Clean Fuels from Coal Gasification

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Until 1972, the United States could produce more natural gas or petroleum on demand. When the chokes came off the wells in early 1972, marginal supplies of clean fuels were no longer available from a domestic source. Today, nuclear and coal-fired electricity remain the only margins against rising energy demand that are under domestic control. The former entails high capital costs and long construction times, often made longer by controversy. The latter entails environmental problems not yet resolved. Furthermore, electricity cannot be substituted for gas or oil in many applications. Today, Arab nations command the only practicable, quick margin against most of the world's energy needs. Owners of gas- and oil-burning equipment have experienced in recent months the interruptions of supply and skyrocketing costs that Arab decisions can create.

Synthetic fuels from coal could provide a new margin. Since even a small synthetic fuels industry could have a large effect upon the price of oil, speed is more important than the industry's initial size. What is the quickest path to synthetic fuels?

In considering this question, we must take stock both of technologies now in use (or in use recently) and also of engineering firms competent to reproduce and adapt these technologies quickly. We must consider how the technologies may be applied with maximum effect.

Some few coal-conversion procedures survived the worldwide shift to oil and natural gas in recent decades. They survived in small nations that wished to produce town gas (*1*) or ammonia or other chemicals from native coals. For example, coal is being gasified today in Turkey, India, South Africa, Scotland, Morocco, Yugoslavia, and Korea.

Substantially all surviving procedures include a step in which coal is reacted with either air or a mixture of oxygen and steam. By gasifying coal with air, the engineer can produce "power gas" (*2*), a mixture of carbon monoxide and hydrogen with nitrogen. Power gas has a relatively low heating value, about one-sixth that of natural gas. By gasifying with oxygen and steam, one obtains "blue water gas" or "synthesis gas," a mixture of carbon monoxide and hydrogen. In existing plants, this gas is being converted to ammonia or methanol or, in South Africa, to synthetic gasoline. The gas could also be used as a fuel and has a heating value about one-third that of natural gas. Here I will dub it "industrial gas."

Table 1 lists gasification systems that possess immediate commercial credibility (with some caution: see footnotes for Table 1).

Table 2 lists markets for clean fuel gases made from coal. We should promptly initiate projects for each of the markets based upon several gasifiers. Our immediate need is not for the best possible gasification systems but for experience on systems that are sure to work.

The projects might include conversion of industrial gas to methane for addition to the nation's natural gas pipelines, as well as conversion to methanol or liquid hydrocarbons for addition to the supply of liquid fuels. Each of these syntheses, however, entails an energy loss of at least about 20 percent as well as expensive hardware.

A quicker route to "new" gas and liquid fuel is to retrofit equipment now being fired with natural gas or oil, so that it can use either power gas or industrial gas made from coal. The Electric Power Research Institute of Palo Alto, California, has initiated studies to identify gas- and oil-fired utility boilers that are candidates for such retrofit. Comparable studies should get under way quickly for industrial boilers. One might expect to "liberate" some 3 to 4×10^{12} cubic feet (1 cubic foot = 0.028 cubic meter) of gas annually from utility and industrial boilers, and perhaps some 300 to 400×10^6 barrels of oil (1 barrel = 159 liters). It should be appreciated that much gas- and oil-fired equipment could not be altered to burn coal directly.

Even earlier visibility for a new energy margin can come from application of the historic gas producer. Our several opportunities are best considered in light of a review of available gasification techniques. Processes for making power gas or industrial gas are characterized by (i) the physical form and disposition of the carbonaceous material brought into contact with air or oxygen-steam mixture and (ii) the method of extracting inorganic ash matter from the reaction zone. For (i), there are gravitating-bed gasifiers of lump coal, suspension gasifiers of pulverized coal, and fluidized-bed gasifiers of crushed coal. For (ii), ash can be withdrawn as relatively free-flowing powder, clinkers or ash agglomerates, or molten slag. The form of the ash reflects the temperature to which it has been exposed. Almost every combination of (i) and (ii) has been operated, at least experimentally (*3*).

Gasification in Gravitating Beds

Air-blown producers have provided fuel gas continuously since 1836. In the mid-1920's, there were 150 manufacturers of producers in the world. There were nearly 12,000 producers in the United States consuming perhaps about 25×10^6 tons per year of coal (1 short ton = 0.907 metric ton) (*4*). By the 1960's, only a few producers in the Pennsylvania anthracite region were left; but the industrialist of South Africa, for example, has always recognized the gas producer as a competitive route to clean energy.

