APPENDIX A

DATA TABLES FOR SELECTED MODULES

The unit emissions data derived for each of the modules are given in the following tables. The source of original data and the assumptions made are given in footnotes to each table, so that the calculations can be repeated. The references cited are listed at the end of this Appendix.

Table 34. ENVIRONMENTAL DATA FOR MODULE

Module - Gas Well
Unit - 10^6 Btu

Environmental Parameters	Fuel Input, Natural Gas
Air	
NO_x, lb	0.23[1]
SO_2, lb	0
CO, lb	0
Particulate, lb	0
Total organic material, lb	0.1[2]
Heat, 10^6 Btu	0
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Heat, 10^6 Btu	0
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	12.6[3]
Occupational Health	
Deaths	2.2×10^{-9} [4]
Total Injuries	2.1×10^{-7} [5]
Man Days Lost	3.5×10^{-5} [6]
Land Use, acre-hr/10^6 Btu	0.06[7]
Approx. Module Efficiency	96%[8]

Footnotes for Table 34:

(1) a. Natural gas consumed to maintain pumping power in gas well(A-15) = 0.032 ft^3/ft^3 recovered.
b. NO_x emission factor(A-1) = 7.3 x 10^{-3} lb/ft^3 consumed.
c. Heating value of natural gas (assumed) = 1000 Btu/ft^3.

(2) a. Natural gas loss in gas well operation(A-15) = 0.0022 ft^3/ft^3 recovered.
b. Density of natural gas = 0.045 lb/ft^3.

(3) a. Hydrocarbon recovered (liquid phase)(A-15) = 0.047 ft^3 (equivalent gas volume)/ft^3 recovered.
b. The hydrocarbon is assumed as heptane (Molecular weight = 96).

(4) a. Total number of fatal injuries in oil and gas production(A-17, A-19) = 95.
b. Total energy from oil and gas production(A-17, A-18) = 43 x 10^{15} Btu.

(5) a. Total number of nonfatal injury in oil and gas production in 1969(A-17, A-19) = 9023.

(6) a. Total man-days lost in oil and gas production in 1969(A-17, A-19) = 1.49 x 10^6 man-days.

(7) a. Land requirement for gas well is assumed to be the same as that for oil well.

b. Land use for oil well (see Table A-5) = 0.06 acre-hour/10^6 Btu

(8) a. Efficient (assumed) = 96%.

TABLE 35. ENVIRONMENTAL DATA FOR MODULE

Module - Removal of Sulfur from Natural Gas
Unit - 10^6 Btu (output)

Environmental Parameters	Fuel Input, Natural Gas
Air	
NO_x, lb	Nil
SO_2, lb	0.025(1)
CO, lb	Nil
Particulate, lb	Nil
Total organic material, lb	Nil
Heat, 10^6 Btu	Nil
Water	
Suspended solids, lb	Nil
Dissolved solids, lb	Nil
Total organic material, lb	Nil
Heat, 10^6 Btu	Nil
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	Nil
Ash, lb	Nil
Sludge, lb	Nil
Tailings, lb	Nil
Hazardous, lb	Nil
By-Products	0.24(2)
Occupational Health	Not determined
Deaths	Not determined
Total Injuries	Not determined
Man Days Lost	Not determined
Land Use, acre-hr/10^6 Btu	0.005(3)
Approx. Module Efficiency	100%(4)

Footnotes for Table 35:

(1) a. Table K-2 (in Reference A-26) gives the following 1970 data from 6 states:
SO_2 in Claus plants tail gas at 90% eff. = 441 T/D
SO_2 purged from plants not recovering sulfur = 2,335 T/D
Total gas production = 26.76 x 10^9 ft^3/d.
b. Assume 95% efficiency for Claus plants applied to all sour gas treatment plants, then:

$$\frac{(441/0.1 + 2335) \text{ ton } SO_2/\text{day} \times .05 \times 2000 \text{ lb/ton}}{26.76 \times 10^9 \text{ ft}^3/\text{day} \times 10^3 \text{ Btu/ft}^3} = 0.025 \frac{\text{lb } SO_2}{10^6 \text{ Btu}}$$

(2) a. at 95% efficiency for the Claus plants, the amount of SO_2 converted to sulfur is 19 times the amount of SO_2 emitted. Therefore, the amount of by-product sulfur produced is:

$$.025 \text{ lb } SO_2 \text{ emitted} \times 19 \times \frac{32 \text{ lb S}}{64 \text{ lb } SO_2} = 0.24 \text{ lb S}$$

(3) a. Land requirement for a 100 million ft^3/day plant (assumed) = 20 acres.

(4) a. Energy requirements for desulfurization process were not determined.

Table 36. ENVIRONMENTAL DATA FOR MODULE

Module -- Gas Pipeline
Unit -- 10^6 Btu

Environmental Parameters	Fuel Input, Natural Gas
Air	
NO_x, lb	0.304$^{(1)}$
SO_2, lb	0
CO, lb	0
Particulate, lb	0
Total organic material, lb	0
Heat, 10^6 Btu	0
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Heat, 10^6 Btu	0
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	
Occupational Health	
Deaths	Not determined
Total Injuries	Not determined
Man Days Lost	Not determined
Land Use, acre-hr/10^6 Btu	1.0$^{(2)}$
Approx. Module Efficiency	95.9%$^{(3)}$

Footnotes for Table 36:

(1) a. Natural gas consumed to maintain a compressor at 750 psia(A-15) = 0.042 ft^3/ft^3 transmitted.
b. NO_x emission factor for running gas engines(A-1) = 7300 $lb/10^6$ ft^3 burned.

(2) a. Land requirement for pipelines to run a 1000 MW Power Plant (A-12) = 213 acres.

(3) a. Efficiency (assumed) = 95.9%.

TABLE 37. ENVIRONMENTAL IMPACTS OF MODULE

Module--Space Heating(1)
Unit--10^6 Btu (Input)

Environmental Impacts	Nat. Gas
Air	
NO_x, lb	0.081
SO_2, lb	0.001
CO, lb	0.015
Particulate, lb	0.005
Total organic material, lb	0.004
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	0
Sludge, lb	0
Approx. Module Efficiency	70%

Footnotes for Table 37:

(1) a. Values taken from Table A-46 in reference (A-26) were corrected to input basis.

TABLE 38. ENVIRONMENTAL DATA FOR MODULE

Module -- Oil/Gas Well, Onshore
Unit -- 10^6 Btu (output)

Environmental Parameters	Fuel Input, Crude Oil
Air	
NO_x, lb	8×10^{-6} (1)
SO_2, lb	6×10^{-5} (2)
CO, lb	3×10^{-8} (3)
Particulate, lb	3×10^{-6} (4)
Total organic material, lb	4×10^{-7} (5)
Heat, 10^6 Btu	0
Water	
Suspended solids, lb	0
Dissolved solids, lb	6.2 (6)
Total organic material, lb	0.008 (7)
Heat, 10^6 Btu	0
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	
Occupational Health	
Deaths	2.2×10^{-9} (8)
Total Injuries	2.1×10^{-7} (9)
Man Days Lost	3.5×10^{-5} (10)
Land Use, acre-hr/10^6 Btu	0.06 (11)
Approx. Module Efficiency	100%

Footnotes for Table 38:

(1) a. Amount of oil that becomes air pollutants per barrel of oil produced (assumed) = 2×10^{-5} barrels.
b. Heating value of oil (assumed) = 6.3×10^6 Btu/bbl.
c. NO_x emission factor (A-1) = 60 lb/10^3 gal.
d. Oil is assumed to be the same as industrial residual oil.

(2) a. SO_2 emission factor (A-1) = 157S lb/10^3 gal.
b. Sulfur content of oil, S (assumed) = 2.88%.

(3) a. CO emission factor (A-1) = 0.2 lb/10^3 gal.

(4) a. Particulate emission factor (A-1) = 23 lb/10^3 gal.

(5) a. Hydrocarbon emission factor (A-1) = 3 lb/10^3 gal.

(6) a. Dissolved solid emission comes from saltwater brine.
b. Total brine production (A-16) = 25 million bbls/day.
c. Total on shore oil production rate (A-17) = 3.3×10^9 bbls/year.
d. 4% of brine goes to streams (assumed).
e. There are 100 lb of dissolved solids per barrel of oil (assumed).

(7) a. The brine is cleaned to remove all but 50 ppm oil (assumed).

(8) a. Total number of fatal injury in oil and gas production in 1969 (A-17, A-19) = 95.
b. Total energy from oil and gas production (A-17,A-18) = 43×10^{15} Btu.

(9) a. Total number of nonfatal injury in oil and gas production in 1969 (A-17,A-19) = 9023.

(10) a. Total man-days lost (A-17,A-19) = 1.49×10^6 man-days.

(11) a. Land requirement for an oil well producing 6200 barrels of oil per year (assumed) = 1/4 acres.

(12) a. Efficiency of operation (assumed) = 100%.

TABLE 39. ENVIRONMENTAL DATA FOR MODULE

Module -- Oil Pipeline
Unit -- 10^6 Btu (output)

Environmental Parameters	Fuel Input, Crude Oil
Air	
NO_x, lb	0.009[1]
SO_2, lb	0.016[2]
CO, lb	2×10^{-5}[3]
Particulate, lb	0.002[4]
Total organic material, lb	0.0003[5]
Heat, 10^6 Btu	0.009[6]
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Heat, 10^6 Btu	0
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	0
Occupational Health	
Deaths	9×10^{-10}[7]
Total Injuries	8×10^{-8}[8]
Man Days Lost	1.5×10^{-5}[9]
Land Use, acre-hr/10^6 Btu	0.3[10]
Approx. Module Efficiency	99.1[11]

Footnotes for Table 39:

(1) a. Fraction of crude oil transported by pipeline$^{(A-20)}$ = 77.4%.
b. Total crude oil transported in 1970$^{(A-20)}$ = 1.58×10^9 barrels.
c. Fraction of crude oil transported by diesel powered pump$^{(A-21)}$ = 16.3% of crude oil transported by pipeline.
d. Crude oil consumed to supply power for pumping$^{(A-22)}$ = 1.45×10^8 gal/year.
e. NO_x emission factor$^{(A-1)}$ = 80 $lb/10^3$ gal burned.
f. Heating value of crude oil (assumed) = 6.3×10^6 Btu/bbl.

(2) a. SO_2 emission factor$^{(A-1)}$ = 142 $lb/10^3$ gal burned.

(3) a. CO emission factor$^{(A-1)}$ = 0.2 $lb/10^3$ gal burned.

(4) a. Particulate emission factor$^{(A-1)}$ = 16 $lb/10^3$ gal burned.

(5) a. Hydrocarbon emission factor$^{(A-1)}$ = 3 $lb/10^3$ gal burned.

(6) a. Assumed efficiency of oil pipeline = 99.1%.

(7) a. Death rate in oil transportation by pipeline (assumed) = 0.08 deaths/10^6 man-hours.
b. Man-hours required to transport the amount of oil for running a 1000 MW Power Plant (assumed) = 7×10^5 man-hours.

(8) a. Injury rate in oil transportation by pipeline (assumed) = 7.22 injuries/10^6 man-hours.

(9) a. Man-days lost per death (assumed) = 6000 days/death.
b. Man-days lost per injury (assumed) = 125 days/injury.

(10) a. Land usage for pipeline$^{(A-12)}$ = 65 acres/year.
b. Period of land use (assumed) = 35 years.

(11) a. Efficiency of pipeline operation (assumed) = 99.1%.

