUTURE PLANS FOR PROCESS	PROCESS ADVANTAGES	PROCESS DISADVANTAGES
CSF	Conoco Coal Development Company	Lignite Subbituminous Bituminous	Stirred slurry extractor plus ebullated bed catalytic hydrogenation	EXTRACTOR 850 psig, 765°F HYDROTREATER 3000 psig, 800°F	2 0 BBL/ton oil 1400 SCF/ton gas (833 BTU/SCF)	7500 SCF/Ton 15 000 SCF/T hydrotreating	H_2 supplied by donor solvent in extractor which is continuously recovered and rehydrogenated for recycle to extractor	20 TPD pilot plant in start up at Cresap, West Virginia			1. Pressurized slurry feed system 2 Mechanical extraction under pressure 3. Hydrotreating of extract required
EDS	Exxon Research and Engineering Company	Lignite Subbituminous Bituminous	Proprietary Extractor Fixed bed catalytic solvent hydrogenation	1800 2600 psig 700° 800°F	~3 0 BBL/ton low sulfur fuel oil	6000 8000 Gasification of insoluble coal and reforming of product gas to supply H	Follows CSF scheme, where donor solvent is continuously recovered and rehydrogenated for recycle to the extractor	1 TPD Wilsonville plant in operation	Design and construction of 250 TPD pilot plant	1. Different product slate can be obtained by varying operating conditions	1 High pressure slurry feed system
SRC	Gulf Oil Corporation	Lignite Subbituminous Bituminous	M. Hydrovertical tube dissolver	1000 psig 818°F	1100 LB/ton low sulfur, low ash char (16 000 BTU/LB) 9 1% ash	3000-6000 SCF/ton	Gaseous hydrogen used in dissolver for hydrotreating	50 TDP plant operating at Ft. Lewis, Wash 6 TPD pilot plant at Wilsonville, Alabama	Design of two 6000 tpd demonstration plants One using SRC I the other SRC II	1 High conversion rates 2 No physical solids preparation required	1. High pressure slurry feed system
H-COAL	Hydrocarbon Research, Inc.	Lignite Subbituminous Bituminous	Ebullated bed Catalyst	2200 2700 psig 800° 870°F	~3 0 BBL/ton synthetic crude 15° API 20% fuel gas	13,000-18,000 SCF/T	Lower H_2 consumption yields low sulfur fuel oil Higher H_2 figure yields the 15° API syncrude	Successfully tested in 3 TPD plant	Construction of 600 T/D demonstration plant underway	1. Based on commercialized H Oil process for heavy residues 2. Continuous regenerative catalyst produces constant activity 3. Low hydrogen consumption	1. High pressure slurry feed system
SYNTHOIL	U S Bureau of Mines	Lignite Subbituminous Bituminous	Fixed bed Catalyst	2000 4000 psig 800°F	~3 0 BBL/ton 200 LB/ton char (17 000 BTU/LB) 3000 SCF/T fuel gas	4000 + SCF/T Suggest using a gasification scheme, but none specified or tested	The apparent very short residence time required was attractive H scale up more practical Later tests showed it was not	1/2 TPD pilot plant no longer in operation	Construction completed in 18 TPD pilot plant never utilized	1 High liquid yields 2 Can handle moderately heavy slurries 3 Low hydrogen requirement	1 High pressure slurry feed system 2 Solid residue contains high amounts of unconverted coal 3 High hydrogen recycle rates 4. Late work showed reaction rates to be low
CCL	Gulf Oil Corporation	Lignite Subbituminous Bituminous	Fixed bed Catalyst	2000+ psig 750° 1000°F	~3 0 BBL/ton low sulfur fuel oil	16 000 22 000 SCF/ton Indicate reforming of product gas for H_2	Short residence time Special reactor design Coke resistant, high activity catalyst	1 TPD pilot unit in operation	The 600 TPD pilot plant is currently in design	1 Catalyst exhibits high resistance to carbon deposition 2 High liquid yields	1 High pressure slurry feed system