About a year ago, the Glen-Gery Corporation of Reading, Pennsylvania, reactivated a Wellman-Galusha producer to furnish fuel gas to a brick kiln. This company has placed an order for a new producer, to be supplied by McDowell-Wellman Engineering Company of Cleveland, and has three others on standby (*5*). Producers for anthracite should be revived, and probably

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will be, just as quickly as coal can be made available. Pennsylvania anthracite is low in sulfur, and only dedusting of the power gas will be needed to satisfy environmental concerns. The producers could, for example, serve manufacturers of brick, glass, ceramics, and baked foods, as well as those who melt or anneal metals.

The low heating value of power gas is not as much of a disadvantage as it might initially appear to be. The flow of combustion products determines many aspects of equipment for heat recovery and heat utilization. For the user, a better comparison with natural gas is the heating value per unit volume of combustion products. On this basis, the "worth" of power gas is only about 15 percent below that of natural gas (*4*).

Can-Do, Inc., of Hazleton, Pennsylvania, in the heart of the anthracite district, is examining the feasibility of an installation to provide power gas to some 80-odd energy customers in its two industrial parks. The initial installation might include up to eight producers. Yet to be resolved are engineering questions in regard to the distribution and utilization of the gas, but answers can be obtained quickly by analysis at the desk; the feasibility of making the gas is not in question. If the Can-Do gas works should prove a feasible and attractive development, it could provide quick visibility for a new margin against energy demand.

In a producer, humidified air is introduced into the bottom of a column of lump coal, to which fresh coal is continuously being supplied at the top. Oxygen in the air disappears, within a short distance of the air inlet, in a shallow combustion zone that separates a lower region of carbon-free ash matter and an upper region comprising lumps of carbon. These descend by gravity toward the combustion zone in a motion countercurrent to the flow of hot gases rising from this zone. Humidity in the air has the effect of controlling the temperature at the hottest point, by putting into play the endothermic reaction of steam and carbon. This reaction, as well as the endothermic reaction of carbon with carbon dioxide formed in the combustion zone, occurs as the hot gases pass upward through the bed of carbon. In an efficient design, a high conversion of steam to hydrogen and carbon monoxide, and of carbon dioxide to carbon monoxide, is achieved.

The ash must not form clinkers too hard to be crushed readily. An eccentric grate is provided that can loosen weakly sintered ash as it advances. There are ports, however, through which an operator can insert a poker to break up hard clinkers that may form on occasion.

Table 1. Commercial gasification systems.

Blown with air to yield "power gas"	Blown with oxygen and steam to yield "industrial gas"
Historic gas producer	Gas producer
Winkler (East German)*	Winkler (East German)†
Ignifluid‡	Lurgi pressure gasifier§
Lurgi pressure gasifier§	Winkler (West German)
	Koppers-Totzek
	Babcock & Wilcox-duPont‖

* Air-blown Winkler gasifiers ran only for about 1 year in 1929. † All East German Winkler experience has been with lignite. ‡ The Ignifluid gasification system has not been operated as a "pure" gasifier but to supply power gas for prompt burning in a boiler directly above a gasification bed. § The Lurgi is the only gasifier available for operation at elevated pressure. ‖ The Babcock & Wilcox-duPont gasifier operated for only about a year.

The flow of rising gases must be kept below a rate at which they would buoy the bed. Working on rice and buckwheat anthracite (about 5 to 15 millimeters), a 10-foot producer (1 foot = 30.5 centimeters) can gasify about 20 ton/day. The same producer, fitted with a stirrer to permit gasification of a caking bituminous coal, can handle up to about 80 ton/day of such coal at a size of 30 to 50 millimeters. Producers of this size in South Africa treat 80 tons of subbituminous coal per day at a size of 15 to 65 millimeters. A disadvantage of a producer gasifying bituminous or subbituminous coal is that tars appear in the gas and complicate its cleaning. The M. W. Kellogg Company of Houston and Pennsylvania State University are formulating plans to study the performance of a producer on caking bituminous coals, including the problems of removing sulfur and tar from fuel gas.

Although producers can supply the first new gas to U.S. industry, their long-range role is limited by their small capacity. Industrial boilers commonly burn the equivalent to hundreds of tons of coal per day; electricity boilers, thousands of tons. The scale-up of the historic producer to such capacities in a reasonable time is not credible.

Lurgi Mineraloeltechnik of Frankfurt (Main), West Germany, introduced nearly 40 years ago a producer blown with oxygen and steam at 20 atmospheres (*6*). South Africa has a plant with 13 Lurgi units that provide synthesis gas for the production of 5000 barrels of gasoline per day. Other Lurgi units furnish town gas and synthesis gas for ammonia. For these purposes, a gas of high hydrogen content is advantageous. It was no disadvantage, therefore, that the pressure producer required a steam flow roughly double that needed at atmospheric pressure to keep ash free-flowing and to guarantee against clinkers. (In a pressure producer, the operator cannot resort to a poker!)