TABLE 40. ENVIRONMENTAL DATA FOR MODULE

Module - Conventional Refinery, Domestic Crude
Unit - 10^6 Btu (output)

Environmental Parameters	Fuel Input, Domestic Crude(0.76% S)[1]
Air	
NO_x, lb	0.023[2]
SO_2, lb	0.12[3]
CO, lb	0.003[4]
Particulate, lb	0.002[5]
Total organic material, lb	0.025[6]
Heat, 10^6 Btu	0.10[7]
Water	
Suspended solids, lb	0.004[8]
Dissolved solids, lb	0.09[9]
Total organic material, lb	0.001[10]
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0.0004[11]
Solid	
Slag, lb	0
Ash, lb	0
Sludge (dry weight), lb	0.007[12]
Tailings, lb	0
Hazardous, lb	0
By-Products, lb	0.24[13]
Occupational Health	
Deaths	1.3×10^{-9}[14]
Total Injuries	9.6×10^{-8}[15]
Man Days Lost	2.3×10^{-5}[16]
Land Use, acre-hr/10^6 Btu	0.008[17]
Approx. Module Efficiency	90%[18]

Footnotes for Table 40:

(1) a. Sulfur content of input crude taken as 0.76%

(2) a. Average refinery energy consumption(A-24) = 70,400 Btu/bbl crude oil processed.
b. Assume all energy supplied by combustion of crude or refinery products
c. Heating value of crude oil (assumed) = 6.3×10^6 Btu/bbl.
d. NO_x emission from combustion operations (A-26) = 130 lb/10^3 bbl crude oil processed.

(3) a. Assume 0.75% S residual burned as refinery fuel.
b. SO_2 emission (A-26) = 695 lb/10^3 bbl crude oil processed
c. 95% removal, no Claus plant tail gas treatment.

(4) a. CO emission from catalytic cracking catalyst regenerator (A-26) = 15 lb/10^3 bbl crude oil processed.

(5) a. Particulate emission from catalytic cracking (A-26) = 12 lb/10^3 bbl crude oil processed (after controlled by cyclones).

(6) a. Hydrocarbon emission (A-26) = 140 lb/10^3 bbl crude oil processed.

(7) a. Refinery energy consumption(A-24) = 704,000 Btu/bbl of crude oil processed.
b. Heating value of crude oil (assumed) = 6.3×10^6 Btu/bbl.

(8) a. Suspended solids emission (assumed) = 20 lb/10^3 bbl processed.

(9) a. Dissolved solids emission (assumed) = 500 lb/10^3 bbl processed.

(10) a. Total organic material emission (assumed) = 8 lb/10^3 bbl processed.

(11) a. Phenol emission (assumed) = 2 lb/10^3 bbl processed.

(12) a. Average sludge production rate(A-25) = 0.08 $yd^3/10^3$ bbl processed.
b. Density of sludge (assumed) = 60 lb/ft^3.
c. Solid content of sludge (assumed) = 30%.

(13) a. Assume an average of 0.2% sulfur in the products.
b. Density of crude oil (assumed) = 7.29 lb/gal.

(14) a. Deaths attributed to the operation of a refinery supplying fuel to a 1000 MW power plant(A-12) = 0.09 deaths.

(15) a. Injuries attributed to the operation of a refinery supplying fuel to a 1000 MW power plant(A-12) = 6.4 injuries.

(16) a. Total work days lost attributed to the operation of a refinery supplying fuel to a 1000 MW power plant(A-12) = 1,530 man-days.

(17) a. Minimum land requirement for refinery processing units (assumed) = 2 acres/1000 bbl/day.

(18) a. Energy required to operate plant(A-24) = 704,000 Btu/bbl crude oil processed.

TABLE 41. ENVIRONMENTAL IMPACTS OF MODULE

Module-- Space Heating(1)

Unit--10^6 Btu (Input)

Environmental Impacts	Dist. Oil
Air	
NO_x, lb	0.135
SO_2, lb	0.263
CO, lb	0.030
Particulate, lb	0.017
Total organic material, lb	0.004
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	0
Sludge, lb	0
Approx. Module Efficiency	70%

Footnotes for Table 41:

(1) a. Values taken from Table A-46 in reference (A-26) were corrected to input basis.

TABLE 42. ENVIRONMENTAL DATA FOR MODULE

Module - Crude Oil Gasification
Unit - 10^6 Btu (output)

Environmental Parameters	Fuel Input, Crude Oil
Air	
NO_x, lb	0.08(1)
SO_2, lb	0.03-0.05(2)
CO, lb	Negligible
Particulate, lb	0.002(3)
Total organic material, lb	0.004(4)
Heat, 10^6 Btu	0.3(5)
Water	
Suspended solids, lb	--
Dissolved solids, lb	0.02(6)
Total organic material, lb	Negligible
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	--
Solid	
Slag, lb	--
Ash, lb	0.06-0.12(7)
Sludge, lb	0.06-0.12(8)
Tailings, lb	--
Hazardous, lb	--
By-Products	1.3-2.5(9)
Occupational Health	
Deaths	Not determined
Total Injuries	Not determined
Man Days Lost	Not determined
Land Use, acre-hr/10^6 Btu	0.03-0.05(10)
Approx. Module Efficiency	77%(11)

Footnotes for Table 42:

(1) a. Plant efficiency of crude oil SNG plant (assumed) = 77%.
b. 23% of input is consumed as liquid fuel for plant operation (assumed).
c. NO_x emission factor[(A-1)] = 40 lb/10^3 gal.
d. Heating value of input crude = 6.3 x 10^6 Btu/barrel (assumed).

(2) a. Sulfur content of crude oil (assumed) = 2 to 4%.
b. Sulfur removal efficiency of Claus plant and tail gas treatment (assumed) = 99%.
c. Density of crude oil - 7.3 lb/gal.

(3) a. Particulate emission factor for fluid catalytic cracking unit[(A-1)] = 61 lb/10^3 bbl fresh feed.
b. Fraction of fresh feed to be cracked in this process (assumed) = 1/3.
c. Particulate removal efficiency of cyclone (assumed) = 50%.

(4) a. Losses of crude oil to atmosphere (assumed) = 20 lb/10^3 bbl input.

(5) a. 23% of input fuel is consumed for plant operation (assumed).

(6) a. Salt content of crude oil (assumed) = 100 lb/10^3 bbl.

(7) a. Solid waste from spent catalyst not worth reclaiming (assumed) = 300 to 600 lb/10^3 bbl.

(8) a. Sludges from water treatment (assumed) = 300 to 600 lb/10^3 bbl.

(9) a. By-product is sulfur. Quantity derived from assumed sulfur content of input crude (2 to 4%) and 99% recovery in Claus unit and tail-gas treatment.

(10) a. Land required for a 100,000 bbl/day plant (assumed) = 600 to 1000 acres.

(11) a. Efficiency of plant (assumed) = 77%.

TABLE 43. **ENVIRONMENTAL DATA FOR MODULE**

Module - Strip-mined coal, West
Unit - 10^6 Btu (output)

Environmental Parameters	With Land Restoration and Treatment of Acid Drainage(1)
Air	
NO_x, lb	0.00008 (Bulldozer operation)(2)
SO_2, lb	Negligible
CO, lb	Negligible
Particulate, lb	0.07(3)
Total organic material, lb	Negligible
Heat, 10^6 Btu	Negligible
Water	
Suspended solids, lb	0.28(4)
Dissolved solids, lb	Not determined
Total organic material, lb	Negligible
Heat, 10^6 Btu	Negligible
Acid (H_2SO_4), lb	Nil
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	None
Occupational Health	
Deaths	6.5×10^{-9} (5)
Total Injuries	3.1×10^{-7} (6)
Man Days Lost	9.6×10^{-5} (7)
Land Use, acre-hr/10^6 Btu	0.16(8)
Approx. Module Efficiency	99.8%

Footnotes for Table 43:

(1) a. Impacts will be negligible after land restorations. Stated impacts will occur during the actual operation.

(2) a. NO_x comes from a disel powered bulldozer used for reclamation.
b. Time requirement for reclamation (assumed = 4 hr/acre.
c. Bulldozer engine power (assumed) = 150 hp.
d. Fuel consumption rate(A-1) = 0.5 lb/hp - hr.
e. NO_x emission factor(A-1) = 0.37 lb/gal fuel used.
f. Average thickness of coal seam (assumed = 5 ft.
g. Coal bulk density (assumed) = 82 lb/ft^3.
h. Heating value of western coal (assumed) = 9235 Btu/lb.

(3) a. Emission factor (given for suspended particulate from primary rock crushing and for mining of copper ore) = 0.1 lb/ton of overburden.
b. Average overburden per ton of coal = 13 tons.

(4) a. Rate of silt run-off (assumed) = 5000 $tons/mi^2$-year.
b. Average thickness of coal seam (assumed) = 5 ft.
c. Coal bulk density (assumed) = 82 lb/ft^3.
d. Reclamation period (private communication, EPA) = 3 years.

(5) a. Death rate for strip coal mining(A-12) = $0.12/10^6$ ton coal.
b. Heating value of coal (assumed) = 18.47×10^6 Btu/ton of coal.

(6) a. Injury rate for strip coal mining(A-12) = 5.65 injuries/10^6 ton coal.

(7) a. Man-days lost per death (assumed) = 6000 days/death.
b. Man-days lost per injury (assumed) = 182.6 days/injury.

(8) a. Land required for 10^6 tons of coal(A-12) = 112 acres.
b. Time requirement for reclamation (assumed) = 3 years.

(9) a. Efficiency of strip mine operation (assumed) = 99.8%.

TABLE 44. ENVIRONMENTAL DATA FOR MODULE

Module - Railroad Transportation of Coal
Unit - 10^6 Btu (output)

Environmental Parameters	Fuel Input, Coal
Air	
NO_x, lb	0.02(1)
SO_2, lb	0.0014(2)
CO, lb	0.015(3)
Particulate, lb	0.0015(4)
Total organic material, lb	Negligible
Heat, 10^6 Btu	0.0039(5)
Water	
Suspended solids, lb	Negligible
Dissolved solids, lb	Negligible
Total organic material, lb	Negligible
Heat, 10^6 Btu	Negligible
Acid (H_2SO_4), lb	Negligible
Solid	
Slag, lb	Negligible
Ash, lb	Negligible
Sludge, lb	Negligible
Tailings, lb	0.083(6)
Hazardous, lb	Negligible
By-Products	Negligible
Occupational Health	
Deaths	3.2×10^{-8}(7)
Total Injuries	3.2×10^{-7}(8)
Man Days Lost	2.2×10^{-4}(9)
Land Use, acre-hr/10^6 Btu	0.29(10)
Approx. Module Efficiency	100%(11)

Footnotes for Table 44:

(1) a. Total quantity of coal transported(A-7) = 695 x 10^6 tons/year.
b. Total shipment from rail and barge(A-8) = 8.13%.
c. Total shipment from rail (assumed) = 7.13%.
d. NO_x emission per 10^6 hp-hr(A-9) = 15.43 tons/10^6 hp-hr.
e. Assume a 3,000 horsepower required for each 2,000 tons of gross load in a locomotive-train system.
f. Average horsepower of the locomotive-train system(A-10) = 74.9% of the maximum horsepower.
g. Ratio of average gross tonnate to average net tonnage(A-10) = 2.3481.

(2) a. SO_2 emission per 10^6 hp-hr(A-9) = 1.1 tons/10^6 hp-hr.

(3) a. CO emission per 10^6 hp-hr(A-9) = 11.9 tons/10^6 hp-hr.