TABLE A-3

SUMMARY OF RETORTING PROCESSES

	GAS COMBUSTION	URGI RUHRGAS	TANAKO KILN	ARAKO KILN (ALT.)	PETROSIX	SUPERIOR'S GRATE RETORT	OSCO	UNION RETORT "A"	UNION RETORT "B"	UNION SGR	OCCIDENTAL MODIFIED IN SITU
DEVELOPER	Bureau of Mines	Urgi Ruhrgas	Tanaka Dev. Corp	Arako Dev. Corp	Petrobras, Cameron & Jones	Superior Oil Company	The Oil Shale Corp.	Union Oil Co. of Calif.	Union Oil Co. of Calif.	Union Oil Co. of Calif.	Occidental Petroleum Co.
RETORTING (ANSFER)	Internal combustion of spent shale carbon residue	Hot circulating solid Ash) No internal combustion	Internal combustion of spent shale carbon residue.	Hot recycle gas No combustion in retort	Hot recycle gas No combustion in retort.	Either direct (with partial combustion of recycle gas) or indirect.	Hot circulating ceramic balls No internal combustion.	Internal combustion of spent shale carbon residue.	Hot recycle gas No combustion in retort.	Hot recycle gas, with steam and hot gas from shale gasifier.	Internal combustion of spent shale carbon residue plus recycle gas.
Date Operated	1964-1, 1965-6, 1966-6	1960's, 1976	Limestone (Comm.) 1969 to date 1974 to date	1978	1972 – To date.	1975 to date.	1956-7, 1965-6, 1971-2	1948, 1966-8		1973-74	1972 to date.
TIES											
Tons Per Day	26,150	18	100		2000	10 TPH Maximum capacity – operated @ about 16 TPH	14,1000	2,30,300 to 1200	Laboratory only.	3	Not readily available (in situ)
RE OPERATION	Hot gas – solids interacting resulting clinker formation could not operate with grade shale (over 20 gal/ton).		Program for oil shale pilot plant operation completed. Executing contract to produce 100,000 Bbl of oil for refining tests	Pilot plant operates some Petrosix operation using U.S. shale at 30-35 gal/ton.	Operating with Brazil oil shale (23 gal/ton) Have had some refluxing of shale oil which forms tarry substances and plugs bed.	Circular traveling grate, adapted from iron ore sintering. Operated by Superior at M. Dowell-Wellman facilities – Cleveland Ohio.	Pilot plant operation successful. Full scale plant (50,000 B/D) in preliminary engineering stage.	Utilizes rock pump. Process appears workable if commercial-sized equipment can be developed.	Utilizes rock pump. Process appears workable if commercial-sized equipment can be developed.	Utilizes rock pump and separate coke gasifier	First large scale unit (1976) produced 30,000 bbl, but had low yields due to poor rubblization. Second gave very poor yields due to unexplained channeling. Third is under way.
E REQUIRED	1/4" to 3"	Less than 1/2"	1/4" to 3"	1/4" to 3"	1/4" to 3"	~3"	Less than 1/2"	1/8" to 3"	1/8" to 3"	1/8" to 1"	Not reported
°API	26		21.4	11.7	19.6		21	21	21	21.5	26.6
Sulfur, Wt. %	0.8		0.81		1.06		0.8	0.7		0.7	0.66
Nitrogen, Wt.	1.8		1.95		0.94		1.8	1.8		1.8	1.50
Pour Point, °F	80		85	10	25	80	80	80	m	70	25
SHALE OIL YIELD (FISCHER ASSAY)	2 – 87		94-96	97	80 – 90 (Est.)	95 – 100		91		100	Much depends on degree of rubblization.
	Retorting is similar to grate approach. Development work needed in solid distribution and off-gas distribution system	Commercial plant of 1,000 T/D in operation using preheated brown coal. Ran 100 T of Colorado shale in late 1976 for 2 week pilot test. Data not available but reportedly ran very smoothly	Retort has worked well in demonstration plant built at S. of M. Anvil Points facilities. Have made and stored 80,000 bbl of the 100,000 bbl to be refined for U.S. Navy	An alternate scheme demonstrated at Anvil Points plant.	Process should work using low grade shale – < 30 gal/ton. Additional development work needed to utilize high grade shale	Claims to have eliminate most environmental objections. Recovers nahcolite, soda ash, and alumina as salable by-products. Reduced volume of residue permits returning all solid waste to mine.	Mechanical and technical problems seem to be resolved. Process appears to be one of most efficient to date. Tosco claims it is fully developed on demo scale and is ready for commercial application. Final EIS has been issued by BLM.	Union believe technology established for design of 50,000 T/D retort. They are proceeding with plans for privately financed full-scale module.	Retort "B" could be operated in combination w/Retort "A" to yield 92 Vol % to Fischer Assay.	High (87%) thermal efficiency. Proceeding with 1000 T/D demo retort and 5000 T/D prototype solids pump	Modified in situ with 15 or 20% of deposit removed, followed by explosive fracturing to produce retortable rubble. Could be commercial even for lean shales (10 gal/T).