Lurgi has recently adapted its pressure producer for blowing with air and steam to produce power gas at high pressure for use in a gas turbine (*7, 8*). No other pressure gasifier is commercially available, but the Lurgi has not been operated under U.S. conditions. Commonwealth Edison Company of Chicago has recognized the importance of gaining experience on such operation in an electricity-generation context, as well as experience on gas cleaning. Commonwealth will install three Lurgi units at its Powerton station, each gasifying about 500 tons of Illinois bituminous coal per day.

In tests sponsored by the American Gas Association, a Lurgi at Westfield, Scotland, has recently completed successful campaigns on run-of-mine Illinois No. 6 coal and on sized Pittsburgh No. 8 coal. The latter is a highly caking coal.

The air-blown Lurgi has the dis-

Table 2. Markets for clean fuel gases produced from coal.

Power gas	Industrial gas	Pipeline-quality gas
Agriculture		Homes
Small industry		Small business
Industrial and utility boilers	Industrial and utility boilers	
Industrial furnaces	Industrial furnaces	
Service to industrial parks	Service to industrial parks	
Gas turbines and combined cycles*	Gas turbines and combined cycles*	
	Hydrogen production*	
	Chemical synthesis*	
	Liquid fuel synthesis*	

* For these uses, there is a large advantage in gasifying at elevated pressure.

advantage that its power gas contains a great deal of hydrogen (and steam besides) that causes an unnecessary loss of water latent heat to the atmosphere. The loss amounts to about 10 percent of the heating value of the coal gasified. In addition, it is not likely that the Lurgi could be scaled up quickly to sizes much beyond 500 ton/day.

Slagging-Bed Gasification

A path toward gravitating-bed gasifiers of higher capacity is the development of equipment in which ash is removed as molten slag. Indeed, the iron blast furnace is a slagging gasifier, and Japanese furnaces today gasify up to about 4000 tons of coke per day (*9*). It is no surprise, then, to find that hard coke has been gasified in experimental slagging gasifiers, blown with oxygen and steam, at capacities as high as 635 ton/day in Germany (*10*) and 230 ton/day in Russia (*11*). The gasifiers resembled the blast furnace: oxygen and steam were blown through a number of horizontal blowpipes or tuyeres into the bottom of a deep bed of coke.

The British Gas Council conducted trials of oxygen-blown gasification in similar equipment at 20 atmospheres at the 120 ton/day scale (*12*). Similar experiments were conducted at 4 atmospheres by the British Ministry of Power (*13*) and at 28 atmospheres by the U.S. Bureau of Mines at Grand Forks, North Dakota (*14*), the latter experiment gasifying lignite.

An overall impression left by these experiments is that tuyere-blown gasifiers working on anything other than hard coke will be difficult to scale upward to large capacities, especially for elevated pressures. Each tuyere creates a "raceway," that is, a cavity in the fuel bed in which coke particles are tumbled about in violent cyclonic motion, and thereby degraded in size. The raceway is larger at larger gas inputs, and the degradation is more troublesome.

The British Coal Utilisation Research Association has studied (*15*) a slagging grate invented by Secord (*16*) having the advantage that treatment of the lump coal is gentle. Weak and friable cokes were gasified successfully at a rate of 5 ton/day. Oxygen and steam entered the fuel bed across a grate consisting of horizontal, thin-walled, water-cooled, narrowly spaced steel

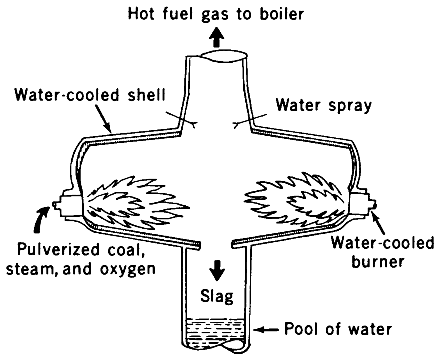


Fig. 1. Schematic cross section of the Koppers-Totzek gasifier.

tubes. Below the grate was a zone supplied with coal fines that burned to create slagging temperatures in this zone and at the grate.

Brief Russian trials (up to 4 hours) of a small air-blown gasifier (9 ton/day) at 5 atmospheres suggest that Secord's grate might accommodate at least one-half of the fuel as coal fines fed below the grate (*17*).

Slagging-bed gasifiers cannot make an early contribution to U.S. energy needs. The Secord grate is worth study.

