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LIGNITE COMBUSTION
AP-42 Section 1.7
Reference Number
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LIGNITE AND BROWN COAL

Lignite and brown coal are the common names given to coals intermediate between peat and bituminous coal in both geological age and general properties: They are not universally used in the same sense, however. In the ASTM classification, the entire category is designated lignitic, the consolidated ones being lignite and the unconsolidated, brown coal. This usage is followed in some other countries, predominantly English-speaking ones. In Germany, many other European countries, and in Australia, among others, brown coal is the generic term for the whole class, lignite signifying the firmer, fibrous, woody variety. In this article, "lignitic coal" will be used as the comprehensive term. Distinction between the many varieties of such coal is important in enabling selection for a particular purpose, for example for combustion, for the extraction of wax, or for a high yield of tar and correspondingly low yield of coke or the reverse. Some progress has been made in recent years in arriving at international agreement on the classification of lignitic coals, but much more remains to be done, especially in rationalizing the confusing nomenclature.

Lignitic coals are inferior to those of higher rank, particularly in their high water content (up to 70%, as mined), heat value, and mechanical strength, and hence the market is often local, its radius being determined both by the properties of the coal and by economic factors. Despite this, a combination of circumstances, economic, political, and geographical, has militated to enhance their importance, and, thus, to stimulate much scientific study and the development of specific technologies in winning, in improvement of properties (for example, by briquetting, which brings it nearer in characteristics to higher rank coal and helps to widen the market area), and in use in specifically designed plants or appliances. The outcome has been, on the world scale, that lignitic coals have been produced at greatly increased rates, and, unlike hard coals, they have maintained their position in the energy pool. In the United States, development of the large resources of lignitic coal has been inhibited by the plentiful supplies of petroleum, natural gas, and hard coal, and production is relatively small.

Geology (1)

Nearly all of the charted lignitic coal reserves were laid down in the Tertiary period (about 2.5 to 60 million years ago). Those of Southeastern Europe, Alaska, and Southern Nigeria are of the Pliocene epoch (about 2.5 million years old); those of Central Germany, France, and East and Southeast Australia are Miocene (about 20 million years old); other European deposits, including the only English one of note, are Oligocene (about 40 million years old); and some, for example in North America (Rocky Mountain states, Pacific Coast area, and Alaska), are Eocene (about 60 million years old). Relatively few deposits are younger (eg those of New Zealand and Tasmania are Pleistocene, about 1 million years old) or older (eg some in North America are Cretaceous, about 100 million years old). The oldest occurs in the lower Carboniferous (eg that of the Moscow basin, about 200 million years old). (See also Coal, Vol. 5, pp. 607–609.)

Many different kinds exist, a wide variation often being found within one seam. Distinct banding may be shown, as in the Frimmersdorf Open Cut in the Rhine Valley of West Germany, which was separated into eight varieties, and in deposits of western U.S.A., in which a number of types were recognized. Such variations are not explicable wholly by differences in geochemical change wrought in the original peat (for example, by depth of burial or differential earth movements); differences in the composition of the peat itself, due mainly to variation in the original plant population, and in the kind and extent of decomposition of plant components, are also of great importance.

A comparative study of the environmental conditions and plants existing in peat swamps of today, in conjunction with a study of the geological history of the lower Rhine basin in the middle and late Tertiary, has thrown fresh light on the origin of the important brown-coal fields of Cologne and the lower Rhine. A wide range of plant communities succeeding one another accounted, mainly, for the vertical differences in seams. A predominant plant community could result in a certain kind of brown coal, but with variations in properties brought about by different types of bacterial decay, because of fluctuations in water level in the swamp. Lateral variations were also found (and occur frequently in large deposits), owing to the accumulation of various types of peat in different co-existing environments (2,3). In the deposits of the Latrobe Valley in Victoria, Australia, bands are also found, mainly of two types, but here the same plant-remains, in the same relative proportions, are found in both. The different extent of decay of the original plant material, owing to the varying depths of swamp water, is thought to be the main cause here (4). Regional changes in West German brown coals arose where marine conditions were adjacent to the area in which freshwater sedimentation was occurring. As the vegetable debris accumulated, the bog was impoverished of nutrients as they became slowly fixed in the peat, resulting in an increase in acidity, so that upper parts of deposits were laid down under distinctly acid conditions. The resulting coals, thus, had different properties.

Segregation of plant components also accounts for the peculiar nature of some kinds of lignitic coal; for example, those rich in spores may be found at the tops of seams or in isolated, lenticular basins to which the original plant debris had been transported by water.

