COMPARISON OF INVESTMENT AND PRODUCTION COSTS OF THE VARIOUS METHODS.

From the preceding pages, it can be seen that each method has a special field of application, according to the properties of the coal, its price, and the utilization of the gas. Therefore, it is difficult to compare the methods economically in a general way.

Reliable figures for a comparison of the economy of two methods can only be based on a certain project, the same coal, and the possible combination of the gas production with the production of power and steam, and the requirements and surplus quantities of steam and energy used or available in the synthesis process.

In Table 2, the investment costs for the principal methods have been calculated for the production of 100,000 normal cubic meters per hour or 3,500,000 cubic feet per hour of $CO + H_2$ in a synthesis gas for a synthesis operated with an iron catalyst under 20 atmospheres pressure. The investment costs of the boiler and power house are decreased because in this case, steam and residual gas are available from the synthesis and in some methods energy is also available from waste heat of the gas production or from carboniser gas. It also provides a direct drive of the big turbo-compressors required for the production of oxygen, and for the compression of the primary gas by means of steam-turbines. In this way, the investment costs of the power plant can be reduced considerably.

The investment costs do not include the equipment for the removal of the last traces of sulfur (hot removal) before entering the synthesis reactors. This equipment is the same for all the methods of gasification. The hot removal probably cannot be avoided even with pulverized coal gasification and after a splitting reaction.

Table 2.- Investment costs of gas production for 3,500,000 dubic feet per hour $CO+H_2$.

	Mechanical grate generator	Carbonizer generator	Pressure generator	Winkler generator	Koppers generator	Slagging generator
Coal handling	500,000	800,000	800,000	800,000	2,500,000	500,000
Carbonizer generator	1,600,000	2,400,000	4,100,000 (Carbonizer generator and Condensation cooling)	4,200,000 (Carbonizer generator and Condensation cooling)	6,000,000 (Carbonizer generator and Condensation cooling)	1,200,000
Condensation cooling	1,200,000	1,500,000				1,200,000
Benzine recovery	—	900,000	800,000	—	—	—
Storage of by-products	—	200,000	200,000	—	—	—
Distribution of energy, steam, and water.	500,000	600,000	500,000	500,000	600,000	400,000
Recooling system	300,000	400,000	300,000	300,000	300,000	300,000
Water wash	2,800,000	2,500,000	3,800,000	3,000,000	2,500,000	—
Sulfur removal	600,000	600,000	—	800,000	800,000	1,000,000
Compresser plant	1,200,000	1,200,000	—	1,200,000	1,100,000	1,000,000
Oxygen plant	4,500,000	4,900,000	5,800,000	5,000,000	4,800,000	4,800,000
Roads, tracks	700,000	750,000	750,000	700,000	700,000	700,000
Office, laboratories, repair shops	700,000	750,000	750,000	700,000	700,000	700,000
Boiler, power house	7,000,000	5,500,000	6,000,000	6,500,000	6,000,000	7,000,000
Miscellaneous	1,100,000	1,100,000	1,200,000	1,200,000	1,200,000	1,000,000
Total	$22,700,000	$24,100,000	$25,000,000	$24,900,000	$27,200,000	$19,800,000

Figures are calculated with U.S. dollar = 2 RM, from the costs of German plants.

An approximate idea of the economical advantages and disadvantages of the different methods may be taken from a comparison of their main investment and operating figures (Table 3.).