APPENDIX TO CHAPTER 5, B

Appendix B-1: EXISTING U.S. AND FOREIGN LOW- AND MEDIUM-BTU GASIFICATION SYSTEMS

(Courtesy: "Low and Medium Btu Gasification Systems: Technology Overview" U.S. EPA, 1978; EPA-600/7/78-061)

Gasifier	Licensor/developer	Number of gasifiers currently operating (No. of gasifiers built) Low-Btu gas	Medium-Btu gas	Synthesis gas	Location	Scale
Lurgi	Lurgi Mineralöltechnik GmbH	5	(39)	(22)	Foreign	Commercial
Wellman-Galusha	McDowell Wellman Engineering Co.	8(150)			US/Foreign	Commercial
Woodall-Duckman/ Gas Integrale	Woodall-Duckham (USA) Ltd.	(72)@@		(8)**	Foreign	Commercial
Koppers-Totzek	Koppers Company, Inc.			(39)**	Foreign	Commercial
Winkler	Davy Powergas		(23)**	6(14)	Foreign	commercial
Chapman (Wilputte)	Wilputte Corp.	2(12)	-	-	US	Commercial
Riley Morgan	Riley Stoker Corp.	1	-	-	US	commercial
Wellman Incadenscent	Applied Technology Corp.	(2*)**	-	-	US/Foreign	Commercial/ Demonstration
BGC/Lurgi Slagging	British Gae Corp. and Lurgi Mineralöltechnik GebH		1		Foreign	Demonstration
Bi-Gas	Bituminous Coal Research, Inc.		1		US	Demonstration
Foster Wheeler/Stoic	Foster Wheeler/Stoic Corp	1*(2)**	-	-	US	Demonstration
Pressurized Wellman-Galusha (MERC)	ERDA	1*			US	Demonstration
GFERC Slagging	ERDA	-	1*		US	Demonstration
Texaco	Texaco Development Corp.	-		1*	US	Demonstration
BCR Low-Btu	Bituminous Coal Research, Inc.	1*			US	Demonstration
combustion Engineering	Combustion Engineering Corp.	1*			US	Demonstration
Hygas	Institute of Gae Technology	-	1		US	Demonstration (High-Btu)
Synthane	ERDA	-	1		US	Demonstration (High-Btu)
$C0_2$ Acceptor	ERDA	-	1		US	Demonstration (High-Btu)
Foster Wheeler	Foster Wheeler Energy Corp.	1			US	Pilot
Babcock & Wilcox	The Babcock & Wilcox Co,	1			US	Pilot
U-Gas	Institute of Gas Technology, Phillips Petroleum Corp.	1			US	Pilot (400 lb/hr coal)
Westinghouse	Westinghouse Electric Corp.	1			US	Pilot
Coalex	Inex Resources, Inc.	1 (1*)			US	Pilot

* Under construction.
Demonstration scale indicates 2000 to 10,000 lb/hr coal feed.
Pilot scale indicates 400 to 1500 lb/hr coal feed.