(4) a. Particulate emission (assumed) = 10% of CO.

(5) a. Hp-hr required to move the ton-mill of coal transported by rail per year = 7554.6 x 10^6 hp-hr/yr.
b. Definition and value of the brake thermal efficiency(A-11)=

$$\frac{\text{Fuel flow/Brake fuel consumption}}{\text{[Fuel flow] Fuel heating value}} = \frac{(100/(0.456)}{(19,156)(3.929 \times 10^{-4})} = 29.1\%.$$

c. Energy that the fuel carries into the locomotive = 2.59 x 10^{10} hp-hr/year.

(6) a. The fraction of intransit storage-handling dust loss = 0.1% of the total coal transported.

(7) a. Number of death occurred on the railroad system(A-10) = 2299 death/year.
b. Total ton-miles shipped by rail(A-8) = 7.7 x 10^{11} tons/year.
c. Ton-miles shipped for coal by rail(A-8) = 1.26 x 10^{11}/year.

(8) a. Number of injuries occurred on the railroad system(A-10) = 23356 injuries/year.

(9) a. Man days lost per death (assumed) = 6000 man days.
b. Man days lost per injury (assumed) = 100 man days.

(10) a. Current land rights of the railroad system(A-10) = 3760 sq miles.

(11) a. Module efficiency (assumed) = 100%.

TABLE 45. ENVIRONMENTAL IMPACTS OF MODULE

Module--Space Heating(1)

Unit--10^6 Btu (Input)

Environmental Impacts	Coal (1%)
Air	
NO_x, lb	0.117
SO_2, lb	1.47(2)
CO, lb	3.49
Particulate, lb	0.775
Total organic material, lb	0.775
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	6.9(3)
Sludge, lb	0
Approx. Module Efficiency	50%

Footnotes for Table 45:

(1) a. Values taken from Table A-46 in reference (A-26) were corrected to input basis.

(2) a. Sulfur content of coal is assumed to be 1%.

(3) a. Ash content of coal is assumed to be 10%.

b. Heating value of coal = 13,000 Btu/lb coal.

c. Ash emission as particulate = 0.78 lb/10^6 Btu.

TABLE 46. ENVIRONMENTAL DATA FOR MODULE

Module - Hygas (Gasification of Coal-High Btu)
Unit - 10^6 Btu (output)

Environmental Parameters	Fuel Input, Coal, East
Air	
NO_x, lb	0.25 (1)
SO_2, lb	0.55 (2)
CO, lb	0
Particulate, lb	0.12 (3)
Total organic material, lb	0.0014 (4)
Heat, 10^6 Btu	0.34 (5)
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	Negligible
Heat, 10^6 Btu	Negligible after cooling tower
Phenols, lb	4.6×10^{-5} (6)
Solid	
Slag, lb	0
Ash, lb	6.7 (7)
Sludge, lb	25.8 (8)
Tailings, lb	0
Hazardous, lb	0
By-Products	2.0 (9)
Occupational Health	
Deaths	5×10^{-9} (10)
Total Injuries	1.7×10^{-7} (10)
Man Days Lost	4.6×10^{-5} (11)
Land Use, acre-hr/10^6 Btu	0.02 (12)
Approx. Module Efficiency	66% (13)

Footnotes for Table 46:

(1) a. NO_x emission comes from a 110 MW power plant in the Hygas plant.
b. NO_x emission factor (assumed) = 0.72 $lb/10^6$ Btu generated by the power plant.
c. Hygas plant capacity(A-6) = 80 x 10^6 scfd.
d. Heating value of gas produced(A-6) = 950 Btu/ft^3.

(2) a. SO_2 emission comes from two limestone scrubbers.
b. Sulfur from limestone scrubbers(A-6) = 1300 lb/hr.
c. Sulfur content of coal used in this calculation (assumed)=3%.
d. Adjustment factor for sulfur content(A-6) = 0.68.

(3) a. Ash content of coal used in this calculation (assumed) = 14.4%.
b. Adjustment factor for ash content(A-6) = 1.31.
c. 65% of total ash goes to scrubber as particulate (assumed).
d. Limestone scrubber efficiency for removal of particulate (assumed) = 99%.

(4) a. Hydrocarbon emission comes from a 110 MW power plant.
b. Hydrocarbon emission factor (assumed) = 0.04 $lb/10^6$ Btu.

(5) a. Efficiency of Hygas plant(A-6) = 66%.

(6) a. Assumed to be same as for CO_2 acceptor (see CO_2 Acceptor for the detail).

(7) a. Ash comes from boiler (bottom ash).

(8) a. Sulfur from limestone scrubbers(A-6) = 7600 lb/hr.
b. Sulfur content of sludge = 12%.
c. Adjustment factor for sulfur content in fuel(A-6) = 0.68.
d. Sludge comes from limestone scrubbers (limestone slurry plus particulate collected).

(9) a. Elemental sulfur from Claus plant is the sole by-product (assumed).
b. Adjustment factor for sulfur content in coal = 0.68.

(10) a. Man-hours required for a 1×10^{10} Btu/hr capacity Hygas plant (assumed) = 4000 man hours/day.
b. Injury rate (assumed) = 10 injuries/10^6 man hours.
c. 3% of injury assumed fatal.

(11) a. Man-days lost per death (assumed) = 6000 days/death.
b. Man-days lost per injury (assumed) = 95 days/injury.

(12) a. Personal communication with EPA.

(13) a. Reported by Processes Research.(A-6)

TABLE 47. ENVIRONMENTAL DATA FOR MODULE

Module -- Conventional Boiler
Unit -- 10^6 Btu (input)

Environmental Parameters	Fuel Input, Natural Gas
Air	
NO_x, lb	0.39 (1)
SO_2, lb	0.0006 (2)
CO, lb	0.0004 (3)
Particulate, lb	0.015 (4)
Total organic material, lb	0.04 (5)
Heat, 10^6 Btu	0.63 (6)
Water	
Suspended solids, lb	0.016 (7)
Dissolved solids, lb	0
Total organic material, lb	0
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	0
Occupational Health	
Deaths	1.5×10^{-10} (8)
Total Injuries	8.9×10^{-9} (9)
Man Days Lost	2.9×10^{-6} (10)
Land Use, acre-hr/10^6 Btu	0.02 (11)
Approx. Module Efficiency	37% (12)

Footnotes for Table 47:

(1) a. NO_x emission factor[(A-1)] = 39 lb/10^6 ft^3 of natural gas.
b. Heating value of natural gas (assumed) = 1000 Btu/ft^3.

(2) a. SO_2 emission factor for burning natural gas = 0.6 lb/10^6 ft^3.

(3) a. CO emission factor for burning natural gas = 0.4 lb/10^6 ft^3.

(4) a. Particulate emission factor for burning natural gas = 15 lb/ 10^6 ft^3.

(5) a. Hydrocarbon emission factor for burning natural gas = 40 lb/ 10^6 ft^3.

(6) a. Efficiency of gas fired conventional boiler = 37%.

(7) a. Suspended solid emission from a 1000 MW gas fired Power Plant (A-12) = 548 tons.

(8) a. Deaths attributed to a 1000 MW gas fired Power Plant[(A-12)] = 0.01 death/year.

(9) a. Injuries attributed to a 1000 MW gas fired Power Plant[(A-12)] = 0.6 injuries/year.

(10) a. Man-days lost attributed to a 1000 MW gas fired Power Plant[(A-12)] = 197 man-days/year.

(11) a. Land requirement for a 1000 MW gas fired Power Plant[(A-12)] = 150 acres.

(12) a. Efficiency of gas fired Power Plant (assumed) = 37%.

TABLE 48. ENVIRONMENTAL IMPACTS OF MODULE

Module--Conventional Boiler
Unit--10^6 Btu (Input)

Environmental Impacts	Dist. Fuel Oil (0.3% S)
Air	
NO_x, lb	0.75 (1)
SO_2, lb	0.336 (2)
CO, lb	0.0003 (3)
Particulate, lb	0.057 (4)
Total organic material, lb	0.014 (5)
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	0
Sludge, lb	0
Approx. Module Efficiency	37% (6)

Footnotes for Table 48:

(1) a. Heating value of distillate fuel oil(A-1) = 140,000 Btu/gal.

b. NO_x emission factor(A-1) = 105 lb/1000 gal.

(2) a. Sulfur content of distillate fuel oil, S (assumed) = 0.3%.

b. SO_2 emission factor(A-1) = 157 S lb/1000 gal.

(3) a. CO emission factor(A-1) = 0.04 lb/1000 gal.

(4) a. Particulate emission factor(A-1) = 8 lb/1000 gal.

(5) a. Hydrocarbon emission factor(A-1) = 2 lb/1000 gal.

(6) a. Plant efficiency was assumed to be 37%.

TABLE 49. ENVIRONMENTAL DATA FOR MODULE

Module -- Oil Barge
Unit -- 10^6 Btu (Output)

Environmental Parameters	Fuel Input, Residual Oil
Air	
NO_x, lb	0.0013 (1)
SO_2, lb	0.0014 (2)
CO, lb	0.0011 (3)
Particulate, lb	0.0018 (4)
Total organic material, lb	0.0008 (5)
Heat, 10^6 Btu	0.004 (6)
Water	
Suspended solids, lb	nil
Dissolved solids, lb	nil
Total organic material, lb	0.015 (7)
Heat, 10^6 Btu	nil
Acid (H_2SO_4), lb	nil
Solid	
Slag, lb	nil
Ash, lb	nil
Sludge, lb	nil
Tailings, lb	nil
Hazardous, lb	nil
By-Products	nil
Occupational Health	
Deaths	9×10^{-10} (8)
Total Injuries	8×10^{-8} (9)
Man Days Lost	1.5×10^{-5} (10)
Land Use, acre-hr/10^6 Btu	0 (11)
Approx. Module Efficiency	99.6% (12)

Footnotes for Table 49:

(1) a. Assume 20,000 tons per shipment.
b. NO_x emission factor for motor ship(A-1) = 1.4 lb/mi.
c. Trip distance per shipment (assumed) = 325 miles.

(2) a. SO_2 emission factor for motor ship(A-1) = 1.5 lb/mi for 0.5% sulfur content for fuel.

(3) a. CO emission factor for motor ship(A-1) = 1.2 lb/mi.

(4) a. Particulate emission factor for motor ship(A-1) = 2lb/mi.

(5) a. Hydrocarbon emission factor for motor ship(A-1) = 0.9 lb/mi.

(6) a. Total heat required per 10^6 Btu transported (assumed) = 3800 Btu.

(7) a. Total oil discharge in oil transport and in tank cleaning operations(A-12) = 0.27% of shipment.

(8) a. Death rate in oil transportation by barge(A-12) (assume that barge operation is similar to tanker operation) = 0.08 deaths/10^6 man-hours.
b. Man-hour required to transport the amount of crude oil to operate a 1000 MW Power Plant(A-12) = 7×10^5 man-hours.

(9) a. Injury rate in oil transportation by barge(A-12) (assume that barge operation is similar to tanker operation) = 7.22 injuries/10^6 man-hours.

(10) a. Man-days lost per death (assumed) = 6000 days/death.
b. Man-days lost per injury (assumed) = 125 days/injury.

(11) a. Land requirement for port facilities not estimated.

(12) a. Energy consumption rate per 10^6 Btu of crude oil transported (assumed) = 3800 Btu.