Table 3.- Production figures: Production of 3,500,000 cu.ft. $CO+H_2$ per hour at 20 atmospheres pressure, purified.a/

Gasification method	Investment costs b/ (Millions of Dollars)	Thermal efficiency of gas, percent c/	Fuel	By-products	Labor d/ (Number of Men)	O_2 consumption, cu.ft./cu.ft. or 310 B.t.u.	Outside steam from generator lb./h.	Compression of gas	Power consumption KW/h. e/
Fixed bed									
Atmospheric pressure									
Mechanical grate producer	23,~~000~~	80	coke	no	320	0.25	110,000	yes	49,000
Carbonization gasification producer	21,~~000~~	80	non-caking coal	yes	280	0.24	100,000	yes	49,000
Slagging generator	20,~~000~~	75	lump coke	no	250	0.27	—	yes	42,000
20 Atmospheres pressure									
Lurgi city gas, 3,200,000 cu.ft./h.	15,~~000~~	83	non-caking coal	yes	250	0.11	225,000	no	21,000
Lurgi synthesis gas	22,~~000~~	70	non-caking coal	yes	320	0.30	110,000	no	35,000
Fluidized bed									
Winkler	25,~~000~~	65	non-caking coal	no	370	0.3	-	yes	44,000
Pulverized coal									
atmos. pressure (Koppers)	27,~~000~~	75	non-caking and caking coal	no	380	0.28	-	yes	44,000
20 atmospheres pressure	24,~~000~~	75	non-caking and caking coal	no	380	0.28	110,000	no	30,000 g/

a/ See also "Production of synthesis gas from Wyoming Coal". Investment costs of Koppers process are ~~in-~~ estimated ~~creased according to~~ from information "Models". Lurgi figures are decreased for larger units and heat exchange in splitting stage.
b/ Includes boiler and power house, based on surplus of steam and residual gas from the synthesis.
c/ Thermal units of gas/thermal units of coal or coke (minus own consumption of gas).
d/ Labor for carbonization (100) is charged to by-products; laboratory, administrative, power house, and repair shops included.
e/ Includes oxygen production and compression of gas. Power from waste heat is deducted.
f/ For carbonization and tar recovery, $3,000,000 is deducted.
g/ This is to show the chance of further improvement of gasification of pulverized coal.

In order to bring these figures on the same basis with regard to by-product operation and direct complete gasification respectively, $3,000,000 of the investment costs and 100 laborers have been deducted from the total figures of by-product gasification. These figures show that there is no essential difference between the various methods with regard to production figures of gasification. The production of city gas by pressure gasification is the only outstanding process. Low oxygen consumption, low power consumption are reasons for low investment and production costs, without considering the high thermal efficiency and the higher heating value of the gas.

The table does not consider the value of by-products and the costs of the fuel. However, these two items are most important factors in the calculations of the production costs of the gas.

The value of by-products must be from the production costs of gasoline and Diesel oil when hydrogenation and synthesis methods are used. In this case, 0.20 to 0.25 RM/kg. of gasoline and Diesel oil have been the production costs of the more economical European plants and 15 cents per gallon of gasoline may be considered as a very optimistic figure to be expected in this country after further improvements of the methods and in very large plants. In Germany, 40 percent of the production costs of hydrogenation gasoline have been considered to be a very attractive price of tar as a raw material for hydrogenation plants. The plants treating tar by distillation and refining methods were operated on the same basis with regard to the price of tar. It seems reasonable to evaluate by-products of gasification and carbonization on the same ratio to the price of gasoline from coal, that is:

$$1 \text{ kg. of tar} = \frac{0.15}{3} \times 0.4 = \$0.02.$$

A complete calculation has been made for the production of synthesis gas from Wyoming coal.* The principal figures of these calculations adjusted to Tables 2 and 3, and with the above evaluation of by-products, are shown in Table 4. The investment costs include carbonization and by-product recovery. These figures also show that the Winkler method and the Koppers method are not cheaper gasification methods as such. Their only advantage is the utilization of fuels which cannot be used in other methods. The gas production, however, is cheaper only in case these fuels are considerably cheaper than those required for the other methods. In Table 4, figures have been added for the slagging generator operated with oxygen and a lumpy coke. The last column gives the figures of a blue water-gas plant operated with the same coke at a price of $6.50 per metric ton. With a price of $4.00 per metric ton for semi-coke, the costs of the gas produced in a slagging generator equal the costs of the gas produced by the Winkler or the Koppers generator from subbituminous coal at $1.00 per metric ton.