Suspension Gasifiers

For the past 20 years, the Koppers Company, Inc., of Pittsburgh has marketed the Koppers-Totzek gasifier (Fig. 1), in which finely pulverized coal (70 percent smaller than 75 micrometers) reacts in a dilute suspension with oxygen and steam at atmospheric pressure (*18*). The gasifier

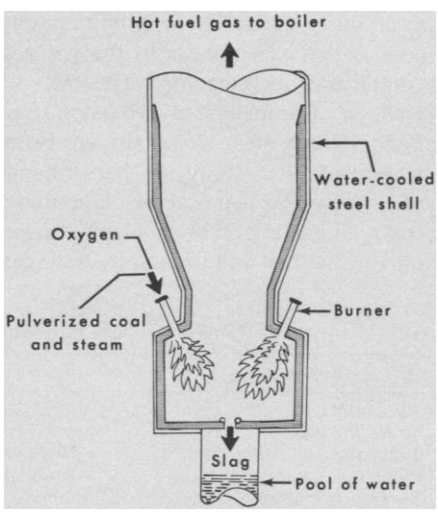


Fig. 2. Schematic cross section of the Babcock & Wilcox–duPont gasifier, operated on bituminous coal for about 1 year in the mid-1950's at Belle, West Virginia.

is a refractory-lined steel shell with a water jacket for producing steam. A design with two opposing burner heads can gasify over 400 tons of coal per day, whereas a four-headed gasifier, with burners 90 deg apart, can handle 850 ton/day. The reaction temperature is 1900° to 2000°C. For most coals, much of the ash matter drops out of the reaction zone as slag, but fine ash particles also leave with gas flowing upward into a boiler. Some reaction of carbon with steam and carbon dioxide occurs. These reactions are endothermic, and, if the coal is reactive, such as lignite or subbituminous, they may reduce the gas temperature to around 1200°C at the gasifier outlet. For less reactive coals, endothermic reactions do not come much into play, and the operator must spray water into the gas to lower its temperature so that ash matter will not stick to tubes in the boiler.

The Koppers-Totzek gasifier was exploited in the first instance to provide synthesis gas for ammonia. For this purpose, the gas preferably contained as little methane as possible. The high temperature afforded a gas that normally contained less than 0.1 percent (by volume) of methane. It also led to equipment of great flexibility, no doubt accounting for the commercial success of the Koppers-Totzek in a period during which little equipment was sold for coal gasification. All kinds of coal can be handled, including highly caking bituminous coals with no pretreatment as well as coals that have a high ash fusion temperature such as Pennsylvania anthracite. Many Koppers-Totzek gasifiers were retrofitted successfully to gasify heavy oil.

For present energy needs, the high temperature of this gasifier carries a price: the Koppers-Totzek needs expensive oxygen. If Koppers-Totzek gas is burned in an electricity boiler, for example, roughly 10 percent of the electricity will be needed to provide the oxygen.

It is probably not feasible to substitute air for the oxygen, since air would have to be preheated beyond about 900°C to achieve the high temperature of the Koppers-Totzek. One could employ air enriched in oxygen at less preheat, and this alternative should be explored.

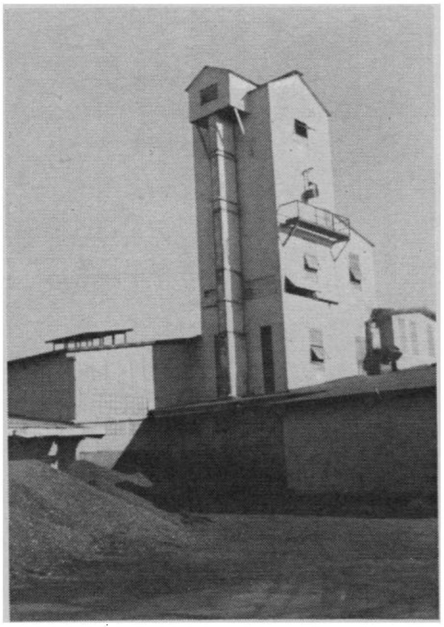
The Koppers-Totzek is probably best suited for large installations that supply industrial gas to a pipe network or for large combined-cycle electricity equipment. Several systems are said to be at an advanced stage of negotiation, and the Koppers-Totzek appears to be the front-runner in the competition for providing new supplies of clean fuel gas in large applications.

The suspension gasifier is the particular choice of most steam power engineers familiar with pulverized-fuel combustion, and many efforts have sought to develop a suspension gasifier that brings endothermic gasification reactions more into play than the Koppers-Totzek design can do. Such efforts face the inherent problem that the carbon inventory is small, making it difficult to promote the slow endothermic reactions. Mixing of gases in the reaction zone tends to defeat an attempt to create a temperature gradient through agency of endothermic reactions, and the several approaches taken reflect different ways to reduce mixing (*19*).