** Undetermined number overseas currently in operation.

Appendix B-2: Continued

POPULATION OF LOW/MEDIUM-BTU GASIFIERS

Gasifier type / Gasifier name	Licensor/Developer	Stacus
Fixed-Sod, Dry Ash		
Lurgi	American Lurgi Corp. (USA)	Present commercial operation
Wellman-Galusha	McDowell Wellman Engr. Co. (USA)	Present commercial operation
Chapman (Willputte)	Wilputte Corp. (USA)	Present commercial operation
Woodall-Duckhan/Gas Integrale	Woodall-Duckham, Ltd. (USA)	Present commercial operation
Riley Morgan	Riley Stoker Corp. (USA)	Present demonstration unit testing; commercially available
Pressurized Wellman-Galusha (MERC)	Morgantown Energy Research Center/ERDA (USA)	Present development unit testing
Foster Wheeler/Stoic	Foster Wheeler Energy Corp. (USA)	Demonstration unit planned
Kilngas	Allis Chalmers Corp. (USA)	Present development unit testing ; commercially ● vallabla
Kellogg Fixed Bad	M. u. Kellogg Go. (USA)	Present I18v'dome unit testing
GEGAS	General Electric Research and Development (USA)	Present development unit testing
Counol Fixed Bed	Consolidation Coal co. (USA)	Present development unit testing
IFE Two Stage	International Furnace Equipment Co., Ltd.	Past commercial operation
Kerpely Producer	Bureau of Mines/ERDA (USA)	Past commercial operation
Marischka	Unknown	Past commercial operation; anthracite or coke only
Pintsch Hillebrand	Unknown (Germany)	Past commercial operation
U.G.I. Blue Water Gas	U.G. I .Corp. /DuPont (USA)	Past commercial operation; coke only
Power Gas	Power Gas Co. (USA)	Past commercial operation
Wellman Incandescent	Applied Technology (uDA)	Present commercial operation
BCR/Kaiser	Unknown	Past development unit testing
Fixed-Bed. Slagging Ash		
BGC/Lurgi Slagging Gasifier	British Gas Council (GB) Lurgi Mineralöltechnik (W. Germany)	Present development unit testing
GFERC Slagging Gasifier	Grand Forks Energy Research Career/ERM (USA)	Present development unit testing; lignite only
Luena	Unknown	Put Commercial operation; coke only
Thyssen Galocsy	Unknown	Past commercial operation; coke only

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POPULATION OF LOW/MEDIUM-BTU GASIFIERS

Gasifier name	Licenser/Developer	Status
Gasifier type		
Fluidized-Bed, Dry Ash		
Winkler	Davy Powergas *Co. (USA)*	Present commercial operation
Hygas	Institute *of* Gas Technology (USA)	Present development unit testing
Synthane	Pittsburgh Energy Research Center/ERDA (USA)	Present development unit testing
Hydrane	Pittsburgh Energy Research Center/ERDA (USA)	Present development unit testing
Cogas	Cogas Development Co. (USA)	Present development unit testing
Exxon	Exxon Corp. (USA)	Present development unit testing
BCR Low-Btu	Bituminous Coal Research (USA)	Present development unit testing
CO_2 Acceptor	Consolidation Coal co. (USA)	Present development unit testing
Electrofluidic Gasification	Iowa State Univ./ERDA (USA)	Present development unit testing
LR Fluid Bed	Unknown (Germany)	Past commercial operation
HRI Fluidized Bed	Hydrocarbon Research Inc. (USA)	Past development unit testing
BASF-Flesch-Demag	Badische Anilin und Soda Fabrik (West Germany)	Past development unit testing
GEGB Marchwood	Unknown	Past development unit testing
Heller	Unknown (Germany)	Put development unit testing
Fluidized-Bed, Agglomerating Ash		
U-Gas	Institute of Gas Technology (USA)	Present development unit resting
Bactmlle/Carbide	Battelle Memorial Institute *(USA)*	Present development unit testing
Westinghouse	Westinghouse Electric Corp. (USA)	Present development unit testing
City College *of* NY *Mark 1*	Hydrocarbon Research Inc./ A.M. Squires (USA)	Present development unit testing
Two-stage Fluidized	British *Gas* Council (England)	Present development unit testing
ICI Moving Burden	Imperial Chemical Industries, Ltd. (England)	Past development unit testing
Entrained-Bed, Dry Ash		
Garrett Flash Pyrolysis	Garrett Research and Development co. (USA)	Present development unit testing
Bianchi	Unknown (France)	Past development unit testing; lignite only