In contrast to the coals of the Carboniferous, most lignitic coals show evidence of their origins from a typical modern flora, both gymnosperm and angiosperm. Remains of the former, with wood predominating, are the better preserved, because of the impregnation of their cells with resins, tannins, etc. Among the coniferous woods found in European and North American lignitic coals are those of species of pine, spruce, Sequoia, and Taxodium; in Victorian brown coal, Agathis (Kauri pine) is commonest. Angiosperm wood has largely decayed to form structureless humic products, including "humic acids," but, occasionally, structured sclerenchymatous and suberised tissue are recognizable. Sometimes the structure of woody cells is preserved on conversion to fusain or charcoal. Fungal remains are found, often in the woody tissue.

Other common angiosperm remains are the cuticles, together with leaf tissue, as in the Russian "paper coal" and in parts of the upper Yallourn seam in Victoria (the latter probably from species of *Oleaceae*), and pollen grains of many types, which, as in peat, are important because of their good state of preservation and ease of identification. The pollen of Sciadopitys has been used, particularly, in studies of German brown coal, because it marks a transition from a warm to a cold climate. That of the southern beech (*Nothofagus*) occurs frequently in Victorian brown coal, affording evidence that conditions were largely temperate and wet when much of it was laid down (confirmed by the paucity of tropical and semitropical plant remains, and of plants growing in dry conditions). The presence of pollen grains of other species (eg *Podocarpus*, *Dacrydium*, and *Mohria*), together with remains of conifers, shows, however, that a minor part of Victorian brown coal (Wensleydale) was formed under dry conditions. The drift coals of Nigeria are examples of spore-rich lignitic deposits, and include pollen grains of palms, of semitropical ferns, and of other tropical and semitropical plants.

Among the geochemical factors also accounting for variations in the properties of lignitic coals, depth of burial is important. Thus, for a particular deposit, deeper coals are usually the more consolidated and of lower water content, eg in the Morwell deposit at Maryvale (Victoria) the decrease is at an average rate of 0.5 to 1% for every 100 ft of coal. The carbon and hydrogen contents were found to increase at the rate of 0.5 and 0.05% (dry, ash-free coal basis), respectively.

Classification and Nomenclature

Because of the increasingly important part played by lignitic coals in the economic life of a growing number of countries, the need for an international classification has become more pressing. The main problems in classification, toward the solution of which good progress has been made in recent years, are (a) the demarcation of the whole class, on the basis of agreed criteria, from peat at the one end to bituminous coal at the other, (b) the subdivision of different types within the whole class, again on the basis of selected properties, and (c) the adoption of standardized, descriptive terms to apply to the broad categories and their subdivisions.

The difficulties in demarcation arise from the gradual transition in properties in going from peat to the higher rank coals, though the bulk of lignitic coals are clearly definable. At the lower end, "mature peats" or "immature brown coals" are found; at the upper, apart from the existence of intermediate types, the dividing line is sometimes drawn differently, for example in the designation in some countries as "black lignite" of coals included in others in the lowest rank of bituminous coals (eg the subbituminous C of the ASTM classification).

The scheme of classification formulated by the coal classification working party of the Coal Committee of the Economic Commission for Europe (ECE), officially adopted in 1958 and recommended to the various participating governments for practical application (Table 1) (5), takes the heat value of 5700 kcal/kg (moist, ash-free basis), previously adopted as the lower value in the International Classification of Hard Coal by Type, as the upper value for the lower rank coals. The group is subdivided on the basis of total moisture content (ash-free basis) of the coal as mined and tar yield (dry, ash-free basis). As total moisture is correlated with heat value, it is a guide to the use of the coal as a fuel; the tar yield indicates its value as a raw material for the chemical industry. Thus, this is mainly a use classification, and does not purport to be a scientific one. The majority of lignitic coals fall within it, but many immature coals formerly considered as brown coals have heat values of above 5700 kcal/kg, and thus do not. Among these are "pitch coals" (Glanzbraunkohlen), and nearly all black lignites with a stratified structure; such deposits occur in the U.S.A., U.S.S.R., Czechoslovakia, Yugoslavia, and Hungary. The lack of discrimination between different types on the basis of their petrographic characteristics is a further weakness noted in the classification. A simplified system based on a two-figure classification index, likewise derived from moisture content and tar yield, but using, in addition, a symbol denoting petrographic index, was adopted in 1961 as the International Classification for Brown Coals for the Peoples Democracies (6).

Table 1. International Classification of Coals with a Gross Calorific Value below 5700 kcal/kg[a] (Statistical Grouping, ECE) (5)

Group number	Group parameter tar yield % (dry, ash-free)	Code number					
40	25	1040	1140	1240	1340	1440	1540
30	20–25	1030	1130	1230	1330	1430	1530
20	15–20	1020	1120	1220	1320	1420	1520
10	10–15	1010	1110	1210	1310	1410	1510
00	10 and less	1000	1100	1200	1300	1400	1500
	Class number	10	11	12	13	14	15
Class parameter	total moisture %[b] (ash-free)	20 and less	>20–30	>30–40	>40–50	>50–60	>60–70

[a] Moist, ash-free basis (30°C and 96% relative humidity).