TABLE 50. ENVIRONMENTAL IMPACTS OF MODULE

Module--Conventional Boiler[1]

Unit--10^6 Btu (Input)

Environmental Impacts	1% S Resid
Air	
NO_x, lb	.7
SO_2, lb	1.04
CO, lb	0
Particulate, lb	0.05
Total organic material, lb	0.01
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	0
Sludge, lb	0
Approx. Module Efficiency	37%

Footnotes for Table 50:

(1) a. Values were taken from Table A-43 in reference (A-26). SO_2 emission was corrected to 1% sulfur resid.

TABLE 51. ENVIRONMENTAL DATA FOR MODULE

Module -- Oil Tanker
Unit -- 10^6 Btu (Output)

Environmental Parameters	Fuel Input, Crude Oil
Air	
NO_x, lb	0.0015 (1)
SO_2, lb	0.0016 (2)
CO, lb	0.0013 (3)
Particulate, lb	0.0021 (4)
Total organic material, lb	9×10^{-5} (5)
Heat, 10^6 Btu	0.005 (6)
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0.015 (7)
Heat, 10^6 Btu	0
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	0
Occupational Health	
Deaths	9×10^{-10} (8)
Total Injuries	8×10^{-8} (9)
Man Days Lost	1.5×10^{-5} (10)
Land Use, acre-hr/10^6 Btu	0 (11)
Approx. Module Efficiency	99.5 (12)

Footnotes for Table 51:

(1) a. NO_x emission by oil tanker to transport crude oil for a 1000 MW Power Plant[(A-12)] = 51 tons/year.

(2) a. SO_2 emission by oil tanker to transport crude oil for a 1000 MW Power Plant [(A-12)] = 55 tons/year.

(3) a. CO emission by oil tanker to transport crude oil for a 1000 MW Power Plant[(A-12)] = 44 tons/year.

(4) a. Particulate emission by oil tanker to transport crude oil for a 1000 MW Power Plant[(A-12)] = 72 tons/year.

(5) a. Hydrocarbon emission by oil tanker to transport crude oil for a 1000 MW Power Plant[(A-12)] = 3 tons/year.

(6) a. Efficiency of oil tanker operation (assumed) = 99.5%.

(7) a. Total oil discharge in oil transport and in tank cleaning operations[(A-12)] = 0.027% of shipment.

(8) a. Death rate in oil transportation by tanker[(A-12)] = 0.08 deaths/10^6 man-hours.
b. Man-hours required to transport the amount of crude oil to operate a 1000 MW Power Plant[(A-12)] = 7 x 10^5 man-hours.

(9) a. Injury rate in oil transportation by tanker[(A-12)] = 7.22 injuries/10^6 man-hours.

(10) a. Man-days lost per death (assumed) = 6000 days/death.
b. Man-days lost per injury (assumed) =125 days/injury.

(11) a. Land requirement for port facilities not estimated.

(12) a. Efficiency of oil tanker (assumed) = 99.5%.

TABLE 52. ENVIRONMENTAL DATA FOR MODULE

Module - Conventional Boiler (Coal)
Unit - 10^6 Btu (Input)

Environmental Parameters	Fuel Input, Coal, West
Air	
NO_x, lb	0.98(1)
SO_2, lb	1.65(2)
CO, lb	0.054(3)
Particulate, lb	0.07(4)
Total organic material, lb	0.016(5)
Heat, 10^6 Btu	0.63(6)
Water	
Suspended solids, lb	0.025(7)
Dissolved solids, lb	0
Total organic material, lb	0.011(8)
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	9.0(9)
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	0
Occupational Health	
Deaths	3.3×10^{-10}(10)
Total Injuries	1.4×10^{-8}(10)
Man Days Lost	5.1×10^{-6}(11)
Land Use, acre-hr/10^6 Btu	0.1(12)
Approx. Module Efficiency	37%(13)

Footnotes for Table 52:

(1) a. NO_x emission factor[(A-1)] = 18 lb/ton coal burned.
b. Heating value of western coal (assumed) 9200 Btu/lb.

(2) a. SO_2 emission factor[(A-1)] = 38 S lb/ton coal burned.
b. Sulfur content, S (assumed) = 0.8%.

(3) a. CO emission factor[(A-1)] = 1 lb/ton coal burned.

(4) a. Particulate emission factor[(A-1)] = 16A lb/ton coal burned.
b. Ash content, A (assumed) = 8.4%.
c. Electrostatic precipitator efficiency (assumed) = 99%.

(5) a. Hydrocarbons emission factor[(A-1)] = 0.3 lb/ton coal burned.

(6) a. Efficiency of conventional boiler (assumed) = 37%.

(7) a. Total solid to water[(A-12)] = 0.036 lb/10^6 Btu.
b. Fraction of suspended solid (assumed) = 70%.

(8) a. Fraction of organic material in total solid (assumed) = 30%.

(9) a. Ash content of coal (assumed) = 8.4%.

(10) a. Man-hour required per 10^6 Btu for conventional power plant[(A-13)] = 2.4×10^{-3} man hour.
b. Total injuries per 10^6 man-hour[(A-13)] = 5.7.
c. Death rate[(A-12)] = 2.4% of injuries.

(11) a. Days lost per death (assumed) = 6000 days/death.
b. Days lost per injury (assumed) = 229 days/death.

(12) a. Land required for a 1000 MW power plant (assumed) = 800 acres.

(13) a. Efficiency of conventional boiler (assumed) = 37%.

TABLE 53. ENVIRONMENTAL DATA FOR MODULE

Module--Physical Cleaning of Coal
Unit--10^6 Btu (output)

Environmental Parameters	With Environmental Control
Air	
NO_x, lb	0.006[(1)]
SO_2, lb	0.004[(2)]
CO, lb	--
Particulate, lb	0.01[(3)]
Total organic material, lb	--
Water	
Suspended solids, lb	Negligible
Dissolved solids, lb	Negligible
Total organic material, lb	Negligible
Acid (H_2SO_4), lb	Negligible
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0.3[(4)]
Tailings, lb	Negligible
Approx. Module Efficiency	88%[(5)]

Footnotes for Table 53:

(1) a. NO_x from thermal dryer. Operating characteristics for evaporating water from wet coal[(A-2)] = 550 tons of coal produced per 50 tons of water evaporated.

b. Heat required for water evaporation = 1000 Btu/lb water.

c. Heating value of coal = 12,000 Btu/lb of coal.

d. NO_x emission factor[(A-1)] = 18 lb/ton of coal burner.

e. No control equipment.

(2) a. SO_2 emission factor[(A-1)] = 38 S lb/ton coal burned.

b. Sulfur content of coal, S (assumed) = 3%.

c. Lime scrubber control efficiency (assumed) = 90%.

(3) a. Particulate emission factor for thermal dryer[(A-1)] = 25 lb/ton coal product.

b. Heating value of coal product = 13,180 Btu/lb.

c. Control efficiency of multiple cyclones with wet scrubber[(A-1)] 99.0% removal.

(4) a. Sludge comes from SO_2 and H_2SO_4 control (assumed).
b. Sulfur content of sludge (assumed) = 12%.

(5) a. The efficiency is assumed to be 88%.

TABLE 54. ENVIRONMENTAL DATA FOR MODULE

Module - CAFB Boiler (Residual Oil) + Combined Cycle
Unit - 10^6 Btu (input)

Environmental Parameters	Fuel Input, Residual Oil (Imported)
Air	
NO_x, lb	0.16[1]
SO_2, lb	0.45[2]
CO, lb	0
Particulate, lb	0.01[3]
Total organic material, lb	0.04[4]
Heat, 10^6 Btu	0.62[5]
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	3.0[6]
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	1.4[7]
Occupational Health	
Deaths	2×10^{-9} [8]
Total Injuries	7×10^{-8} [8]
Man Days Lost	1.7×10^{-5} [9]
Land Use, acre-hr/10^6 Btu	0.06[10]
Approx. Module Efficiency	38%[11]

Footnotes for Table 54:

(1) a. Experimental data obtained by Westinghouse.[A-23]

(2) a. SO_2 from boiler[A-23] = 0.35 lb/10^6 Btu.
b. SO_2 from Claus unit[A-23] = 0.1 lb/10^6 Btu.

(3) a. Electrostatic precipitator is employed to control particulate emission (assumed).
b. Particulate emission factor[A-23] = 0.01 lb/10^6 Btu.

(4) a. Hydrocarbon emission factor for burning CAFB gas (assumed) = 40 lb/10^6 ft^3.

(5) a. Efficiency of the module (assumed) = 38%.

(6) a. Sulfur content of oil (assumed) = 3%.
b. Limestone requirement per pound of sulfur = 1.75 lb.
c. Heating value of oil (assumed) = 6.3 x 10^6 Btu/bbl.

(7) a. Sulfur content of oil (assumed) = 3%.
b. Sulfur emission = 0.225.

(8) a. Injury rate per man hour (assumed) = 10 injuries/10^6 man hours.
b. Death rate of injury = 3%.
c. 70 men operate a 1000 MW plant (assumed).

(9) a. Man days lost per death (assumed) = 6000 days/death.
b. Man days lost per injury (assumed) = 95 days/injury.

(10) a. Land requirement for a 1000 MW oil-fired power plant (assumed) = 300 acres.
b. Additional land requirement for CAFB gas unit (assumed) = 150 acres.

(11) a. Assumed efficiency = 38%.

TABLE 55. ENVIRONMENTAL IMPACTS OF MODULE

Module--Conv. Boiler with limestone scrubber[1]
Unit--10^6 Btu (Input)

Environmental Impacts	Resid (3.5% S)
Air	
NO_x, lb	0.7
SO_2, lb	0.366[2]
CO, lb	0
Particulate, lb	0.0005[3]
Total organic material, lb	0.01
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	0
Sludge, lb	13.8[4]
Approx. Module Efficiency	37%

Footnotes for Table 55:

(1) a. Values were taken from Table A-42 in reference (A-26) except as modified below.

(2) a. Sulfur content of resid (assumed) = 3.5%.

b. SO_2 emission was considered twice that given in Table A-42 in reference (A-26).

c. SO_2 removal efficiency of lime scrubber (assumed) = 90%.

(3) a. Particulate emission factor[(A-1)] = 8 lbs/1000 gal.

b. Particulate removal efficiency (assumed) = 99%.

(4) a. SO_2 in sludge [from Footnote (2)] = 3.29 $lb/10^6$ Btu.

b. Generally sulfur in lime scrubber sludge is assumed as 12% by weight.

TABLE 56. ENVIRONMENTAL IMPACTS OF MODULE

Module--Conventional Boiler - No Control[1]
Unit--10^6 Btu (Input)

Environmental Impacts	Resid (3.5% S)
Air	
NO_x, lb	0.7
SO_2, lb	3.66[2]
CO, lb	0
Particulate, lb	0.05
Total organic material, lb	0.01
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	0
Sludge, lb	0
Approx. Module Efficiency	37%

Footnotes from Table 56:

(1) a. Emission values were taken from Table A-42 in reference (A-26) except as described below.

(2) a. In this module sulfur content of resid was assumed as 3.5%.

b. Thus SO_2 emission was considered to be twice that given in Table A-42 in reference (A-26).