POPULATION OF LOW/MEDIUM-BTU GASIFIERS

Gasifier name	Licenser/Developer	Status
Gasifier type		
Paninduo	Unknown *(France)*	Past development unit testing; lignite only
USBM Annular Retort	Bureau of Mines/ERDA (USA)	Past development unit testing; lignite only
USBM Electrically Heated	Bureau of Mines/ERDA (USA)	Past development unit testing
Entrained-Bed, Slagging Ash		
Koppers-Totzek	Koppers Co. (USA)	Present commercial operation
Bi-Gas	Bituminous Coal Research, Inc. (USA)	Present development unit testing
Texaco	Texaco Development Corp. (USA)	Present development unit eating
Coalex	Inex Resources, Inc. (USA)	Present development unit testing; commercially ● milabla
PAMCO/Foster Wheeler	Pittsburgh ● od Midway Coal Co. / Foster Wheeler (USA)	Present development unit testing
Combustion Engineering	Combustion Engineering (USA)	Present development unit testing
Brigham Young University	Brigham Young University/ Bituminous Coal Research (USA)	Present development unit testing
Babcock and Wilcox	The Babcock and Wilcox CO. (USA)	Past commercial operation
Ruhrgas Vortex	Ruhrgas A. G. (West Germany)	Past commercial operation
IGT Cyclonizer	Institute of Gas Technology (USA)	Pastdevelopment unit testing
Inland Steel	Inland Steel CO. (USA)	Past dcvdopment unit testing
USBM, Morgantown	Morgantown Energy Research Center/ERDA (USA)	Past development unit testing
Great Northern Railway	Great Northern Railway Co. (USA)	Past development unit testing
FRS Cyclone	Unknown (England)	Past development unit testing
Molten Media, Slagging Ash		
Kellogg Molten Salt	M. W. Kellogg CO. (USA)	Present development unit testing
Atgas/Patgas	Applied Technology Corp. (USA)	Present development unit testing
Rockgas	Atomics International (USA)	Present development unit testing
Rummel Single Shaft	Union Rheinische Braun Kohlen Kraftstoff A. G. (West Germany)	Past commercial operation
Sun Gasification	Suo Research and Development Co. (USA)	Past development unit testing
Otto-Rummel Double Shaft	Dr. C. Otto and Co.	Past development unittesting

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APPENDIX TO CHAPTER 5, C

COOPERATIVE AGREEMENTS AND FEASIBILITY STUDY GRANTS FOR SYNFUELS

(Source: U.S. DOE 7/80)

COOPERATIVE AGREEMENTS

TECHNOLOGY	REQUESTED FROM DOE	DESCRIPTION/SITE
Coal Liquids		
Texas Eastern Synfuels	$24,300.00	Texas Eastern Synfuels proposes to construct a coal liquefaction facility which will produce the equivalent of 56,000 barrels of oil per day. Texas Eastern Synfuels is a joint venture of Texas Eastern Corporation, and Texas Gas Transmission Corporation. Proposed project is a Fischer Tropsch plant--like the SASOL facility in South Africa--that would convert approximately 28,000 tons per day of coal into a mixture of transportation fuels, Synthetic Natural Gas (SNG), and chemicals. Approximately 44 percent of the output is SNG (145 mmSCF/D); about 30 percent transportation fuel, and the test chemicals Site is near Hendersen, Kentucky.
High Btu Gas		
Great Plains Gasification Associates	$22,000,000	The project will employ a Lurgi pressurized, fixed bed gasification process with Lurgi methanization requiring 14,000 tons/day of lignite coal to produce 137.5 mmCF/day of synthetic gas, 98 tons of ammonia/day and 85 tons/day of sulfur. The facility will be sited in the Beulah Hazen area of Mercer County, North Dakota and has a total capital requirement of $1.5 billion