[b] Of freshly mined coal.

The International Committee for Coal Petrology published in 1963 a classification of brown coals (Table 2) (7) which usefully correlates properties, including % reflectance of vitrinite, but in which the criteria for demarcation from hard coal evidently differ from the above. The nomenclature is a simpler version of that used in German practice in which the soft brown coals are further subdivided into foliaceous and earthy, to the latter of which most brown coal belongs.

The ASTM classification of coals by rank divides "lignitic" coals from bituminous at a lower heat value of 8300 Btu/lb (4610 kcal/kg) (moist basis), the subdivisions of

Rank increasing

Rank stages			% Reflectance of vitrinite	Important microscopic characteristics	% C in vitrinite	Volatile matter % d.a.f.[a] in vitrite	% H_2O in situ	Calorific value of vitrite (a.f.)[b]	Applicability of the different parameters for the determination of rank
		Peat		Large pores Details of initial plant material still recognizable Free cellulose	50 —				Calorific value (a.f.) or moisture in situ (moisture-holding capacity)
Brown coal		Soft brown coal		No free cellulose Plant structures still recognizable (cell cavities frequently empty)	60 —		75~		
			ca 0.3	Marked gelification and compaction takes places		ca 53	35~	7,200 Btu/lb (4,000 kcal/kg)	
	Hard brown coal	Dull brown coal		Plant structures still partly recognizable	70 —	ca 49	25~	9,900 Btu/lb (5,500 kcal/kg)	Reflectance of the vitrinites
		Bright brown coal		(cell cavities filled with collinite)					Carbon (d.a.f.)
			ca 0.5			ca 45	8–10~	12,600 Btu/lb (7,000 kcal/kg)	Volatile matter (d.a.f.)
Hard coal		Bituminous hard coal		Exinite becomes markedly lighter in color ("Coalification jump")	80 —	30			X-ray diffraction (graphite lattice)
		Anthracite	ca 2.5	Exinite no longer distinguishable from vitrinite in reflected light	90 —	10		15,500 Btu/lb (8,650 kcal/kg)	H. (d.a.f.)
		Graphite	11.0	Reflectance anisotropy	100 —	0			

[a] Dry ash-free.

[b] Ash-free.

Table 2. Classification of Coals by Rank, International Committee for Coal Petrology (7)

the former being lignite (consolidated) and brown coal (unconsolidated): Some English-speaking countries have followed this usage. The use of lignite in this sense, or for a brown coal of relatively low water content. or merely as a synonym for brown coal, differs from the more strictly, etymological use of the equivalent term in Germany and other European countries for a brown coal with a definite, woody, fibrous structure.

Other structural and chemical criteria have been taken to differentiate types of lignitic coal; many of the terms used are useful. but not always capable of exact definition. Humic brown coals of various designations contain substantial amounts of extractable humic acids, and include banded humic varieties showing macroscopic stratification. Sapropelic coals are more homogeneous macroscopically, and often have high concentrations of single plant components. They include paper coal (Papierkohle) (see p. 383) made up largely of leaf tissue, especially cuticles; pollen or spore coals (brown coal cannel); those rich in algal remains (the brown coal equivalent of boghead coal); and resinous and waxy coals, of which pyropissite, with abnormal concentrations of wax, up to 85%, is an extreme example (8).

It is clear from the above that much remains to be done in rationalizing the classification and nomenclature of lignitic coals. Recent progress in international classification and physicochemical methods of research has been reported (9).

Composition, Properties, and Analysis (8,10,11)

The appropriate sections in the article on Coal, Vol. 5, should be consulted for information on petrology (pp. 609–612), properties (pp. 621–635), including solvent extraction, p. 635), reactions (pp. 636–637), constitution (pp. 637–644, and especially, p. 643), pyrolysis (pp. 648–650), properties of commercial importance (pp. 650–653), and analysis and general testing (pp. 653–654). In the following, the more important characteristics distinguishing lignitic coals from bituminous are given, their significance in practice being noted where appropriate (see also under Uses in this article).

Macroscopic Appearance. Normally brown to dark brown when moist, but often considerably lighter when dried. The commonest type, the earthy, humic variety, may be light, reddish brown at a freshly exposed surface, but darkens rapidly on oxidation. In such coal, and in most other lignitic coals, the structure is weak and breakage easy. This, together with the tendency to shrink and crack on drying, makes them prone to disintegrate on weathering and in handling, transportation, and use. Some lignitic coals are of firmer structure (eg the fibrous, more woody (lignite, in the ASTM classification) and canneloid (spore-rich) varieties, and the more mature lignitic coals, in general). Plant remains are sometimes visible macroscopically.