With coal of 7.2 percent tar content, the value of by-products equals the costs of the coal required for by-products and gas production, and the total production of liquid fuels is increased by 30 to 40 percent. Even if the costs of coal above 1/4-inch size are increased by 20 percent to $1.20 per metric ton (column 5), the production costs of the gas would be increased only very slightly.

The figures of Table 4 show that with a higher tar content of the coal, the difference of production costs is increased in favor of by-product methods.

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*Hubmann, Otto: Production of Synthesis Gas From Wyoming Coal.

Table 4.- Production costs for 3,500,000 cu.ft./hr. synthesis gas $(CO+H_2)$. purified and compressed.

Process	Subbituminous coal, $1 per metric ton: Winkler generator	Subbituminous coal, $1 per metric ton: Koppers gasification of pulverized coal	Subbituminous coal, $1 per metric ton: Lurgi pressure gasification	Subbituminous coal, $1 per metric ton: Carbonization, gasification carbonization with air, gasification with oxygen	Semi-coke, $4 per metric ton: Mechanical grate generator	Semi-coke, $4 per metric ton: Slagging generator	Coke, $6.5 per metric ton: Water gas[a] generator
Investment costs, million dollars	25	27	25	23	23	20	18
Coal consumption, metric ton/year	800,000	740,000	945,000	925,000	600,000	600,000	650,000
Tar products, metric ton/year	-	-	44,200	60,500	-	-	-
Laborers	370	380	420	380 380	280	250	280
Coal, million dollars	0.8	0.74	0.945	0.925 1.11[b]	2.40	2.40	4.22
Wages, million dollars	0.93	0.95	1.05	0.95 0.95	0.70	0.63	0.70
Material and overhead, million dollars interest on operating capital	0.35	0.40	0.40	0.40 0.40	0.35	0.35	0.35
Interest amortization, 12.5 percent replacement material.	3.13	3.38	3.13	3.00 3.00	2.88	2.50	2.25
Value of tar, million dollars	—	—	0.884	1.21 1.21	—	—	—
Production costs, million dollars/year	5.21	5.47	4.641	4.065 4.25	6.33	5.88	7.52
Production costs, dollars/1000 Nm^3	6.20	6.50	5.52	4.83 5.06	7.53	7.00	8.9
Production costs, dollars/1000 cu.ft.	0.174	0.183	0.156	0.126 0.143	0.215	0.20	0.256

a/ Figures from German plant.
b/ Costs of subbituminous coal above 1/4-inch, $1.20 per metric ton.

The gasification of caking coals for which gasification of pulverized coal is the only feasible method in this country, obviously can produce gas at a similar price as the gasification of strip-mined subbituminous coal only if the caking coal is very cheap.

With a price of \$2.00 per ton of caking coal, the costs of the gas production are increased by "2 x 600,000 - 740,000) = \$460,000 approximately. The costs of the gas are increased by $\frac{460,000}{840,000}$ or \$0.54 per 1000 Normal cubic meters $CO + H_2$.

to \$7.05 per 1000 normal cubic meters $CO+H_2$

or \$0.20 per 1000 cubic feet $CO+H_2$.

Based on a recovery of 150 gallons of finished gasoline per normal cubic meter ($CO+H_2$), the costs of gas per kg. (gallon) of gasoline, depending on the method of gas production and on the coal, have been calculated (see Table 5).

Columns 1 to 4 are figures for a cheap subbituminous coal with a medium tar content; the by-product methods are more favorable. If the tar content of the coal is lower, the difference between the by-product methods 3 and 4 and the methods 1 and 2 decreases. If the coal is mined mostly as a powder, method 1 or even method 2 may be the only method to handle this fuel without briquetting.