Wycoal Gas	$13,155,000	Wycoal plans to construct a facility using Lurgi and Texaco gasification units to process 16,000 tons of sub-bituminous coal daily to produce high Btu gas. All liquid by-products will also be gasified. The facility is to be located in Douglas, Wyoming. The Statement of work **proposed** will involve developing a definitive basis for plant design estimating costs, securing permits and approvals, obtaining financing and identifying long-lead delivery items. There is a market for the SNG via a pipeline system to the midwest owned by the participants. The project would produce the equivalent of 51,000 barrels of oil per day.

FEASIBILITY STUDY GRANTS

TECHNOLOGY	REQUESTED FROM DOE	DESCRIPTION/SITE
Coal Liquids		
Cook Inlet Region Anchorage, Alaska 99509	**$3,900,000**	Feasibility study of producing 54,000 barrels per day of methanol from low sulfur coal using Winkler gasifier and ICI methanol synthesis. Site: West side of Cook Inlet, Alaska
W. R. Grace Denver, Colorado 80223	$786,477	'Stage 111 of a feasibility study of a coal sourced methanol plant using a Koppers/Totzek Gasifier. Site: Moffat County, NW Colorado
Clark Oil & Refining Milwaukee, Wisconsin 53227	$4,000,000	Feasibility study of producing synthesis gas from coal, steam, oxygen & methanol from synthesis gas using a KT Gasifier, ICI & the Mobil M Process. Site: S. Illinois

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Houston Natura Gas/Texaco Houston, Texas 77001	$3,260,000	Fourteen month feasibility study of producing fuel grade methanol from coal using Ziegler coal deposits. Site: Covent, Louisiana
AMAX, Inc. Grenwich, Connecticut	$2,190,000	Feasibility study of a coal to methanol plant producing 14,910 barrels per day using Koppers or Lurgi Gasifiers. Site: Diluth, Minnesota
Dakota Company B smark, North Dakota 58501	$4,000,000	Feasibility study for constructing an 85,000 barrel/day coal to methanol plant using Lurgi gasifier and Lurgi methanol synthesis. Site: Dunn, North Dakota
Republic of Texas Coal Co. and Mitchell Energy Corp. Houston, Texas 77002	$808,781	Feasibility study of gasification, in-situ deep Texas lignite and conversion of remaining medium BTU synthesis gas to methanol and high octane gasoline. Site: Somewhere in Texas Gulf Coast
Hampshire Energy Milwaukee, Wisconsin	$4,000,000	Ten-month feasibility study of converting 15,000 tons of coal/day to 20,000 barrels/day of gasoline * Site: Gillette, Wyoming

High Btu Gas

Crow Tribe of Indians Washington, D.C. 20036	$2,729,393	Nine month feasibility study, High Btu Gas (Lurgi Process - SNG) at Crow Reservation, MT. Site: East of Billings, MT.
Texas Eastern Synfuels, Inc. Houston, Texas 77001	$3,018,000	Nine month feasibility study, High Btu Gas (Lurgi Process - SNG, Methanol) at San Juan County, New Mexico. Site: East of Navajo Indian Reservation