Physicochemical Structure. Lignitic coals are organogels traversed by pores and capillaries of varying diameters, some of which retain a certain amount of water (about 15 to 30%, depending on the nature and extent of this inner surface) strongly enough for it to remain on air drying, the larger proportion being lost. Theories of adhesion have been put forward involving the pore and/or colloidal structure, to account for the different ways in which the water is held in the moist coals (10). The nature of the coal surface is important in briquetting which, to be effective, requires the reduction of this water to a suitable predetermined value (see pp. 397–398). The permeability is greater than that of bituminous coal, by a factor of from 20 to 3000 times according to one estimate (13), and is important in relation to the greater availability of the reactive organic surfaces in combustion and gasification processes. Mineral matter is dispersed unevenly throughout the structure, partly as metallic salts (mainly calcium) of the humic acids.

Properties. *Bulk density* is 1.05 to 1.35; in many deposits (eg Rhineland and Victoria) the maximum value is about 1.20. Hence, greater space in storage, transportation and in plant and appliances is required as compared with an equivalent weight of hard coal—considerably greater if the comparison is on the basis of an equivalent heat value.

Elasticity and Plasticity. In general, the more mature the coal the greater its degree of elasticity and the lower its degree of plasticity. The ratio of the elastic energy to the plastic energy involved in compressing coals, the plasticity index, has been used as a means of assessing their briquettability (12). Only the softer, less mature coals can be briquetted without a binder (see p. 397). Shearing and cracking often take place in mining; in open-cut mining, release of pressure may cause a forward movement into the cut.

Humic acids, the brown, colloidal substances formed by the decomposition of various plant components, but especially of lignin, are extractable with caustic alkali and ammonia solutions from nearly all lignitic coals, sometimes in large amount (up to about 65% on the dry basis) in the less mature coals, but the yields are not diagnostic for particular varieties. The acids bound as salts may be liberated by treatment with mineral acid, further yielding up to about 20%. The pH of the pit-moist coals is, thus, on the acid side (about 4.0 to 6.5), the value depending on the amount of free humic acid present.

Extraction with nondispersing solvents, such as benzene, benzene–alcohol mixtures, 1-propanol, and 1-butanol, yields from 5 up to about 20% (or more, in exceptional cases) of a material, sometimes called "wax" or "bitumen," often regardless of its composition. The amount and composition of the extract owe more to the petrological nature of the coal than to its degree of maturity. Suitable "waxy" coals are extracted for montan wax (see under Uses, pp. 53–59, where the composition of such extracts is given).

Tar yield is generally higher than for bituminous coals, and is often exceptionally high for lignitic coals with large amounts of extractable matter. This property is mainly of importance in selecting coals for carbonization.

Oxidation. Their great avidity for oxygen, with the generation of heat, means that special care must be taken in mining and storage. More humic acids are formed on oxidation with air or oxygen, or with chemical reagents such as potassium permanganate or nitric acid, than is generally the case for bituminous coals; many lignitic coals will be rendered almost entirely soluble in alkali solutions by such treatment. The reaction with nitric acid has long been used in attempting to distinguish lignitic from hard coals. The method has recently been improved by photometric measurement of the nitric acid solution obtained (14,15).

Analysis and Its Significance. *Proximate and ultimate analyses, and heat values of a number of humic coals,* are given in Table 3 (8).

Moisture content of freshly-mined humic coals can be as high as 70%, but is usually between 30 and 60%. The lower values are found, generally, in the maturer, more consolidated and the sapropelic coals. It is a most important factor in the economics and technology of use of lignitic coals.

Mineral matter content and ash yield are frequently less than 6% in thick deposits (eg Australian and German brown coals) but often higher, especially in drift coals.

Table 3. Analyses of Lignitic Coals (8)

Coal	Proximate analysis					Ultimate analysis					Heat value, gross dry, kcal/kg
	Moisture	Ash	Volatile matter	Fixed carbon	Volatile matter, daf[a]	C	H	S	N	(O)	
United States											
North Dakota	33.9–	3.5–	25.4–27.6	26.9–	45.2–48.8	71.1–	4.8–	0.3–	1.0–	16.9–	6640–7080
(range for coals	41.2	8.5		31.7		74.4	5.3	2.3	1.1	22.7	
from five areas)											
South Dakota	38.5	5.8	26.9	28.8	48.3	72.0	4.8	0.7	1.4	21.1	6790
Victoria											
Yallourn	66.3	0.7	17.7	15.3	53.4	67.4	4.7	0.3	0.5	27.1	6180
Yallourn north	50.0	2.0	26.0	22.0	54.2	68.3	4.9	0.3	0.6	25.9	6190
Germany											
Lower Rhine	60.0	2.3	20.6	17.1	54.6	68.9	5.3	0.3	25.5		6200
(average for four											
similar coals)											
Central Germany											
Geiseltal	50.4	6.3	27.3	20.0	57.7						6395
Riebeck-Montan	49.2	6.7	26.5	17.6	60.1						6897

[a] Dry ash-free.

