## 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<br>2) Wide range of feed<br>3) Quick turn down ratio<br>4) Feed can be changed | 1) Low pressure – Atmos<br>2) Requires $O_2$ plant<br>3) Hi temp. gasifier operation 3000°F<br>4) High methanation req'mts for pipeline gas<br>5) High compression req'mts for pipeline gas | Mol % ($H_2O$ FREE)<br>$CH_4$ 0<br>$H_2$ 30<br>CO 60<br>$CO_2$ 8<br>$H_2S$ –<br>$N_2$ – | 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<br>Oxygen | Medium<br>Medium | Low<br>Medium/High | 1) Only pressure gasifiers that have long term commercial operation | 1) Requires $O_2$ plant, if SNG is the product<br>2) Requires compression of product gas<br>3) Requires sized coal | Mol % ($H_2O$ FREE)<br>$CH_4$ 10<br>$H_2$ 38<br>CO 24<br>$CO_2$ 28<br>$H_2S$ –<br>$N_2$ – | 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<br>2) Requires sized coal<br>3) Low BTU gas must be used on or near site | Mol % ($H_2O$ FREE)<br>$CH_4$ 3<br>$H_2$ 15<br>CO 29<br>$CO_2$ 3<br>$H_2S$<br>$N_2$ 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<br>Oxygen | Atmos<br>Atmos. | Low<br>Medium/High | 1) H C Liquors can be added during<br>2) No tars or oils produced | 1) Requires $O_2$ plant for Hi BTU gas<br>2) Low pressure – Atmos<br>3) Coal drying may be req'd<br>4) 70% of Ash Overhead<br>5) Reactor brick lined<br>6) High methanation req'mts as only 2% $CH_4$ produced<br>7) High compression req'd for pipeline gas req'mts | Mol % ($H_2O$ FREE)<br>$CH_4$ 2<br>$H_2$ 35<br>CO 48<br>$CO_2$ 15<br>$H_2S$ –<br>$N_2$ – | 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<br>2) High gas output<br>3) Lower steam requirements than conventional Lurgi | 1) Requires $O_2$ plant<br>2) Requires compression of product gas if pipeline gas is required<br>3) Requires sized coal | Mol % ($H_2O$ FREE)<br>$CH_4$ 8<br>$H_2$ 28<br>CO 60<br>$CO_2$ 3<br>$H_2S$ –<br>$N_2$ 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<br>2) No by-products other than slag and sulfur<br>3) Gasifier is entrained flow | 1) Requires $O_2$ plant<br>2) Requires compression of product gas if pipeline gas is required | Mol % ($H_2O$ FREE<br>$CH_4$ 1<br>$H_2$ 30<br>CO 67<br>$CO_2$ 1<br>$H_2S$ 1<br>$N_2$ – | 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<br>Oxygen | Medium<br>Medium | Low<br>Medium/High | 1) Requires no pretreatment of feed<br>2) Gasifier is entrained flow<br>3) No by-product char<br>4) Slurry feed system | 1) Requires $O_2$ plant<br>2) Requires compression of product gas if pipeline gas is required | Mol % ($H_2O$ FREE)<br>$CH_4$ 1<br>$H_2$ 45<br>CO 45<br>$CO_2$ 8<br>$H_2S$ –<br>$N_2$ – | 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<br>2) Does not require $O_2$ plant | 1) Coal requires pretreatment<br>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<br>Oxygen | High<br>High | Low<br>Medium/High | 1) Requires no pretreatment of feed<br>2) Gasifier is entrained flow<br>3) Does not produce char by-product<br>4) Slurry feed system | 1) Requires $O_2$ plant | Mol % ($H_2O$ FREE)<br>$CH_4$ 17<br>$H_2$ 24<br>CO 44<br>$CO_2$ 14<br>$H_2S$ 1<br>$N_2$ - | 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<br>Oxygen | Low<br>Low | Low<br>Medium/High | 1) Requires no pretreatment of feed<br>2) Gasifier is entrained flow<br>3) No by-product char | 1) Requires $O_2$ plant<br>2) Requires compression of product gas | Mol % ($H_2O$ FREE)<br>$CH_4$ -<br>$H_2$ 30<br>CO 58<br>$CO_2$ 9<br>$H_2S$ 1<br>$N_2$ 1 | Operation with air will produce a low BTU gas<br>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<br>Medium/High | 1) Does not require $O_2$ plant<br>2) Requires no pretreatment of feed<br>3) No by-product char<br>4) Gasifier is entrained flow | 1) Atmospheric pressure<br>2) Requires compression of product gas<br>3) Low BTU gas - must be used on or near site | Mol % ($H_2O$ FREE)<br>$CH_4$ -<br>$H_2$ 12<br>CO 23<br>$CO_2$ 5<br>$H_2S$ -<br>[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<br>2) Does not produce char by-product<br>3) Requires no pretreatment of feed | 1) Good only for highly reactive lignite and sub-bituminous coals<br>2) Requires compression of product gas<br>3) Requires sulfur removal on flue and synthesis gas streams<br>4) Large number of fluidized beds may present a control problem. | Mol % ($H_2O$ FREE)<br>$CH_4$ 21<br>$H_2$ 54<br>CO 18<br>$CO_2$ 7<br>$H_2S$ -<br>$N_2$ - | |
| 