Low/Medium Btu Gas

Florida Power St.Petersburg, Florida 33733	$1,380,796	Twelve month feasibility study of Medium Btu Gas Combined cycle. Site: Pinellas Courty, Florida
General Refractories Bala Cynwyd, PA. 19004	$922,555	Nine month feasibility study of low Btu Industrial Fuel Gas. Site: Florence, Kentucky
Central Maine Power Augusta, Maine 04336	$3,624,558	Fifteen month feasibility study of combined cycle, medium Btu gas at Sears Island, ME. (Process: Texaco Gasifier) Site: Waldo County, Maine
EG&G Wesley, Massachusetts 02181	$4,000,000	Feasibility study for a medium Btu gasification facility producing combined cycle power and methanol. Choice or process technologies between Koppers-Totzek or Slagging Lurgi. Site: Fall River, Massachusetts
Philadelphia Gas Works Philadelphia, PA 19102	$1,168,108	Twelve month feasibility study of medium Btu gas (Process: TRD). Site: Philadelphia, Pernsylvania
Celanese Corp Dallas, Texas 75247	No cost	Feasibility study to determine the technical and economic viability of developing a carbon monoxide and hydrogen syngas from either a high Btu coal or a Texas lignite. Site: Near Bishop, Texas
Union Carbide/Linde Division Tonawanda, New York 14150	$3,945,676	Eighteen-month feasibility study of low/Medium Btu Gas. Site: Texas City, Houston, Texas

Oil Shale

Gary Energy Corp. Fruita, Colorado 81521	$3,009,399	Feasibility study for upgrading crude oil shale to gasoline jet fuels, DFO and residual using UOP hydro-processing & hydro-cracking. Site: Fruita, Colorado
Transco Energy Co. Houston, Texas	$3,778,267	Eighteen month feasibility of 2000 BPD (or larger) module of a 50,000 BPD plant. Site: Lewis County, Kentucky

Tar Sands

Natomas Energy Co. San Francisco, California 94108	$357,511	Eight-month feasibility study of extracting 20,000 barrels/day of oil from domestic tar sands - Bitumen. Site: Site may be in Utah or California
Standard Oil of Indiana Chicago, Illinois 60601	$0	Feasibility study of a 5000 barrel/day Tar Sands Bitumen facility. Site: Sunnyside, Utah

Unconventional Gas

Acruex Corporation Mt. View, California 94-42	$440,261	Feasibility study of anaerobic digestion of sewer water to obtain methane. Site: Possibly Oakland, California
Seneca Indian Nation Salamarca, New York 14779	$896,638	Feasibility study of the recovery of natural gas from Devonian Shales - vertical wells. Methane from Devonian Shale. Site: Salamanca, New York

Republic of Texas Coal Co. and Mitchell Energy Corp. Houston, Texas 77002		Feasibility study of gasification, in-situ deep Texas lignite and conversion of remaining medium Btu synthesis gas to methanol and high octane gasoline. Site: Calvert, Robertson County, Texas
Mountain Fuel Supply Co. Salt Lake City, Utah 84139	$1,810,762	Two-year feasibility study of unconventional natural gas in the Pinedale field. Product is natural gas and condensate. Site: Sublette County, Wyoming
Peat		
Minnesota Gas Co. Minneapolis, Minnesota 55402	$3,996,554	Nineteen month feasibility study for the production of high Btu substitute natural gas from peat. Site: Minnesota
Shale Liquid Upgrading		
Union Oil Energy Mining Los Angeles, CA 90017	$4,000,000	Feasibility study for operation of a 10,000 BPD upgrading plant producing premium quality syncrude. Site: Grand Valley, Colorado

COOPERATIVE AGREEMENTS

TECHNOLOGY	REQUEST C FROM DOE	DESCR PT ON/SITE
Unconven ional Gas		
U.S. Steel Corporation	$600,000	U.S. Steel Corporation proposes to build a collection and compression system to capture methane from a mine pre-drainage program. The gas, currently being vented, will be injected into an interstate pipel ne system for sale. The project will produce the equ valent of 200 barrels of oil per day. Site s Oak Grove, Alabama.
Coal Oil Mixture		
Bankl ck Corporatio	$989,500	Banklick Corporation proposes to design and construct a Coal Mining Mixture (COM) preparation plant on a site on Blount Island, Florida owned by the Jacksonville Port Authority and to market the products. In this proposal, the approach is to first grind the coal, then mix it with oil and pulverize the result, and, finally, to mix the product more thoroughly using ultrasonic agitators. A COM prep plant is relativley simple and, in addition to the above equipment, cons sts of coal storage and handling equipment (including a coal pile), oil and COM piping and storage hardware, and associated hardware. Coal would be delivered by rail. The project will produce 6,000 barrels per day.