In collaboration with duPont, Babcock & Wilcox developed an oxygen-blown design that operated commercially at the 400 ton/day scale for about 1 year at Belle, West Virginia, in the mid-1950's (Fig. 2) (*20*). The design directs flames from 12 burners toward a central slag taphole, to produce there a temperature of about 1500° to 1600°C. A narrow "waist" separates the hot zone from a cooler zone above, in which endothermic reactions reduce the temperature of the gases to about 1200° to 1300°C as they leave to enter a boiler. The waist prevents backward convection of heavier, cooler gases from the endothermic zone into the hot, slagging zone.

Between about 1961 and 1963, Babcock & Wilcox conducted air-blown tests at the 60 ton/day scale in equipment like that shown in Fig. 2 (*21*). With air preheated at 550°C, a gas having a heating value of 70 to 80 British thermal units (Btu) per cubic foot was obtained (1 Btu/cubic foot = 3.7×10^4 joule/cubic meter). The Babcock & Wilcox designers believed that a gas at 100 Btu could be achieved in an operation on a larger scale, with a lower heat loss. This is to be compared with a heating value of about 150 Btu for an atmospheric producer or an air-blown Lurgi.

Designers at Combustion Engineering, Inc., have performed studies for an air-blown gasifier like that shown in Fig. 2 and believe that a heating value of about 125 Btu can be achieved by feeding a portion of the raw coal to the upper zone, above the waist. Char would be recovered from steps for cleaning the gas and fed to the lower zone.



Operating gas producer at Shoemakersville, Pennsylvania, brick factory. [Source: Glen-Gery Corporation]

The Szikla-Rozinek boiler incorporated a "suspension" gasification zone, although coal was fed at appreciably larger sizes than coal to other suspension gasifiers. In the Szikla-Rozinek boiler ash matter accumulated in the form of agglomerates suspended by gas rising through the gasification zone, until they grew to a size to fall upon an ingenious ash-discharge mechanism. Rozinek's paper (*22*) is valuable both for its description of this mechanism and other construction details. Unfortunately, so far as I am aware, the Szikla-Rozinek attained a scale of only about 40 ton/day. Further scale-up might not be easy. In any case, it could hardly be considered to be commercially available in the United States.

Gasification in Fluidized Beds

The first commercial fluidized bed was the air-blown Winkler gasifier producing power gas at Leuna, East Germany, for gas engines to run ammonia synthesis gas compressors. Five units operated in 1929 to provide gas for an impressive 130 megawatts of shaft power. The largest unit had a capacity of about 650 tons of dried lignite per day (*23*). The units were idle in the economic recession of 1930, and after that they were revised to blow oxygen and steam.

A disadvantage of the Winkler is that great amounts of carbon fines are produced, that blow out of the unit. To improve utilization of these fines, additional gasification medium (air or oxygen-steam) is blown into the overhead space above the fluidized bed, raising the temperature of this space. With this expedient, carbon gasification efficiency is, in general, about 80 to 85 percent.

Revision of the Leuna gasifiers to blow oxygen and steam allowed the temperature of the gasification bed to be lowered from 950° to 800°C, and that of the overhead space from 1000° to 850°C. The 150°C reduction in temperature reflects the greater reactivity and higher partial pressure of steam in a gasifier blown with oxygen and steam by comparison with the reactivity and especially the partial pressure of carbon dioxide in the air-blown unit (where a high partial pressure of nitrogen prevails). The reduction in temperature eliminated problems associated with formation of "bird's nests" near the gas exit—accumulations of loosely sintered ash matter.

Leuna accomplished major improvements in its Winklers over the years (*24*) but without building new units. The five original Winkler units were finally shut down in 1971.

A different path of development arose in West Germany (*25*) from Pintsch Bamag's (GmbH) desire to provide a gasifier blown with oxygen and steam that could handle bituminous coals less reactive than the lignite gasified at Leuna. The Bamag designers found it necessary to operate the fluidized bed at about 1000°C and to raise the temperature of the overhead space to about 1100°C. Taller reactors were provided, and boiler surface was situated within the reactor near the top to reduce the exit temperature to about 900°C to avoid the growth of troublesome ash deposits in the gas-outlet system. By analogy with the experience at Leuna, it would appear that air-blowing of a bituminous coal would require temperatures appreciably above 1000°C. Davy Powergas, Inc., of Lakeland, Florida, has acquired rights to the Pintsch Bamag experience in Winkler gasification.

The Winklers operate at gas velocities between about 5 to 8 meter/second. Coal feed is coarse, generally 10 millimeters and smaller in size.