TABLE 57. ENVIRONMENTAL DATA FOR MODULE

Module - Fluid-Bed Combustion Plus Combined Cycle
Unit - 10^6 Btu (input to combustion cycle)

Environmental Parameters	Fuel Input, Coal, East
Air	
NO_x, lb	0.14(1)
SO_2, lb	0.7(2)
CO, lb	0
Particulate, lb	0.02(3)
Total organic material, lb	0
Heat, 10^6 Btu	0.62(4)
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	17.3(5)
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	1.9(6)
Occupational Health	
Deaths	1.5×10^{-9}(7)
Total Injuries	3.6×10^{-8}(8)
Man Days Lost	1.4×10^{-5}(9)
Land Use, acre-hr/10^6 Btu	0.12(10)
Approx. Module Efficiency	38%(11)

Footnotes for Table 57:

(1) a. Average value of 0.07 and 0.22 $lb/10^6$ Btu reported in Westinghouse Report.(A-23)

(2) a. SO_2 emission factor reported(A-23) = 1 $lb/10^6$ Btu.
b. Adjustment factor for sulfur content(A-23) = 0.7 (i.e., $\frac{3.0}{4.3}$).

(3) a. Particulate emission factor reported(A-23) = 0.02 $lb/10^6$ Btu.

(4) a. Efficiency of the module (assumed) = 38%.

(5) a. Ash content of eastern coal (assumed) = 14.4%.
b. Heating value of coal (assumed) = 24 x 10^6 Btu/ton.
c. Limestone requirement per pound of sulfur = 1.75 lb.

(6) a. The sole by-product is elemental sulfur.
b. Sulfur content of coal (assumed) = 3%.
c. 90% of sulfur is collected by limestone (assumed).
d. Sulfur loss from Claus unit(A-23) = 0.35 $lb/10^6$ Btu.

(7) a. Injuries calculated from fluid-bed combustion plant and gas-fired power plant operations.
b. 40 men operate a 500 ton coal/hr capacity combustion plant (assumed).
c. Using chemical industry data for gasification plant, injuries per man hour(A-5) = 8.1 injuries/10^6 man hours.
d. Death rate (assumed) = 5% of injuries.
e. Death attributed to a 100 MW gas-fired power plant(A-12) = 0.01 deaths/year.

(8) a. Injuries attributed to a 1000 MW gas fired power plant(A-12) = 0.6 injuries/year.

(9) a. Using chemical industry data for gasification plant, man-days lost per man hour(A-5) = 528 days/10^6 man hours.
b. Man days lost per death (assumed) = 6000 days/death.
c. Man days lost attributed to a 1000 MW gas fired power plant(A-12) = 197 man-days/year.

(10) a. Land requirement for a 1000 MW coal fired power plant (assumed) = 800 acres.
b. Additional land requirement for fluid-bed combustion unit (assumed) = 150 acres.

(11) a. Efficiency(A-23) = 38%.

TABLE 58. ENVIRONMENTAL DATA FOR MODULE

Module - Lurgi Gasifier and Conventional Boiler
Unit - 10^6 Btu (input to conventional boiler)

Environmental Parameters	Fuel Input, Coal, East
Air	
NO_x, lb	0.40 (1)
SO_2, lb	0.93 (2)
CO, lb	0
Particulate, lb	0.015 (3)
Total organic material, lb	0.11 (4)
Heat, 10^6 Btu	0.92 (5)
Water	
Suspended solids, lb	0.016 (6)
Dissolved solids, lb	0
Total organic material, lb	0.002 (7)
Heat, 10^6 Btu	Negligible after cooling tower
Phenols, lb	0.0029 (8)
Solid	
Slag, lb	0
Ash, lb	9.82 (9)
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	1.9 (10)
Occupational Health	
Deaths	1.5×10^{-9} (11)
Total Injuries	3.6×10^{-8} (12)
Man Days Lost	9.4×10^{-6} (13)
Land Use, acre-hr/10^6 Btu	0.12 (14)
Approx. Module Efficiency	25.9% (15)

Footnotes for Table 58:

(1) a. NO_x comes from gas-fired boiler in gasifier plant and gas-fired power plant.
b. NO_x emission factor(A-1) = 0.39 lb/10^6 Btu for natural gas.
c. The emission factor is value for Lurgi gas combustion on the basis of heating value (assumed).

(2) a. Basis: 1000 MW nominal cogas power plant.(A-6)
b. Coal input rate(A-6) = 341 tons/hr.
c. SO_2 emission comes from gas-fired boiler in gasifier plant and gas-fired power plant.(A-6)
d. 1% of sulfur lost to atmosphere from gasifier plant by leaking (assumption).
e. Content of H_2S in Lurgi gas produced(A-6) = 0.105% by volume.
f. Lurgi gas production rate from the plant = 112600 lb-moles/hr.

(3) a. Particulate emission comes from gas-fired power plant (assumed).
b. Emission factor for natural gas(A-1) = 0.015 lg/10^6 Btu.
c. Assumed that the emission factor for natural gas combustion is valid to Lurgi gas combustion on the basis of heating value.

(4) a. 1% of total organic matter (COS and CH_4) is lost from gasifier by leaking (assumed).

(5) a. 63% of the total input energy to gas-fired power plant is lost to atmosphere (based on the assumed efficiency of the power plant).
b. Efficiency of Lurgi gasifier plant (assumed) - 70%.
c. Efficiency loss due to material loss in Lurgi gasifier plant (assumed) = 10%.

(6) a. Suspended solid emission comes from gas-fired power plant (assumed).
b. Emission from a 1000 MW plant(A-12) = 548 tons.

(7) a. Total organic material comes from gas-fired power plant (assumed).
b. Emission factor(A-12) = 73 tons/year for a 1000 MW plant.

(8) a. From data supplied by T. K. Janes, EPA.

(9) a. Ash content of coal (assumed) = 14.4%.

(10) a. The by-product of Lurgi gasifier plant is sulfur from Claus unit.

(11) a. Injuries are combined for Lurgi gasifier plant and gas-fired power plant operations.
b. 40 men operate a 500-ton coal/hr capacity Lurgi gasifier plant (assumed).
c. Using chemical industry data, injuries per man-hour(A-5) = 8.1 injuries/10^6 man-hours.
d. Death rate (assumed) = 5% of total injuries.
e. Death attributed to a 1000 MW gas-fired power plant(A-12) = 0.01 death/year.

(12) a. Injuries attributed to a 1000 MW gas-fired power plant(A-12) = 0.6 injuries/year.

(13) a. Using chemical industry data, days lost per man-hour(A-5) = 528 days/10^6 man-hours.
b. Man-days lost per death (assumed) = 6000 days/death
c. Man-days lost attributed to a 1000 MW gas-fired power plant(A-13) = 197 man days/year.

(14) a. Land requirement for a 1000 MW coal-fired power plant (assumed) = 800 acres.
b. Additional land requirement for Lurgi gasifier plant (assumed) = 150 acres.

(15) a. Efficiency of Lurgi gasifier plant (assumed) = 70%.
b. Efficiency of gas-fired power plant (assumed) = 37%.

TABLE 59. ENVIRONMENTAL IMPACTS OF MODULE (1)
Module-- Conv. Boiler, Phys. Cleaned Coal
Unit--10^6 Btu (Input)

Environmental Impacts	Phys. Cleaned Coal
Air	
NO_x, lb	0.68
SO_2, lb	1.44
CO, lb	0.038
Particulate, lb	0.044
Total organic material, lb	0.011
Water	
Suspended solids, lb	0.025
Dissolved solids, lb	0
Total organic material, lb	0.011
Solid	
Ash, lb	5.41
Sludge, lb	0
Approx. Module Efficiency	37%

Footnotes for Table 59:

(1) a. Data were taken from Table A-10 in reference (A-26) except that SO_2 emission were corrected to 1% sulfur in cleaned coal.

TABLE 60. **ENVIRONMENTAL DATA FOR MODULE**

Module - Coal Liquefaction (solvent refining)
Unit - 10^6 Btu (output)

Environmental Parameters	Fuel Input, Eastern Coal(1)
Air	
NO_x, lb	0.21(2)
SO_2, lb	0.003(3)
CO, lb	0.012(4)
Particulate, lb	0.27(5)
Total organic material, lb	0.0036(6)
Heat, 10^6 Btu	0.067(7)
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	Trace
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	16.0(8)
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	2.95(9)
Occupational Health	
Deaths	1.4×10^{-9}(10)
Total Injuries	2.7×10^{-8}(10)
Man Days Lost	6.5×10^{-6}(11)
Land Use, acre-hr/10^6 Btu	0.08(12)
Approx. Module Efficiency	75%(13)

(1) Impacts were estimated based on the coal containing 14.4% ash, 3.0% S and a heating value of 12,000 Btu/lb. In addition, the coal liquefaction plant was assumed to have a capacity of 222×10^9 Btu/day.

Footnotes for Table 60: (Continued)

(2) a. Solvent refined coal (SRC) has a heating value of 16,000 Btu/lb, 0.05% ash, and 0.6% sulfur(A-6).
b. Plant efficiency(A-6) = 75%.
c. Emission factor for NO_x = 18 lb/ton of coal burned.
'd. Average heating value of consumed coal = 14,000 Btu/lb.
e. Coal consumption rate = 110 tons/hr.

(3) a. Total sulfur content in the input coal = 30,833 lb/hr.
b. Total sulfur content in the SRC = 3.469 lb/hr.
c. Sulfur emitted as SO_2 = 0.1% total sulfur off gas-liquid separator.

(4) a. CO emission factor(A-1) = 1 lb/ton of coal burned.
b. No control equipment.

(5) a. Particulate emission factor(A-1) = 16A lb/ton of coal burned.
b. Emission control efficiency (assumed) 98%.
c. Average ash content of consumed coal, A = 7.23%.

(6) a. Total organic material emission factor = 0.3 lg/ton of coal burned.
b. No control equipment.

(7) a. Total heat released = 0.308×10^{10} Btu/hr.

(8) a. Total ash input rate = 148,000 lb/hr.
b. Total ash output rate in SRC = 289 lb/hr.

(9) Elemental sulfur product = 99.9% of total sulfur-off gas, liquid separator.

(10) a. Assumption: 80 men operate a 1,000 ton/hr capacity solvent refining plant.
b. Use chemical industry data, injuries per man hour(A-5) = 8.1 injuries/10^6 man hours.
c. Use chemical industry data, days lost per man hour(A-5) = 528 days lost/10^6 man hours.
d. Death rate = 5% of total injuries (assumed).

(11) Man days lost per death (assumed) = 6,000 days/death.

(12) Land required for a 222×10^9 Btu/day plant (assumed) = 750 acres.

(13) Plant efficiency(A-6) = 75%.

TABLE 61. ENVIRONMENTAL DATA FOR MODULE

Module - Conventional Boiler
Unit - 10^6 Btu (input)

Environmental Parameters	Fuel Input, Solvent Refined Coal (Eastern)
Air	
NO_x, lb	0.56 (1)
SO_2, lb	0.71 (2)
CO, lb	0.037 (3)
Particulate, lb	0.0003 (4)
Total organic material, lb	0.01 (5)
Heat, 10^6 Btu	0.63 (6)
Water	
Suspended solids, lb	0.025 (7)
Dissolved solids, lb	0
Total organic material, lb	0.011 (8)
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	0.031 (9)
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	
Occupational Health	
Deaths	3.3×10^{-10} (10)
Total Injuries	1.4×10^{-8} (10)
Man Days Lost	5.1×10^{-6} (11)
Land Use, acre-hr/10^6 Btu	0.09 (12)
Approx. Module Efficiency	37% (13)

Footnotes for Table 61:

(1) a. NO_x emissions factor[A-1] = 18 lb/ton coal burned.
b. Heating value of solvent refined coal (SRC) (assumed) = 16000 Btu/lb.

(2) a. Sulfur content of solvent refined coal, S (assumed) = 0.6%.
b. SO_2 emission factor[A-1] = 38 S lb/ton coal burned.

(3) a. CO emission factor[A-1] = 1 lb/ton coal burned.