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<br>2) Requires sulfur removal on flue and synthesis gas streams | Mol % ($H_2O$ FREE)<br>$CH_4$ 1<br>$H_2$ 53<br>CO 24<br>$CO_2$ 20<br>$H_2S$ -<br>$N_2$ 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<br>2) Gasifier is entrained flow<br>3) No by-product char | 1) Requires sized and dryed coal<br>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<br>Oxygen | Medium<br>Medium | Low<br>Medium/High | 1) Does not require $O_2$ plant<br>2) Does not produce char by-product | 1) Requires compression of product gas<br>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<br>2) No oxygen introduced into the gasifier<br>3) Minimum methanation required<br>4) High thermal efficiency | 1) Dilute phase reaction coupled with fluid bed reactor may be difficult to control and operate<br>2) By product char produced | Mol % ($H_2O$ FREE)<br>$CH_4$ 33<br>$H_2$ 23<br>CO 4<br>$CO_2$<br>$H_2S$<br>$N_2$ | |
| 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<br>2) Operates at high pressure does not require compression | 1) Requires $O_2$ plant<br>2) Produces by product oil<br>3) Requires pretreatment of some coals | Mol % ($H_2O$ FREE)<br>$CH_4$ 19<br>$H_2$ 30<br>CO 24<br>$CO_2$ 26<br>$H_2S$ 1<br>$N_2$ | 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<br>2) Sulfur removed in the melt | 1) Corrosion caused by the sodium carbonate melt<br>2) Low BTU gas must be used on or near site | Mol % ($H_2O$ FREE)<br>$CH_4$ 2<br>$H_2$ 12<br>CO 25<br>$CO_2$ 4<br>$H_2S$<br>$N_2$ 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<br>2) By-product char produced | Mol % ($H_2O$ FREE)<br>$CH_4$ 25<br>$H_2$ 28<br>CO 17<br>$CO_2$ 29<br>$H_2S$ 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<br>2) Does not produce char by-product | 1) Requires pretreatment (Caking coals)<br>2) Requires sized coal<br>3) Low BTU must be used on or near site | Mol % ($H_2O$ FREE<br>$CH_4$<br>$H_2$ 13<br>CO 12<br>$CO_2$ 14<br>$H_2S$ | 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<br>2) No char produced | 1) Requires two fluidized beds<br>2) Hi temp gasifier operation above 1800°F<br>3) Requires compression of product gas | Mol % ($H_2O$ FREE<br>$CH_4$<br>$H_2$ 59<br>CO 37<br>$CO_2$ 3<br>$H_2S$ 1<br>$N_2$ | 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<br>2) Does not produce char by-product | 1) Low BTU gas - must be used on or near site | Mol % ($H_2O$ FREE<br>$CH_4$ 3<br>$H_2$ 15<br>CO 19<br>$CO_2$ 9<br>$H_2S$<br>$N_2$ 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<br>Sub-bituminous<br>Bituminous | Hot char recycle | Mechanical Mi... | mospher<br>ssure 00° | 000 .../ton char<br>BBL/ton tar | ...ondu...<br>U S shale but not on U S coal | .000 ... per day commercial plant operating on European brown coal | | Commercially proven | 1 Mechanical mixing<br>2 Product char handling |
| CO... | MC Corporation | ...<br>Sub-bituminous<br>Bituminous | No. flue gas | Multiple fluid beds | ...to psig<br>550-1800°F | 1,000 LB/ton char<br>1 BBL/ton oil<br>8000 SCF/ton gas<br>(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<br>2 Caking coals require pretreatment |
| TOSCOAL | The Oil Shale Corporation | Sub-bituminous | Hot ceramic ball recycle | Rotary vessel | Atmospheric<br>800-870°F | 1000 LB/ton char<br>0 3 0 6 BBL/ton oil<br>1700 SCF/ton gas<br>(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<br>2 Mechanically complex |
| OCCIDENTAL | Occidental Research and Development Corporation | Lignite<br>Sub-bituminous<br>Bituminous | Hot char recycle | Entrained bed | Atmospheric<br>1100°F | 1150 LB/ton char<br>1 0 1 5 BBL/ton liquid<br>3000 SCF/ton gas<br>(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<br>Design of 260 T/D pilot plant underway | 1 Relatively high liquid yields<br>2 Straight forward processing scheme | 1 High sulfur char |
| CLEAN-COKE | U S Steel Corporation | High volatile Bituminous | Hot gas recycle | Fluid bed | PYROLYSIS<br>90 100 psig<br>1200 1400°F<br>HYDROTREATING<br>3000-4000 psig<br>400°F | 700 LB/ton coke pellets<br>< 1 0 BBL/ton oil<br>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<br>400 LB/D coke pelletizer in operation | Design a 250 T/D demonstration plant | | 1 High pressure slurry feed system<br>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 |



ejb&a

# 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 |



ej b&a