In the early 1940's, the U.S. petroleum industry introduced a catalytic fluidization technique in which much finer powders and much lower velocities (between about 20 and 75 centimeter/second) were used. This technique acquired better visibility, especially in academic research, than the high-velocity, coarse-powder approach. During the 1940's and 1950's, at least eight research groups worked upon low-velocity fluidized-bed gasification (*26*), and new efforts have been initiated in the 1960's and 1970's. Temperatures were generally limited to 1000°C, to avoid clinkers. Much of the work was carried out on chars or anthracites. In work on bituminous coal, tars did not appear in the make-gas if the temperatures were above 925°C.

An impression arising from this work is that the production of ultrafine particles of carbon is inherent in fluidized-bed gasification. Even at low velocities, carbon losses can be serious. Rayner (*27*) has reported careful experiments for several carbon feedstocks, including hard coke, and typically found carbon losses to run beyond 20 percent. He did not believe the losses could be reduced by circulating fines back to the bed. He determined that losses were associated with gasification itself and not with mechanical attrition by the action of the bed. Rayner believed that a gasifying carbon particle becomes vesicular and weak and tends to fall into bits, when about 80 percent of the carbon has been removed.

I was therefore surprised to learn that carbon utilization routinely exceeds 99 percent in the operation of the Ignifluid boiler, invented by Albert Godel and marketed by Fives-Cail Babcock of Paris (*28*). The Ignifluid incorporates an air-blown fluidized bed gasifying coarse particles of coke that arise from crushed coal supplied to the bed. Its performance is all the more impressive when one remembers that

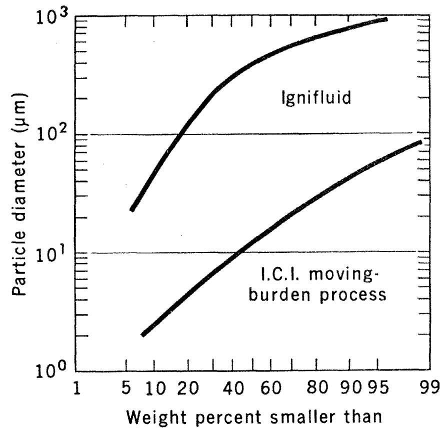


Fig. 3. Comparison of the size of "fly carbon" recovered by the second stage mechanical collectors of an Ignifluid boiler operating on bituminous coal (fluidizing velocity, about 20 meter/second) with that from a fluidized bed of the Imperial Chemical Industries, Ltd., "moving burden process" (velocity about 30 centimeter/second) (*27*). In the latter instance, the fly carbon represented a loss of more than 20 percent of the carbon fed. In the Ignifluid, reinjection of the fly carbon leads to 99 percent carbon utilization.

a Lurgi generally affords a carbon burnup of between about 95 and 98 percent, whereas utilization in a suspension gasifier can fall below 90 percent for less reactive coals and will approach 99 percent only for highly reactive lignites.

The Ignifluid bed operates at conditions that are a logical extrapolation from Winkler art, if one wished to devise an air-blown gasifier for relatively unreactive coal: velocities of 10 to 15 meter/second and temperatures of about 1200° to 1300°C. In spite of this logic, Godel deserves great credit for having shown the wit and courage to attempt such extreme conditions. At these temperatures the ash matter of all coals is sticky, and one might expect the attempt to lead to a catastrophically huge clinker. On the contrary, Godel discovered that small clinkers appear throughout the bed and remain fluidized and grow in size without risk. Apparently the high fluidizing–gas velocity produces an effect much like the continuous action of a poker.

Air is introduced into the bed through an escalating grate. The edges of the grate are relatively stagnant, and clinkers that come to rest there tend to remain. They are sticky and capture other clinkers by collision, so that a continuous pad of clinkers, low in carbon, forms toward the upper end of the grate, which dumps the clinkers into an ash pit. Secondary air is admitted above the fluidized bed to burn the power gas and supply heat to a boiler.

A team at City College has studied the Ignifluid (*29*). A major question has been: What accounts for its good carbon utilization? One possibility is that micrometer-size carbon particles do not survive passage through the secondary combustion zone above the bed. There is a large circulation of carbon particles upward through the boiler, into mechanical dust-collecting devices, and thence into a lance for reinjection at high velocity into the deep end of the fluidized bed. In one Ignifluid the rate of circulation was measured to be about one-half of the bituminous coal feed, and carbon utilization efficiency was stated to depend upon careful aim of the lance toward the deep end of the bed (*30*). This Ignifluid has two mechanical collectors in series, and the finer dust from the second collector was astonishingly coarse by comparison with carbon dust reported by Rayner (*27*) for a fluidized-bed gasifier running at low velocity (see Fig. 3). A fine particle injected about 1 meter below the surface of the deep end of the bed would remain in the bed for a number of minutes. The City College team's present view is that micrometer-size particles of the size seen by Rayner simply cannot survive for several minutes at the conditions of the Ignifluid bed. It will be important to put this view to a test.