(4) a. Ash content of SRC, A (assumed) = 0.05%.
b. Particulate emission factor[A-1] = 16 A lb/ton coal burned.
c. Electrostatic precipitator efficiency (assumed) = 99%.

(5) a. Hydrocarbon emission factor[A-1] = 0.3 lb/ton coal burned.

(6) a. Efficiency of conventional boiler (assumed) = 37%.

(7) a. Total solid to water[A-12] = 0.036 lb/10^6 Btu.
b. Fraction of suspended solids (assumed) = 70%.

(8) a. Fraction of organic material in total solid (assumed) = 30%.

(9) a. Ash content of coal (assumed) = 0.05%.

(10) a. Man-hour required per 10^6 Btu for conventional power plant[A-13] = 2.4×10^{-3} man hour/10^6 Btu.
b. Total injuries per 10^6 man hour[A-13] = 5.7.
c. Death rate[A-12] = 2.4% of injuries.

(11) a. Days lost per death (assumed) = 6000 days/death.
b. Days lost per injuries (assumed) = 229 days/injury.

(12) a. Land requirement for a 1000 MW power plant (assumed) = 700 acres.

(13) a. Efficiency of conventional boiler (assumed) = 37%.

TABLE 62. ENVIRONMENTAL DATA FOR MODULE

Module - Conventional Boiler and Limestone Scrubbing
Unit - 10^6 Btu (input)

Environmental Parameters	Fuel Input, Coal, East
Air	
NO_x, lb	0.60 (1)
SO_2, lb	0.50 (2)
CO, lb	0.042 (3)
Particulate, lb	0.1 (4)
Total organic material, lb	0.013 (5)
Heat, 10^6 Btu	0.65 (6)
Water	
Suspended solids, lb	0.025 (7)
Dissolved solids, lb	0
Total organic material, lb	0.011 (8)
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	2.4 (9)
Sludge, lb	27.3 (10)
Tailings, lb	0
Hazardous, lb	0
By-Products	0
Occupational Health	
Deaths	3.3×10^{-10} (11)
Total Injuries	1.4×10^{-8} (11)
Man Days Lost	5.1×10^{-6} (12)
Land Use, acre-hr/10^6 Btu	0.1 (13)
Approx. Module Efficiency	35% (14)

Footnotes for Table 62:

(1) a. NO_x emission factor$^{(A-1)}$ = 18 lb/ton coal burned.
b. Heating value of eastern coal (assumed) = 12000 Btu/lb.
c. NO_x removal efficiency by limestone scrubber (assumed) = 20%.

(2) a. Sulfur content of eastern coal, S (assumed) = 3%.
b. SO_2 emission factor$^{(A-1)}$ = 38 S lb/ton coal burned.
c. Limestone scrubber efficiency (assumed) = 90%.

(3) a. CO emission factor$^{(A-1)}$ = 1 lb/ton coal burned.

(4) a. Ash content of eastern coal, A (assumed) = 14.4%.
b. Particulate emission factor$^{(A-1)}$ = 16 A lb/ton coal burned.
c. Scrubber efficiency for particulate removal = 99%.

(5) a. Hydrocarbon emission factor$^{(A-1)}$ = 0.3 lb/ton coal burned.

(6) a. Efficiency of conventional boiler with limestone scrubbing (assumed) = 35%.

(7) a. Total solid to water$^{(A-12)}$ = 0.036 lb/10^6 Btu.
b. Fraction of suspended solids (assumed) = 70%.

(8) a. Fraction of organic material in total solid (assumed) = 30%.

(9) a. Ash content of eastern coal (assumed) = 14.4%. 20% to bottom ash.

(10) a. Sulfur content of sludge (assumed) = 12%. Add fly ash collected.

(11) a. Man-hour required per 10^6 Btu for conventional power plant$^{(A-13)}$ = 2.4×10^{-3} man hour/10^6 Btu.
b. Total injuries per 10^6 Man hour$^{(A-13)}$ = 5.7.
c. Death rate$^{(A-12)}$ = 2.4% of injuries.

(12) a. Days lost per death (assumed) = 6000 days/death.
b. Days lost per injury (assumed) = 229 days/injury.

(13) a. Land requirement for a 1000 MW power plant (assumed) = 800 acres.

(14) a. Efficiency of conventional boiler with limestone scrubbing (assumed) = 35%.

TABLE 63. ENVIRONMENTAL DATA FOR MODULE

Module - Conventional Boiler & MgO-Scrubbing
Unit - 10^6 Btu (Input)

Environmental Parameters	Input: Eastern Coal
Air	
NO_x, lb	0.60 (1)
SO_2, lb	0.50 (2)
CO, lb	0.042 (3)
Particulate, lb	0.1 (4)
Total organic material, lb	0.013 (5)
Heat, 10^6 Btu	0.65 (6)
Water	
Suspended solids, lb	0.025 (7)
Dissolved solids, lb	0
Total organic material, lb	0.011 (8)
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	2.4 (9)
Sludge, lb	0
Tailings, lb	10.4 (10)
Hazardous, lb	0
By-Products	6.13 (11)
Occupational Health	
Deaths	3.3×10^{-10} (12)
Total Injuries	1.4×10^{-8} (12)
Man Days Lost	5.1×10^{-6} (13)
Land Use, acre-hr/10^6 Btu	0.1 (14)
Approx. Module Efficiency	35% (15)

Footnotes for Table 63:

(1) a. NO_x emission factor(A-1) = 18 lb/ton coal burned.
b. Heating value of eastern coal (assumed) = 12,000 Btu/lb.
c. NO_x removal efficiency by MgO-scrubber (assumed) = 20%.

(2) a. Sulfur content of eastern coal, S (assumed) = 3%.
b. SO_2 emission factor(A-1) = 38 S lb/ton coal burned.
c. MgO-scrubber efficiency (assumed) = 90%.

(3) a. CO emission factor(A-1) = 1 lb/ton coal burned.

(4) a. Ash content of eastern coal, A (assumed) 14.4%.
b. Particulate emission factor(A-1) = 16 A lb/ton coal burned.
c. Scrubber efficiency for particulate removal = 99%.

(5) a. Hydrocarbon emission factor(A-1) = 0.3 lb/ton coal burned.

(6) a. Efficiency of conventional boiler with MgO-scrubbing (assumed) = 35%.

(7) a. Total solid to water(A-12) = 0.036 $lb/10^6$ Btu.
b. Fraction of suspended solids (assumed) = 70%.

(8) a. Fraction of organic material in total solid (assumed) = 30%.

(9) a. Ash content of eastern coal (assumed) = 14.4%. 20% to bottom ash.

(10) a. MgO reacts with SO_2 to product 80% of $MgSO_3 \cdot 6H_2O$ and 20% of $MgSO_4 \cdot 7H_2O$ (assumption).
b. 1% blowdown of $MgSO_3 \cdot 6H_2O$ and $MgSO_4 \cdot 7H_2O$ (assumed).
c. Loss in regeneration (assumed) = 5%. Add fly ash collected.

(11) a. Sulfur reacted with MgO is regenerated in the form of H_2SO_4.
b. Regeneration efficiency (assumed) = 100%.

(12) a. Man-hour required per 10^6 Btu for conventional power plant(A-13) = 2.4×10^{-3} man-hour/10^6 Btu.
b. Total injuries per 10^6 man hour(A-13) = 5.7.
c. Death rate(A-12) = 2.4% of injuries.

(13) a. Days lost per death (assumed = 6000 days/death.
b. Days lost per injury (assumed) = 229 days/injury.

(14) a. Land requirement for a 1000 MW power plant (assumed) = 800 acres.

(15) a. Efficiency of conventional boiler with MgO-scrubbing (assumed) = 35%.

TABLE 64. ENVIRONMENTAL DATA FOR MODULE

Module - Conventional Boiler
Unit - 10^6 Btu (Input)

Environmental Parameters	Fuel Input, Eastern Coal
Air	
NO_x, lb	0.75 (1)
SO_2, lb	4.75 (2)
CO, lb	0.042 (3)
Particulate, lb	0.1 (4)
Total organic material, lb	0.013 (5)
Heat, 10^6 Btu	0.63 (6)
Water	
Suspended solids, lb	0.025 (7)
Dissolved solids, lb	0
Total organic material, lb	0.011 (8)
Heat, 10^6 Btu	Negligible after cooling tower
Acid (H_2SO_4), lb	0
Solid	
Slag, lb	0
Ash, lb	12.0 (9)
Sludge, lb	0
Tailings, lb	0
Hazardous, lb	0
By-Products	0
Occupational Health	
Deaths	3.3×10^{-10} (10)
Total Injuries	1.4×10^{-8} (10)
Man Days Lost	5.1×10^{-6} (11)
Land Use, acre-hr/10^6 Btu	0.1 (12)
Approx. Module Efficiency	37% (13)

Footnotes for Table 64:

(1) a. NO_x emission factor$^{(A-1)}$ = 18 lb/ton of coal burned.

(2) a. SO_2 emission factor$^{(A-1)}$ = 38 S lb/ton of coal burned.
b. Sulfur content, S (assumed) = 3%.

(3) a. CO emission factor$^{(A-1)}$ = 1 lb/ton coal burned.

(4) a. Particulate emission factor$^{(A-1)}$ = 16A lb/ton coal burned.
b. Ash content, A (assumed) = 14.4%.
c. Electrostatic precipitator efficiency (assumed) = 99%.

(5) a. Hydrocarbons emission factor$^{(A-1)}$ = 0.3 lb/ton coal burned.

(6) a. Efficiency of conventional boiler (assumed) = 37%.

(7) a. Total solid to water$^{(A-12)}$ = 0.036 lb/10^6 Btu.
b. Fraction of suspended solid (assumed) = 70%.

(8) a. Fraction of organic material in total solid (assumed) = 30%.

(9) a. Ash content of coal (assumed) = 14.4%

(10) a. Man-hours required per 10^6 Btu for conventional power plant$^{(A-13)}$ = 2.4×10^{-3} man-hour/10^6 Btu.
b. Total injuries per 10^6 man hour$^{(A-13)}$ = 5.7.
c. Death rate$^{(A-12)}$ = 2.4% of injuries.

(11) a. Days lost per death (assumed) = 6000 days/death.
b. Days lost per injury (assumed) 229 days/injury.

(12) a. Land required for a 1000 MW power plant (assumed) = 800 acres.

(13) a. Efficiency of conventional boiler (assumed) = 37%.

TABLE 65. ENVIRONMENTAL DATA FOR MODULE

Module - Strip Mined Coal, East
Unit - 10^6 Btu (output)

Environmental Parameters	With Land Restoration and Treatment of Acid Drainage(1)
Air	
NO_x, lb	0.0002(2)
SO_2, lb	Negligible
CO, lb	Negligible
Particulate, lb	0.14(3)
Total organic material, lb	Negligible
Heat, 10^6 Btu	Negligible
Water	
Suspended solids, lb	0.55(4)
Dissolved solids, lb	0.18
Total organic material, lb	Negligible
Heat, 10^6 Btu	Negligible
Acid (H_2SO_4), lb	Nil
Solid	
Slag, lb	0
Ash, lb	0
Sludge, lb	0.24(5)
Tailings, lb	Negligible
Hazardous, lb	0
By-Products	None
Occupational Health	
Deaths	5×10^{-9}(6)
Total Injuries	2.5×10^{-7}(7)
Man Days Lost	7.4×10^{-5}(8)
Land Use, acre-hr/10^6 Btu	0.3(9)
Approx. Module Efficiency	99.6%(10)

Footnotes for Table 65:

(1) Impacts will be negligible after land restoration. Stated impacts will occur during the actual operation.