Column 5 relates to a synthesis plant based on cheap caking coal.

Column 6 is based on a small-sized coke or semi-coke, produced from a non-caking, bituminous or subbituminous coal in a Lurgi carbonizer plant. Naturally the production costs for the gas are slightly higher than in a combined carbonization-gasification as in Column 4. A 1/6- to 1-1/2 inch coke probably is also available at a similar price from large coke oven plants.

Table 5.- Costs of synthesis gas ($CO+H_2$) per gallon gasoline.

150 gallons gasoline per Nm^3 $CO+H_2$

1 gallon of gasoline = 3.78 x 0.72 = 2.72 kg.

Fuel	Subbituminous coal, $1 per metric ton				Caking coal $2 per metric ton	Semi-coke, $4 per metric ton	Coke $6.50 per metric ton
Process	Winkler generator 1	Koppers generator 2	Lurgi pressure generator 3	Carbon-ization generator 4	Koppers generator 5	Mechanical grate generator 6	Water gas generator 7
Cost of gas, cents/kg.	4.14	4.34	3.69	3.23	4.70	5.02	5.98
Cost of gas, cents/gallon	11.20	11.75	10.01	8.76	12.75	13.60	16.2
Primary gas, $CO:H_2$	1:1	2:1 1:1	1.2:1-0.8:1	1.5:1-1:1	2:1-1.2:1	1.5:1-1:1	1.2:1

Column 7 is based on the water-gas generator with a price of $6.50 per metric ton for a 2-inch coke. Such a coke could also be produced from a cheap high-volatile bituminous coal in a carbonizer plant at a price of approximately $4 to $5 per metric ton.

The differences in the production costs of the gas in the various coal fields, and in using a method adapted to the character of the fuel, seems to be within limits, sometimes compensated by lower freight rates for the gasoline and by a certain reduction of investment and operating costs by lower freight and labor costs in building and operating the plant.

The influence of by-products on the price of the gas and on the price of synthesis gasoline is also seen in Table 5, showing the low costs of gas in columns 3 and 4.

In order to compare the production cost of the various methods independent of the utilization of the gas or for those cases where steam and residual gas are not available from the synthesis plant, the production costs have been calculated under the conditions that steam, energy, and oxygen are purchased from other works as far as they cannot be obtained from waste heat or carbonization gas of the gas production.

Investment and consumption figures are shown in Table 7. The production cost can be seen from Table 8. In this case, the production cost depends on the cost of energy and oxygen, and must naturally be higher than in a combined system with reduced cost of overhead, administration, laboratories, etc., and with better thermal efficiency of a combined production of energy and utilization of exhaust steam for the gasification. The production of a high B.t.u. gas (420 B.t.u. per cubic foot) has also been considered in

Table 7.- Investment costs (in thousands of dollars), number of men per shift (underlined figures)) and energy consumption of gas production only.#

Process	Mechanical grate generator		Carboniser generator		Pressure generator		Winkler generator		Koppers generator		Slagging generator		Water gas generator	
Coal handling	500	3	800	5	800	5	800	5	2500	7	500	3	500	3
Carbonizer generator	1600	8	2400	10	4100	18	4200	12	6000	12	1200	5	5500	16
Condensation cooling	1200	2	1500	3							1200	2		
Benzine recovery	--		900	2	800	2	--		--		--		--	
Storage of by-products	--		200	1	200	1	--		--		--		--	
Distribution of steam, energy, and water	400	2	500	2	400	2	500	2	400	2	300	2	300	2
Recooling system	250	1	350	1	250	1	250	1	250	1	250	1	250	1
Water wash	2800	6	2500	6	3800	8	3000	6	2800	6	--		--	
Sulfur removal	600	1	600	1	--		800	2	800	2	1000	2	1000	2
Compressor plant	1200	2	1200	2	--		1200	2	1100	2	1000	2	1000	2
Roads, tracks	600	1	650	1	650	1	600	1	600	1	600	1	600	1
Office, sanitation equipment, repair shops	600	10	650	12	650	12	600	10	600	12	600	12	600	12
Miscellaneous	600	3	650	3	700	3	650	3	650	3	500	3	500	3
O_2 compressor, boiler	--		700	2	800	2	--		--		--		--	
Total investment	10350		13600		13150		12600		15700		7150		10250	
Total labor, men/day		156		208		220		176		192		120		160
Oxygen consumption, Nm^3/hour	26500		28000		30000		30000		28300		27000		--	
Purchase steam at 80 atmospheres, metric ton/hour	50		--		75.4		--		--		--		--	
Purchase energy, KWH/hour	22100		17100		10500		25300		25200		24000		20000	