One special capability of the Ignifluid is the combustion of dirty fuels of high ash content. It will be excellent for anthracite wastes, both culm banks and silts.

Pennsylvania Electric Company (a subsidiary of General Public Utilities) is considering the erection of an 80-

Table 3. Development activities deserving high priority.

Blown with air	Blown with oxygen and steam
Ignifluid	
Revamp to provide "pure" gasifier	Test revamp
Develop larger sizes	
Develop pressure version	Test at pressure
Koppers-Totzek	
	Develop pressure version
Babcock & Wilcox–duPont type of suspension gasifier	
Develop	Get more experience
Develop pressure version	Test at pressure
Gas cleaning	
Get experience with wet systems for removing dust and hydrogen sulfide in electricity-generation context	
Develop techniques for removing dust and sulfur species from hot fuel gas	

megawatt Ignifluid as a "high sulfur combustor" to serve its Seward station. The concept is to beneficiate bituminous coal to a reduced sulfur level for the larger boilers at the station, while burning tailings with 7 to 10 percent sulfur and 40 percent ash in the Ignifluid.

After the outbreak of war in the Middle East last October, the City College team recognized a role for a "quickie" revamp of the Ignifluid gasification system to provide a gas for retrofit of existing gas- or oil-fired boilers (*31*, *32*). The largest present Ignifluids are two units in Casablanca, each capable of treating about 400 tons of a low-grade Moroccan anthracite per day. Quick scaling of the Ignifluid design to capacities of several thousands of tons per day, suitable for retrofitting boilers for several hundred megawatts, appears feasible.

During a recent visit to Paris, I learned that Fives-Cail Babcock has not been idle. A small test Ignifluid (13 ton/day) at La Corneuve is being modified (at Babcock's own expense!) as shown in Fig. 4. A baffle is being added to allow the depth of bed to be increased. With this change ports previously used for the admission of secondary combustion air can admit a portion of the gasification air, this portion preheated to a temperature above that at which air can be furnished through the grate. An arch is being added to separate the chamber into a gasification space below and a combustion space above. Fuel gas quality will be determined from samples taken from the pipe conveying fuel gas from the lower to the upper space.

A much larger experiment is both desirable and justified, and outside funding is urgently needed. The City College team expects that a gas of at least about 125 Btu/cubic foot can be provided.

The Ignifluid gasification system, housed in a circular vessel and with different means for removing ash clinkers, is a strong candidate for development for operation at high pressure. The presence of a significant inventory of carbon affords safety against an explosion that could result in a suspension gasifier if the coal feed is lost and air or oxygen supplies are not shut off at once. Typically, the gas residence time in a suspension gasifier is about 3 seconds, and an explosive mixture would develop in a few seconds if the air or oxygen supply is not instantly interrupted upon loss of fuel. The feeding of fine coal at atmospheric pressure is a well-established art, but it is not established for high pressure. Development of a Koppers-Totzek or Babcock & Wilcox design for high pressure would need to be followed by an ample operating history before the design could be widely adopted. An Ignifluid for pressure could be certified for safety much more quickly. Fives-Cail Babcock are now engaged in an Ignifluid experiment (at Babcock's own expense!) at 4 atmospheres in a circular vessel fitted with an ingenious rotating grate invented recently by Godel (*33*).

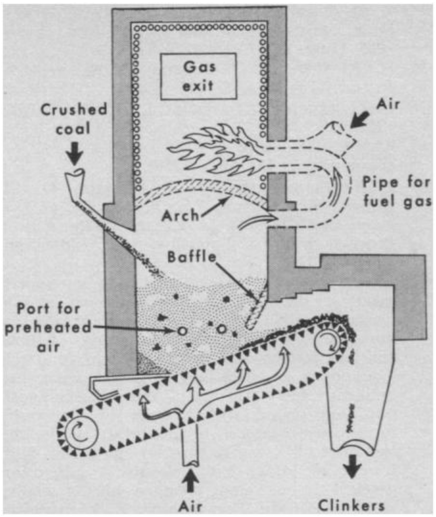


Fig. 4. Experiment on "pure" gasification in a revamp of a small test Ignifluid boiler at La Corneuve, France.

Hydrocarbon Research, Inc., of Trenton, New Jersey, plans tests of a fast fluidized-bed gasifier suitable for pressure that uses the Godel technique for generating ash agglomerates (*8*, *34*). Several approaches to removing the agglomerates will be tried.