The ash tends to have higher SO_3, CaO, MgO, Fe_2O_3, and Na_2O contents than in hard coals, but the amount of phosphorus is generally low; larger proportions of the metals are held in organic combination. Uranium tends to be present in highest amount in lignitic coals; some in the Northern Great Plains contain more than 0.1% (16–18).

Volatile matter ranges from about 42 to 60% and the hydrogen from about 4.3% to 6.1, both on the dry, ash-free basis, for humic coals, but these values tend to be higher in sapropelic and biolithic coals.

Carbon, on the same basis, has a bottom value of about 62%. An upper value of 78% will divide most lignitic coals from bituminous, but, as has been seen, there is no agreement on this for classification purposes.

Tests (19). Subcommittee 2 of Technical Committee 27 of the International Standardization Organization (ISO) is, at present, considering analytical methods, especially for *total moisture content*, by the distillation procedure using toluene or xylene; the *tar yield*, by the Fischer assay method; and the *ash yield*, using substantially the same procedures as for higher rank coals. A test for *extractable matter* with benzene is also under consideration.

Resources and Production

Reserves. The total reserves of lignitic coal for sixteen out of the eighteen countries having more than one billion metric tons are given in Table 4, in order of magnitude (20). The two other countries in this category, the figures for which did not appear in this World Power Conference Survey, are the German Democratic Republic, with 25 billion tons proved by borings, of which 22 billion tons (88%) could be won by open-cast working (21), and China, with estimated reserves of about 4700 million tons, representing, however, only 0.8% of her total coal deposits (22). Substantial amounts are found in twenty-five other countries, of which the most important are in Turkey (882), Spain (780), Burma (265), Austria (251), Italy (190), and Pakistan (141), all figures in parentheses being in millions of metric tons.

Mere size alone of a deposit, however, does not indicate its economic significance; the proportions of estimated reserves that are economically recoverable must be taken into account, and these vary so widely (from 14.7 to over 80%) as to give a different serial order of magnitude for recoverable reserves, eg the figure for the total recoverable reserves for the German Democratic Republic (East Germany) would then be fourth, while that for the German Federal Republic (West Germany) would be several places below. A further degree of significance to the order could be given if the average heat value were taken into account.

The accuracy of these figures is likely to be greatest in those countries where resources are best developed and geological surveys have been active over a long period; thus, a refinement of the estimates is to be expected, especially in the developing countries. In the U.S.S.R. a remarkable increase of estimated reserves to 1.3×10^{12} metric tons was reported in 1960, as compared with the previous figure of 2×10^{11}. It remains to be seen whether the relatively small amounts reported, so far, for certain areas (eg Africa) are because of a natural scarcity or of the relatively little exploration that has taken place.

A further difference in these estimates may be expected with the growth of international agreement on what coals fall within the category of brown coal and lignite;

Table 4. Brown Coal and Lignite Reserves in Order of Magnitude, millions of metric tons (16)

	Measured reserves[a]					
Name of country	Date to which estimate refers	Quantity	Proportion economically recoverable, (%)	Average calorific value, kcal/kg	Indicated and inferred reserves, quantity[b]	Total reserves (columns *3* plus *6*), quantity
1	*2*	*3*	*4*	*5*	*6*	*7*
U.S.S.R.	1960	56,820	near 80	3,076	1,292,810	1,349,630
U.S.A.	1960	9,400	50	unrecorded	396,600	406,000
Australia	1961	39,954	52	2,071	57,036	96,990
Germany, Federal Republic	1960	62,665	14.7	2,000	unrecorded	62,665 plus
Poland	1956	unrecorded		2,000	unrecorded	33,000
Canada	1960	12,250	50	unrecorded	11,850	24,100
Yugoslavia	1956	7,206			14,200	21,406
Czechoslovakia						12,500
Chile	1954	335	70	5,000	5,020	5,375
Bulgaria	1959					3,800
India	1951	unrecorded	unrecorded	unrecorded	unrecorded	2,020
Japan	1955	238	58.9	unrecorded	1,495	1,733
Greece	1952–1961	908	75	1,500	667	1,575
Hungary	1931	1,500				1,500
New Zealand	1959	65	40–50	unrecorded	1,008	1,073

[a] For which there are reliable data of thickness and extent of seams containing not less than 30 cm of brown coal or lignite and situated not more than 500 m below the surface.

[b] Approximate estimates from uncompleted investigations or from relation to measured reserves, within the same limits of thickness and depths of seams.

for the figures quoted, each country decided this for its own reserves. The most important discrepancy, probably, is in the inclusion or omission of high rank lignitic coals or low rank bituminous coals (eg subbituminous C in the ASTM classification). On the basis of the figures quoted, three countries, the U.S.S.R., the U.S.A., and Australia, hold over 90% of the world's estimated resources; if the German republics are also included this figure becomes 97%.