(2) a. NO_x released to atmosphere from reclamation operation was derived based on the assumption that a diesel powered bulldozer is used for reclamation.
b. Time requirement for reclamation (assumed) = 4 hr/acre.
c. Bulldozer engine power (assumed) = 150 hp.
d. Fuel consumption rate$^{(A-1)}$ = 0.5 lb/hp^{-hr}.
e. Emission factor$^{(A-1)}$ = 0.37 lb NO_x/gal of fuel used.
f. Average thickness of coal seam (assumed) = 2 ft.
g. Coal density (assumed) = 82 lb/ft^3.
h. Heating value of coal (assumed) = 12,000 Btu/lb.

(3) a. Emission factor (same as primary rock crushing and copper mining) = 0.1 lb/ton of overburden.
b. Average overburden per ton of coal (private communication, EPA) = 33 tons.

(4) a. Rate of silt run-off (assumed = 5000 tons/Mi^2-year.
b. Average thickness of coal seam (assumed) = 2 ft.
c. Coal bulk density (assumed) = 82 lb/ft^3.
d. Reclamation period (assumed) = 3 years

(5) a. Dissolved solids ($CaSO_4$) and sludge ($FeOH_2$) come from acid treatment (assumed).
b. Drainage water discharge rate for a strip coal mine with a capacity of 10^6 ton coal/year (assumed) = 10^6 gal/day.
c. Acidity of drainage water (assumed) = 1000 ppm.

(6) a. Death rate for strip coal mining$^{(A-12)}$ = 0.12/10^6 ton coal.
b. Heating value of coal (assumed) = 24 x 10^6 Btu/ton coal.

(7) a. Injury rate for strip coal mining$^{(A-12)}$ = 5.65 injuries/10^6 ton coal.

(8) a. Man-days lost per death (assumed) = 6000 days/death.
b. Man-days lost per injury (assumed) = 180 days/injury.

(9) a. Land required for 10^6 tons of coal$^{(A-12)}$ = 280 acres.
b. Time required for reclamation (assumed) = 3 years.

(10) a. Efficiency of strip mine operation (assumed) = 99.6%.
b. Depletive waste not included.

TABLE 66. ENVIRONMENTAL IMPACTS OF MODULE

Module--Coke Oven[1]
Unit--10^6 Btu (Input)

Environmental Impacts	Coal, West
Air	
NO_x, lb	0.0017[2]
SO_2, lb	0.8[3]
CO, lb	0.053[2]
Particulate, lb	0.146[2]
Total organic material, lb	0.175[2]
Water	
Suspended solids, lb	--
Dissolved solids, lb	--
Total organic material, lb	--
Solid	
Ash, lb	0
Sludge, lb	0
Approx. Module Efficiency	70%

Footnotes for Table 66:

(1) a. Low sulfur coal (0.95% S) was assumed in the coke oven operation.

b. Heating value of coal (assumed) = 12,000 Btu/lb coal.

(2) a. Emission factors were taken from reference (A-1).

(3) a. Based on assumption that 50% of sulfur in coal remains in the coke and 50% ultimately is emitted as SO_2.

TABLE 67. ENVIRONMENTAL IMPACTS OF MODULE

Module--Space Heating[1]
Unit--10^6 Btu (Input)

Environmental Impacts	Resid (3.5% S)
<u>Air</u>	
NO_x, lb	0.135
SO_2, lb	3.068[2]
CO, lb	0.030
Particulate, lb	0.017
Total organic material, lb	0.004
<u>Water</u>	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
<u>Solid</u>	
Ash, lb	0
Sludge, lb	0
<u>Approx. Module Efficiency</u>	70%

Footnotes for Table 67:

(1) a. Values were taken from Table A-46 in reference (A-26) except as modified below.

(2) a. SO_2 emission was modified based on sulfur content of fuel oils.

TABLE 68. ENVIRONMENTAL IMPACTS OF MODULE

Module--Space Heating[1]
Unit--10^6 Btu (Input)

Environmental Impacts	Coal (3% S)
Air	
NO_x, lb	0.177
SO_2, lb	4.410[2]
CO, lb	3.490
Particulate, lb	0.775
Total organic material, lb	0.775
Water	
Suspended solids, lb	0
Dissolved solids, lb	0
Total organic material, lb	0
Solid	
Ash, lb	6.9
Sludge, lb	0
Approx. Module Efficiency	50%

Footnotes for Table 68:

(1) a. Values were identical to those in Table A-12 except as modified below.

(2) a. SO_2 emission was modified based on sulfur content of coal.

References

A-1. "Compilation of Air Pollutant Emission Factors", U.S. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, North Carolina, February, 1972.

A-2. Anon, Coal Age, 77(10), 122-138, 1972.

A-3. Leonard, J. W., and D. R. Mitchell, editors, "Coal Preparation", 3rd edition, AIME, New York, 1968.

A-4. Barthauer, G. L., AIME Environmental Quality Conference, Washington, D.C., June 7-9.

A-5. U.S. Department of Labor, Bureau of Labor Statistics, Handbook of Labor Statistics 1971, Bulletin 1705.

A-6. Process Research Inc., "Evaluation of Fuel Treatment and Conversion Processes", report prepared for the EPA, Contract No. 68-02-0242, and CPA-70-1, July 7, 1972.

A-7. Battelle Memorial Institute, "Task Report on EPA Energy Quality Model Exercise for 1975, Series B, Supplement V", report prepared for EPA, Office of Air Programs, 1972.

A-8. "Coal-Bituminous and Lignite", Bureau of Mines Minerals Yearbooks, U.S. Department of Interior, 1970.

A-9. Ephraim, M., "Status Report on Locomotives as Sources of Air Pollution", International Conference on Transportation and Environment, Washington, D.C., May, 1972.

A-10. Battelle Memorial Institute, "A Study of the Environmental Impact of Projected Increases in Intercity Freight Traffic", a report prepared for Association of American Railroads, August, 1971.

A-11. Hare, C. T., and Sprinler, "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines", Southwest Research Report to EPA, October, 1972.

A-12. Environmental Quality. Third Annual Report of the Council on Environmental Quality. August, 1972.

A-13. "Handbook of Labor Statistics", U.S. Department of Labor, Bureau of Statistics, 1971.

A-14. Department of the Interior, "Environmental Effects of Underground Mining and Mineral Processing", an unpublished report.

A-15. Private communication, R. B. Foster, Manager, Industrial Planning Institute of Gas Technology, Chicago, Illinois.

A-16. The Interstate Oil Compact Commission (IOCC) Study.

A-17. "Statistical Abstract of the United States", U.S. Department of Commerce (1971).

A-18. "U.S. Energy Outlook. An Initial Appraisal 1971-1985", an interim report of the National Petroleum Council, Vol. 1, July (1971).

A-19. "Handbook of Labor Statistics", U.S. Department of Labor (1971).

A-20. "Crude Petroleum and Petroleum Products", Bureau of Mines Minerals Yearbook, U.S. Department of the Interior (1970).

A-21. "Crude Oil Pipelines", Pipe Line News, Oildam Publishing Co., 1971-1972 edition.

A-22. Marks, L. S., editor, "Mechanical Engineers' Handbook".

A-23. "Evaluation of the Fluidized Bed Combustion Boiler", Final Report prepared by Westinghouse, Contract No. CPA 70-9.

A-24. American Petroleum Institute, "Petroleum Facts and Figures", 1971 edition.

A-25. Private communication with industry.

APPENDIX B

CALCULATION OF PREDICTED AMBIENT AIR QUALITY FOR THE INDIANAPOLIS AQCR

The calculations required for the determination of ambient air quality to be expected from fuel combustion in the Indianapolis AQCR according to projections based on Scenario 1 and Scenario 3 are presented in this appendix. The Indianapolis AQCR inventory was modified as indicated in the discussion in the body of the report. The resulting base-case data are given in Table 69. These data refer to 1971 fuel quantities and the emissions and AAQ are based on the use of all clean fuel.

The approach will be illustrated by describing the calculations required for 1975. The base-case data (Table 69) were first increased by a growth factor, 1.101, determined by dividing the Dupree and West projected coal use as fuel in 1975 (13,675 x 10^{12} Btu) by the actual 1971 value (12,420 x 10^{12} Btu). The results of the growth factor multiplication are given in the first three lines of Table 70. These data represent the coal use for the Indianapolis AQCR for 1975 and the SO_2 emissions and AAQ which would result if all the coal were low sulfur coal.

The total coal use was broken down into high- or low-sulfur coal use and into various energy technology applications in direct proportion to the fuel utilization projections developed in the body of the report. For convenience, the coal allocations for 1975 were summarized from Tables 6, 7, and 8 for Scenario 1 and from Tables 19, 20, and 21 for Scenario 3. This summary is given in Table 71. For certain of these allocations the percentage of the total is also given in Table 71. For example, in Scenario 1 the high-sulfur coal use in the electrical sector was projected to be 5,775 x 10^{12} Btu, or 42.23 percent of the total. These percentages were then applied to the total coal use projected for the Indianapolis AQCR in 1975. Thus, in Scenario 1, 42.23 percent of the projected total coal, or 1,807,146 tons per year, are allocated as high-sulfur coal to the electrical sector. The results of these calculations are given in the coal-use column of Table 70. The quantities of low-sulfur coal were adjusted to balance the subtotals for each sector.

Each coal-use quantity was multiplied by the emission factor appropriate to the coal type or applied energy technology to obtain the equivalent SO_2 emissions in tons per day as given in Table Table 70.

The SO_2 emissions were summed for each sector and the resulting AAQ contribution calculated for each sector in proportion to the corresponding base-case values. The necessary calculations are shown in Table B-2.

Finally, the sector contributions to AAQ were summed to obtain the total predicted AAQ from coal combustion according to Scenario 1, 43.15 $\mu g/m^3$, and according to Scenario 3, 105.16 $\mu g/m^3$.

These calculations were repeated for the remaining years and the resulting data are given in Tables 72 and 73 for 1980, in Tables 74 and 75 for 1985, and in Tables 76 and 77 for 2000.

It was pointed out in the body of the report that the total emissions calculated for Scenario 3 were larger than for Scenario 1 in 1980, 1985, and 2000 as a result of removing some stack gas cleaning capacity to balance the coal subtotal in the electrical sector. The same result is, of course, observed in Tables 72, 74, and 76. However, it should be noted that it is not the increase in emissions per se which is responsible for the large increase in AAQ observed for Scenario 3, but rather, it is the occurrence of increased emissions in the nonelectrical sectors which is responsible for the increased AAQ. For example, consider the year 2000, Table 76; assume that the same quantity of high sulfur coal (1,131,813 tons/year) projected for Scenario 3 is included in the electrical sector for Scenario 1, and that the low sulfur coal projection for Scenario 1 is reduced by the same amount to balance the subtotal. Also assume that the stack gas cleaning capacity projected for Scenario 1 is retained in Scenario 3 and the low-sulfur coal in Scenario 3 is reduced to balance the subtotal. Now the only difference between the two scenarios is the interchange of high- and low-sulfur coal between the electrical and the nonelectrical sectors. When the AAQ calculations are repeated with these modified coal-use quantities, the results are as follows:

	SO_2 Emissions, Tons/Day	AAQ-R33 $\mu g/m^3$
Scenario 1		
Electrical Sector	313.8	14.7
Other Sectors	91.2	54.6
Totals	405.0	60.3
Scenario 3		
Electrical Sector	192.2	9.0
Other Sectors	218.3	130.6
Totals	410.5	139.6

In this case the total emissions are nearly equal, yet the AAQ for Scenario 3 is still more than twice that for Scenario 1.