Table 8.- Production costs of synthesis gas per unit ($CO+H_2$) compressed and purified. Cost of energy 0.5 cents/KWH; steam $1/metric ton; oxygen 0.5 cents/Nm3. Labor cost, $2500 per man per year.

Process	Winkler generator	Koppers generator	Lurgi pressure generator	Carbonized generator	Mechanical grate generator	Slagging generator	Water gas generator	Pressure gasification 420 B.t.u
Fuel	Subbituminous coal, $1 per metric ton				Semi-coke, $4 per metric ton		Coke $6.50 per metric ton	Anthracite slack $2 per metric ton
Fuel consumption, metric tons per year	740,000	700,000	820,000	925,000	420,000	450,000	650,000	580,000
Investment costs, million dollars	12.6	15.7	13.15	13.6	10.35	7.15	10.25	12.0
Tar consumption, metric tons per year	- -	- -	44,200	60,500	- -	- -	- -	- -
Costs, million dollars								
Coal	0.74	0.70	0.80	0.925	1.68	1.80	4.225	1.16
Oxygen	1.26	1.185	1.26	1.175	1.115	1.135	- -	0.84
Steam	- -	- -	0.64	- -	0.42	- -	- -	1.05
Energy	1.06	1.055	0.582	0.714	0.925	1.005	0.84	0.46
Wages	0.44	0.48	0.55	0.52	0.39	0.30	0.40	0.45
Material overhead	0.3	0.35	0.35	0.35	0.30	0.30	0.30	0.30
Interest amortization, repair material	1.762	2.18	1.84	1.905	1.425	1.002	1.43	1.68
Total cost, million dollars/yr.	5.562	5.95	6.042	5.589	6.255	5.542	7.195	5.94
Value of tar, million dollars	- -	- -	0.884	1.21	- -	- -	- -	- -
Production cost of gas, million dollars	5.562	5.95	5.158	4.379	6.255	5.542	7.195	5.94
Production cost, dollars/1000 Nm3	6.6	7.08	6.12	5.20	7.42	6.59	8.55	7.01
Production cost, dollars/1000 cu.ft.	0.185	0.202	0.175	0.149	0.213	0.188	0.243	0.201
$CO:H_2$ ratio	1:1	1.5:1	1:1	1.2:1	1.2:1	2:1	1.2:1	1:1.8

this table. The same amount of gas of nearly 50 percent more B.t.u.'s can be produced in this case at the same cost per unit, because the equipment for splitting of methane and the additional oxygen consumption are avoided. It indicates the favorable conditions of this method for a combination of a synthesis of hydrocarbons with the production of city gas.

In this case, the synthesis gas contains only 75 percent $CO + H_2$, but the synthesis reactors can be operated with a high space-time yield because the otherwise unwanted C_1-C_3 hydrocarbons can be sold with the residual gas at a good price.

If the residual gas of a synthesis plant can be sold, the synthesis plant has an additional consumption of low-grade coal for the production of energy and the necessity of utilizing small-sized coal in the gas generators may be considerably reduced. The Winkler and the pressure gasification method may even be operated with slack coal screened above 1/8-inch.