Production. The amounts of lignitic coal produced by different countries between 1948 and 1961 are given in the article on Coal, p. 624. Those for 1961–1963 for the nine leading countries are given in order of magnitude in Table 5 (23,24). A few countries differentiate between types in reporting their figures: In 1962, 1760 thousand metric tons of pitch coal (higher rank) was produced by the German Federal Republic, and 3700 and 4662 thousand metric tons of lignite by Czechoslovakia and Hungary, respectively, the residual amounts in each case being brown coal. A comparison of Tables 4 and 5 shows that, by and large, the countries with the largest reserves are the main producers (see next two sections), with the notable exceptions of the U.S.A. and Canada.

In 1961, the total output of the four leading countries, the two German republics, the U.S.S.R. and Czechoslovakia, was 534,775 thousand metric tons, representing just over 80% of total world production; that for the nine countries listed represented almost 95%. Thus, with the notable exception of Australia, the main production is now in the U.S.S.R. and the Eastern Europe countries, many of which have increased production by from two to over four times over the last twenty years.

Over the period when hard coal has been making a smaller and smaller contribution to the world energy pool (a drop from 55 to 33% of the total between 1947 and 1960), brown coal has maintained its position (about 12% in both years) by virtue of greatly increased output (over 100% increase between these years, as compared with about 40% for hard coal). In 1959, a review by the German Institute for Economic Affairs assessed the value of brown coal mined throughout the world at $1153 million; as a percentage of the world total of mined products, brown coal, unlike hard, had maintained its position since 1954.

Table 5. Production of Brown Coal and Lignite in the Nine Leading Countries, 1961–1963, thousands of metric tons

	1961 (23)	1962 (23)	1963 (24)
Germany, Democratic Republic	236,926	246,992	254,219
U.S.S.R.	133,516	130,976	
Germany, Federal Republic	99,030	103,011	106,657
Czechoslovakia	65,303	69,485	73,303
Hungary	25,104	25,310	26,768
Yugoslavia	22,760	23,507	26,085
Bulgaria	16,966	19,104	20,248
Australia	16,540	17,412	18,756
Poland	10,338	11,091	15,345
Total of above	626,483		
Total world production, 1961	*663,500*		

Statements of intention and, for some countries, of future production targets, indicate that by and large the high rate of increase shown between 1948 and 1963 will be maintained over the next fifteen years, at least (25). In some countries (for example, Poland, which has a target of 110 million metric tons for 1980), the rate of increase will probably be much higher. The increasing production and use of liquid and gaseous fuels in the U.S.S.R. has already affected production of brown coal and lignite (see Table 5), but a high target, nevertheless, has been stated for 1980 (600 million metric tons).

Factors Influencing Production (25). The decision to undertake or extend production of lignitic coal in any country is the outcome of a complex of interrelated factors—broadly, historical, economic, and technological; this explains why the degree of exploitation of such resources is not simply proportional to their magnitude.

The first phase of modern industrial development in the West, from the middle of the 18th to the middle of the 19th century, was based on the plentiful hard coal of Britain, where the amount of lignitic coal was insignificant. The technologies developed were not applicable, without modification, where it was plentiful. However, particularly from the middle of the 19th century, the production and use of brown coal grew, mainly in Germany, where much of the apparently limitless reserves was easily won; the earliest, large, industrial use at this time was in the processing of sugar beet.

After the turn of the century, in Germany, briquetting, the techniques involved in carbonization and chemicals production and in electricity generation, were added to the uses which had been developed of lignitic coal as a domestic and industrial source of heat.

A major impetus to the development of her lignitic coal resources came as an aftermath of the 1914–1918 war, with the loss to Germany of the hard coal of Lorraine and a large part of the upper Silesian field and of the Saar basin (the total producing 52 million tons, annually), together with the requirement of an annual cession of hard coal. The subsequent phase of national self-sufficiency and drive to expand frontiers was responsible for a further concentration on this resource, the production of synthetic petroleum having a high priority.

Absence or shortage, or sometimes, unsuitability of other indigenous fuels have made lignitic coals sometimes the prime, often an important, source of energy or chemicals in other parts of the world. Victoria, a number of Eastern European countries, and Southern India have lignitic coal as a major or sole fuel resource. In Yugoslavia, lignitic coal is being looked to as a blending agent with and even as a substitute for the strongly caking Rasa coal in coke manufacture for the iron and steel production, because of the abnormally high organic sulfur content of the latter. Conversely, the presence of high grade fuels, such as hard coal, petroleum, and natural gas, may be a factor in retarding the development of coexisting resources of lignitic coal. The U.S. is the outstanding example here, with ample supplies of all four types of fuel; Canada is another.

Further pressures to develop lignitic resources arise if higher-grade fuels are imported, leading to an unfavorable balance-of-payments situation, and, often, a desire for a more assured source of supply. The level of transportation charges, a major factor in the economics of lignitic coal production and usage, may also be an important reason for opening up other fields closer to the center of use. Thus, the low rank coal from Callide in Queensland, Australia, cost, in 1953, six times as much in Melbourne, Victoria, as at the mine, and was a further stimulus to production of brown coal in Victoria.