TABLE 69. INDIANAPOLIS BASE CASE-1971[a,b]

	Coal use, Tons/Year	SO_2 Emissions, Tons/Day	AAQ-Receptor 33, $\mu g/m^3$
Electrical Sector	3,001,038	156.9	7.35
Other Sectors	885,697	40.7	24.39
Totals, All Sectors	3,886,735	197.6	31.74

(a) Assumed all clean fuels.

(b) Processing plants have been excluded from this table. Seven plants emitted 3.29 T/D SO_2 and contributed 14.78 $\mu g/m^3$ to Receptor 33.

TABLE 70. PREDICTED AMBIENT AIR QUALITY - 1975

Sector/Combustion Mode	Coal Use, Tons/Year	SO_2 Emissions, Tons/Day	AAQ - Receptor 33 $\mu g/m^3$
Indianapolis Base Case (Growth Factor, 1.101, applied to 1971 Base Case)			
Electrical Sector	3,304,143	172.8	8.09
Other Sectors	975,152	44.8	26.85
Totals, all sectors	4,279,295	217.6	34.95
Scenario 1			
Electrical Sector			
Stack gas cleaning	219,099 (5.12%)	3.60	
High sulfur coal, w/o cont.	1,807,146 (42.23%)	282.20	
Low sulfur coal	1,277,898 (Bal.)	62.31	
Subtotals	3,304,143	348.11	16.30 (348.11/172.8 x 8.09)
Other Sectors (Unchanged)	975,152	44.8	26.85
Totals, all sectors	4,279,295	392.93	43.15
Scenario 3			
Electrical Sector			
Stack gas cleaning	219,099 (5.12%)	3.60	
High sulfur coal, w/o cont.	946,580 (22.12%)	147.88	
Low sulfur coal	2,138,099 (Bal.)	104.25	
Subtotals	3,304,143	255.73	11.98 (255.73/172.8 x 8.09)
Other Sectors			
High sulfur coal, w/o cont.	860,201 (20.11%)	149.95	
Low sulfur coal	114,951 (Bal.)	5.60	
Subtotals	975,152	155.58	93.18 (155.55/44.82 x 26.85)
Totals, all sectors	4,279,295	411.28	105.16

TABLE 71. YEAR 1975 COAL ALLOCATIONS

Sector	Scenario 1		Scenario 3	
	10^{12} Btu	Percent of Total	10^{12} Btu	Percent of Total
Residential/Commercial				
Low sulfur coal	325		80	
High sulfur coal	0		245	
Industrial				
Low sulfur coal	4,450		1,945	
High sulfur coal	0		2,505	
Totals, R/C plus Industrial				
Low sulfur coal	4775		2025	
High sulfur coal	0		2,750	20.11
Electrical				
Low sulfur coal	2,425		5,175	
Stack gas cleaning	700	5.12	700	5.12
High sulfur coal	5,775	42.23	3,025	22.12
Total, all sectors	13,675		13,675	

TABLE 72. PREDICTED AMBIENT AIR QUALITY - 1980

Sector/Combustion Mode	Coal Use, Tons/Year	SO_2 Emissions, Tons/Day	AAQ - Receptor 33 $\mu g/m^3$
Indianapolis Base Case (Growth Factor, 1.273, applied to 1971 Base Case)			
Electrical Sector	3,820,321	199.7	9.36
Other Sectors	1,127,492	51.8	31.05
Totals	4,947,813	251.5	40.41
Scenario 1			
Electrical Sector			
Stack gas cleaning	2,121,622 (42.88%)	34.88	
High sulfur coal, w/o cont.	178,616 (3.61%)	27.89	
Low sulfur coal	1,520,083 (Bal.)	74.11	
Subtotals	3,820,321	136.88	6.42 (136.88/197.7 x 9.36)
Other Sectors (Unchanged)	1,127,492	51.8	31.05
Totals, all sectors	4,947,813	188.68	37.47
Scenario 3			
Electrical Sector			
Stack gas cleaning	1,412,600 (28.55%)	23.22	
High sulfur coal, w/o cont.	0		
Low sulfur coal	2,407,721 (Bal.)	117.39	
Subtotals	3,820,321	140.61	6.59 (140.6/199.7 x 9.36)
Other Sectors			
High sulfur coal, w/o cont.	887,638 (17.94%)	138.62	
Low sulfur coal	239,855 (Bal.)	11.69	
Subtotals	1,127,492	150.31	90.1 (150.3/51.8 x 31.05)
Totals, all sectors	4,947,813	290.92	96.69

TABLE 73. YEAR 1980 COAL ALLOCATIONS

Sector	Scenario 1		Scenario 3	
	10^{12} Btu	Percent of Total	10^{12} Btu	Percent of Total
Residential/Commercial				
Low sulfur coal	300		75	
High sulfur coal	0		225	
Industrial				
Low sulfur coal	4,550		1,993	
High sulfur coal	0		2,557	
Totals, R/C plus Industrial				
Los sulfur coal	4,850		2,068	
High sulfur coal	0		2,282	17.94
Electrical				
Los sulfur coal	3,450		6,232	
Stack gas cleaning	6,650	42.88	4,428	28.55
High sulfur coal w/o control	560	3.61	0	
Total, all sectors	15,510		15,510	

TABLE 74. PREDICTED AMBIENT AIR QUALITY - 1985

ector/Combustion Mode	Coal Use, Tons/Year	SO_2 Emissions, Tons/Day	AAQ - Receptor 33 $\mu g/m^3$
ndianapolis Base Case			
rowth Factor, 1.654, applied to 1971 Base Case)			
Electrical Sector	4,963,717	259.5	12.16
Other Sectors	1,464,943	67.4	40.34
Totals	6,428,660	326.9	52.50
cenario 1			
Electrical Sector			
Fluidized-bed	134,359 (2.09%)	3.1	
Low Btu	161,359 (2.51%)	4.9	
Liquefaction	100,300 (1.57%)	2.3	
Stack gas cleaning	2,337,461 (36.36%)	38.4	
Low sulfur coal	2,230,238 (Bal.)	108.7	
High sulfur coal, w/o cont.	0		
Subtotals	4,963,717	157.4	7.4 (157.4/259.5 x 12.16)
Other Sectors (Unchanged)	1,464,943	67.4	40.3
Totals	6,428,660	224.8	47.7
cenario 3			
Electrical Sector			
Fluidized-bed	134,359 (2.09%)	3.1	
Low Btu	161,354 (2.09%)	4.9	
Liquefaction	100,300 (1.57%)	2.3	
Stack gas cleaning	1,083,579 (21.83%)	17.8	
Low sulfur coal	3,484,120 (Bal.)	169.9	
High sulfur coal, w/o cont.	0		
Subtotals	4,963,717	198.0	9.3 (198.0/259.5 x 12.16)
Other Sectors			
High sulfur coal, w/o cont.	921,227 (14.33%)	143.9	
Low sulfur coal	543,716 (Bal.)	26.5	
Subtotals	1,464,943	170.4	102.0 (170.4/67.4 x 40.34)
Totals, all sectors	6,428,660	368.4	111.3

TABLE 75. YEAR 1985 COAL ALLOCATIONS

Sector	Scenario 1		Scenario 3	
	10^{12} Btu	Percent of Total	10^{12} Btu	Percent of Total
Residential/Commercial				
Low sulfur coal	100		25	
High sulfur coal w/o control	0		75	
Industrial				
Low sulfur coal	4,820		2,113	
High sulfur coal	0		2,707	
Totals, R/C plus Industrial				
Low sulfur coal	4,920		2,138	
High sulfur coal	0		2,782	14.33
Electrical				
Fluidized-bed combustion	400	2.09	400	2.09
Gasification, low Btu	480	2.51	480	2.51
Liquefaction	300	1.57	300	1. 57
Stack gas cleaning	6,960	36.36	4,178	21.83
Low sulfur coal	6,080		8,862	
High sulfur coal, w/o control	0		0	
Totals, all sectors	19,140		19,140	

TABLE 76. PREDICTED AMBIENT AIR QUALITY - 2000

ector/Combustion Mode	Coal Use, Tons/Year	SO_2 Emissions, Tons/Day	AAQ - Receptor 33 $\mu g/m^3$
ndianapolis Base Case			
Growth Factor, 2.24, applied to 1971 Base Case)			
Electrical Sector	6,722,325	351.5	16.46
Other Sectors	1,983,961	91.2	54.64
Totals	8,706,286	422.7	71.10
cenario 1			
Electrical Sector			
Fluidized-bed combustion	1,140,523 (13.1%)	26.2	
Low Btu gasification	1,453,950 (16.7%)	44.5	
Liquefaction	957,691 (11.0%)	22.4	
Stack gas cleaning	1,715,138 (19.7%)	28.2	
Low sulfur coal	1,455,023 (Bal.)	70.9	
High sulfur coal, w/o cont.	0		
Subtotals	6,722,325	192.2	9.0 (192.2/351.5 x 16.46)
Other Sectors (Unchanged)	1,983,961	91.2	54.6
Totals, all sectors	8,706,286	283.4	63.6
cenario 3			
Electrical Sector			
Fluidized-bed combustion	1,140,523 (13.1%)	26.2	
Low Btu gasification	1,453,950 (16.7%)	44.5	
Liquefaction	957,691 (11.0%)	22.4	
Stack gas cleaning	583,321 (6.7%)	9.6	
Low sulfur coal	2,586,840 (Bal.)	126.1	
High sulfur coal, w/o cont.	0		
Subtotals	6,722,325	228.8	10.7 (228.8/351.5 x 16.46)
Other Sectors			
High sulfur coal, w/o cont.	1,131,817 (13.0%)	176.7	
Low sulfur coal	852,144 (Bal.)	41.5	
Subtotals	1,983,961	218.3	130.6 (218.3/91.2 x 54.64)
Totals, all sectors	8,706,286	447.1	141.3

TABLE 77. YEAR 2000 COAL ALLOCATIONS, EXCLUDING COAL FOR HIGH Btu GASIFICATION

Sector	Scenario 1		Scenario 3	
	10^{12} Btu	Percent of Total	10^{12} Btu	Percent of Total
Residential/Commercial				
Low sulfur coal	0		0	
High sulfur coal	0		0	
Industrial				
Low sulfur coal	5,300		3,323	
High sulfur coal, w/o control	0		2,977	
Totals, R/C plus Industrial				
Low sulfur coal	5,300		2,323	
High sulfur coal	0		2,977	13.0
Electrical				
Fluidized-bed combustion	3,000	13.1	3,000	13.1
Low Btu	3,820	16.7	3,820	16.7
Liquefaction	2,500	11.0	2,500	11.0
Stack gas cleaning	4,500	19.7	1,523	6.7
Low sulfur coal	3,700		6,677	
High sulfur coal, w/o control	0		0	
Totals, all sectors	22,820		22,820	

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A study was conducted to assess the potential of fuel cleaning, fuel conversion, and emission control technologies, in conjunction with the use of naturally occurring clean fuels, to reduce air emissions from fuel/energy processes sufficiently to maintain ambient air quality in the face of increasing fuel use between now and the year 2000. Total emissions and effluents produced by fuel-burning systems to the year 2000 were calculated according to three different scenarios reflecting different technology availability and fuel allocation. The impact of these emissions on ambient air quality was analysed. An overall index was developed for comparison of the potential usefulness of the energy technologies under consideration. Research and development priorities were recommended.

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