Retrofit of Gas-Fired Boiler to Burn Power Gas

The City College team has examined the problem of retrofitting an existing gas-fired boiler to burn power gas from a revamped Ignifluid. It was assumed that the gasifier and coal pile could not be situated near the existing boiler. It appears possible to match operation of the gasifier and boiler so that steam-superheating and water-heating duties of the boiler are held substantially the same as in the present gas-fired operation. Fuel gas would be cooled to about 260°C for cleaning and would be supplied at this temperature to the existing boiler. Hot water would be sent from the boiler to the gasifier and converted to steam, with about 40°C superheat, for return to the boiler. The effect of this steam is to reduce the fire box duty at the existing boiler by about 40 percent. Power gas at 125 Btu/cubic foot could sustain the reduced fire box duty. The temperatures of the combustion products entering the superheating and water-heating sections of the boiler would be close to present values. With use of New Mexican coal of low sulfur content (obviating the problem of sulfur controls) and containing 30 percent moisture, the overall effect of the retrofit is to reduce boiler efficiency by only 1 point, from 85 to 84 percent on a higher heating value basis.

Conclusions

The quickest way to establish a visible new margin against energy demand is the historic producer serving small industry and gasifying Pennsylvania anthracite. In 2 years many producers could be in operation.

The quickest way to obtain significant supplies of "new" gas or oil is to retrofit existing electricity and industrial boilers for power or industrial gas. Important results could be achieved in 6 years.

Table 3 identifies development activities deserving high priority to speed the capture of gas and oil now burned in boilers, and to speed realization of the advantages of combined-cycle equipment running on coal (*8*).

Obviously, these activities are not enough. Many exciting and worthwhile concepts at various stages of development can furnish improved techniques for converting coal to pipeline gas and liquid fuels for the long run. Reviews of these concepts are available (*6*, *32*, *35*). I have neglected them in this article not to deny their importance but to stress the earlier opportunities from technology that is ready now, or nearly ready.

The oil and gas industries might well consider the historical progression from Wells Fargo to Western Union to American Telephone and Telegraph to Radio Corporation of America. These industries will miss the boat if they regard themselves simply as purveyors of their historical fuels and not as purveyors of clean energy. The gas industry especially will be in trouble if it lets its major industrial customers, such as steel and electricity, provide their own supplies of power and industrial gas.

References and Notes

1. Town gas ("coal gas") comprises primarily hydrogen, methane, and carbon monoxide, and was made historically by heating bituminous coal in retorts in the absence of air. Modern town gas processes depend upon gasifying coal with oxygen and steam.
2. "Power gas" is the historical term introduced by Ludwig Mond in about 1890, when a preferred procedure for generating shaft power was to burn power gas in a gas engine. The term "low-Btu gas" has regrettably become current.
3. I am not aware of an experiment in which molten slag was withdrawn from a fluidized-bed gasifier.
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High-Sulfur Coal for Generating Electricity

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The United States has an abundance of coal. Coal reserves economically recoverable by today's mining technology are estimated at 200 billion tons (*1*), and total domestic coal resources are of the order of 3 trillion tons, or enough to meet a large part of our energy needs for centuries (*2*). We are experiencing an energy shortage in the 1970's, despite such vast amounts of coal, because we have become overdependent on natural gas and oil to supply some of our increasing energy needs, among them that for electrical power.

Electricity provides about 25 percent of our total energy needs. According to a Department of the Interior study (*3*), per capita use of electricity increased from slightly more than 2000 kilowatt-hours in 1950 to 7800 kwh in 1971, and is projected to reach about 32,000 kwh by the year 2000.

Cheap, convenient low-sulfur oil and natural gas are competing with coal as the preferred fuel for the electric utility market (Table 1). While annual consumption of coal for power plants in the northeastern and east northcentral regions of the United States stayed approximately constant in the 6 years from 1966 to 1971, oil consumption has increased by factors of 3 and 25 in these regions, respectively, and gas consumption has increased by up to a factor of 3 (*4–6*). Continued use of petroleum and natural gas at the present rate will aggravate the serious supply problems for these fuels.

Programs under way to augment our oil and gas supplies and to diversify our energy base (*7*), such as coal gasification, extracting oil from western oil shales, harnessing solar energy, wind, and geothermal steam and brines, will have little impact on electricity generating needs for many years. Similarly, although nuclear reactor power plants are expected to provide up to 25 percent of the demand for electricity by 1985 and up to 50 percent by 2000, these optimistic estimates assume the timely development of the fast breeder reactor program and satisfactory solution of environmental problems in siting and operating nuclear reactors. In the meantime, fossil fuel–fired power plants must supply a large part of our electrical power demands, and only coal is available in the United States in sufficient quantity to provide this energy for the next 25 years.

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