A growing trend, especially in, but not entirely confined to, countries with planned economies, is for fuel resources to be used in a more rational and balanced way, so that brown coal may find a place, for example, in many combustion processes, but especially for steam-raising in power stations, instead of a higher grade fuel, such as natural gas, which may be wanted for more appropriate use as a domestic or industrial fuel or as a source of chemicals.

In the winning of lignitic coal, the great natural advantage of its existence, in many countries, in thick seams not far below the surface, has meant that open-cast mining could be developed using mobile equipment, which is relatively cheap for smaller and medium outputs. Once started, open-cuts can easily be extended, making more rapid exploitation of the resource possible than is usually the case for hard coal. Natural stratigraphic conditions, quality of the coal, and ratio of overburden to thickness of seam, are all important in determining the economics of production, and vary greatly. The geological situation in North America, for example, is not, generally, favorable enough to have made production on a large scale attractive, in the face of competition from the other fuels.

The development of sophisticated technologies for the use of lignitic coal, founded in Germany, but now contributed to by many other countries, has been decisive in diminishing its unattractiveness as a natural resource. Especially important were the solution of the problems involved in its efficient combustion in lump and powdered form, the latter, finding its main outlet in power stations; its upgrading by briquetting, enabling its more economic transportation and use over larger areas, and making possible an even wider range of uses in combustion, gasification, and carbonization; and the development of chemical industries based on the extraction of wax, and the use of tar, gas, and char or coke.

Main Deposits and Production Areas (25–30)

Europe and the U.S.S.R. The vaster reserves of lignitic coal in Eastern Europe, as compared with Western, are now tapped to the extent that in five countries, the German Democratic Republic, Czechoslovakia, Hungary, Yugoslavia, and Bulgaria, it is the main solid fuel in the economy. In most Western European countries hard coal is the more important, with the exception of Austria and Italy, the former mining about 6 million metric tons annually and the latter about 1.5 million; the production of France, Greece, Denmark, and Spain falls between these two figures. In some countries such as the Netherlands, Belgium, Sweden, and Britain, in the last of which the only sizeable deposit is at Bovey Tracey in Devonshire, there is no production. The following information is on the resources and production areas of the nine countries included in Tables 4 and 5, in order of magnitude of total reserves.

U.S.S.R. Much of it occurs, untypically, in the Lower Carboniferous. That in the Moscow basin (about 11,000 square miles) is in discontinuous beds made up of flat, lenticular pockets, mainly of dull, laminated lignite, but with some seams, especially at the bottom, of more consolidated, boghead coal. The biggest field in the Kusnetz basin contains coal of a wide range of rank. Other deposits are found in the northern part of the Central Urals (Kiselov basin), in the Eastern Urals (Sverdlov basin), in the Southern Ukraine, the Caucasus (Ahalzich district), the Bashkir Republic, the Kansk Atshinsky basin, the southern part of the Tungus basin, and the Far East (Artimov basin).

Germany's deposits are mainly Eocene–Oligocene; most are found in the southern part of the northern lowland, the two chief areas being the lower Rhineland and the Central German fields. The Democratic Republic is favored not only by the extent and probable life of her resources, but also by the mode of their occurrence, with many thick seams forming interconnected deposits over large areas. The Central German deposit is in the bay of lowland (middle Elbe basin) with the Leipzig-Halle area as center. The field extends from near these cities northwest to Magdeburg and Helmstedt. The main seam east of Halle is 8–12 m thick, but goes up to a maximum of 100 m in the Geiseltal area. East of Merseburg another seam begins, connecting with the Halle workings and stretching up to Leipzig (main seam worked 12–15 m). The Bitterfeld workings, northwest of Leipzig, are also important. Much of the Central German brown coal gives a high yield of extract and of tar, and is thus suitable for chemical processing; the largest works are situated at Geiseltal (eg the Leuna works). The other main center is east of the Elbe in Lower Lusatia. In the Cottbus district, the coal is lower in bitumen and sulfur content, and the most suitable for making a high temperature coke. A number of smaller deposits are also being exploited mainly for domestic, industrial, and power station use. A newer resource is in the Hoyerswerda district.

The Federal Republic's lignitic coal, in contrast, occurs, generally, in thinner seams and is more localized. The main deposit and producing area of lower Rhineland coal is in the Ville district, southwest of Cologne, but may have a life of only 70 years. Smaller outputs come from fields at Helmstedt, Hessen, and Bayern. Brown coal is, and will remain for some time, important in the country's economy, although hard coal has prime place.

Poland's resources are made up of largely isolated, lens-shaped deposits situated in the west, where the main reserves lie, and in the center (main reserves at Turów, Konin/Goslawice/Patnow, Turek/Adomow, and Rogozno). The quality is poor, mainly because of the high mineral-matter content, and the fast-increasing production finds a major outlet in power stations.

Yugoslavia has considerable reserves in many parts of the country, with those in Slovenia, Middle Bosnia, and Serbia of the highest quality; the majority, of lower quality, are in West Slovenia (Velenj basin), Northern Croatia (Zagorje basin), Eastern (Kolubara basin), and Southern Serbia (Kosovo basin).

In *Czechoslovakia*, extensive reserves are found in the Eger valley in Northwest Bohemia, especially around Sokolov and Most. Other deposits are at Grottau, Budweis, and Handlow. The Eger valley lignite is of the highest quality in central Europe. Both open-cut and deep mining are practiced.

Bulgaria. A major deposit at the Dimitrovo field (Pernik) provides about half the total output of all coal. A large field near Dimitrovgrad (Maritsa basin) is being developed. There are smaller deposits at Bobor Dol (Struma basin) and in the Sofia basin.

Greece's reserves are found in several areas, and are not of high quality. Thermal power stations, eg at Ptolemais in Macedonia and at Aliverion (Aliveríou) in Euboea, use this fuel.

Hungary's output of coal is mainly (70%) lignitic, mined near Dorog in the western Bakony hills, and in the northeastern hills. It is also mainly used on the spot for the generation of electricity.

North America. In the U.S.A. (31), lignitic deposits have been found in the Northern Great Plains, the Rocky Mountains, and the Gulf and Pacific areas. North Dakota (the western half), with over 75% of the country's reserves, Montana with 19%, and Texas with 5%, are the main producers. The remaining 1% of reserves is mainly in South Dakota and California. Production in North Dakota reached over 3 million tons in 1950, but had decreased to 2 million by 1958. Apart from the availability of the other higher grade fuels, a deterrent to production has been the relatively poor natural conditions. In North Dakota, for example, although the overburden is not thick (12–70 ft), the seam thickness is only 3–25 ft; at present, the maximum economic stripping ratio is 10:1. In some vertical sections there may be as many as 15–20 seams. It is common for a thick seam to be split into several by clay partings. Some seams have been extensively burnt due to spontaneous combustion of the fuel after exposure, by erosion, to the atmosphere. Most U.S. lignitic coal is woody, splitting readily along the grain, and with a natural bedding moisture of up to 50%, drying to an equilibrium moisture of 15–20%. Sulfur contents tend to be high and mineral matter low. Little can be briquetted without a binder. Its main use is for heating and power production.

The North Dakota and Montana lignite seams continue into *Canada*, terminating in Saskatchewan, which has the biggest reserves. Other deposits are found in Alberta, Yukon, British Columbia, North West Territories, Ontario, and Manitoba. Production, by open-cut mining, mainly in several areas of Western Canada, is relatively small (about 2 million metric tons annually).

Other Regions. *South America's* reserves of lignitic coal (as of coal, in general) are meagre. *Chile* owns most and has the largest production, but this has been falling, from 255 thousand metric tons in 1948 to about 85 thousand in 1963.

Australia, the only country outside Europe in the leading ten producers, has the bulk of her large reserves in Victoria, with smaller ones in South Australia and Queensland. In Victoria, which has no other fuel, the main deposit, made up of many thick seams, is in the southeastern part of the state, in an area of about 200 square miles in the Latrobe Valley. Here the Yallourn coalfield is the main producer, the Top Coal Seam being 200 ft thick and having an overburden of 40 ft. Seams some miles away are even thicker (one, 7 miles distant, is 880 ft thick). Most of the Yallourn coal is used for electricity generation. At Morwell, next in importance in this region, briquetting and gasification are carried out on a large scale, town gas being piped to Melbourne 80 miles to the west. Another large, but deeper, reserve is mined at Bacchus marsh mainly by underground workings, in contrast with the Latrobe workings, which are all open-cut. In South Australia, lignitic coal is also the only major fuel resource, but much of it lies too deep for economic exploitation. However, some of better quality is mined by the open-cut method, and supplements imported fuels for use in electricity generation.

New Zealand's reserves, situated in the South Island, are poorer and more fragmented. Production reached a peak of about 2.25 million tons in 1960, but fell to a little less than 1.9 million tons in 1962.

In the *Far East,* total production is negligible as a proportion of world output, but there are some large reserves, eg in India and Japan, and several important developments. *India's* reserves rank eleventh in order of world importance, the largest being at Neyveli, about 145 miles from Madras, the exploitation of which by modern means is likely to become increasingly important in the economy of South India. Other lignite of poor quality is found in Kashmir. *Pakistan's* only substantial reserve (about 25 million tons), and the only one in production, is in the Western province at Jhimpir-Meting, about 60 miles from Karachi. The largest producer in the Far East is the *Democratic People's Republic of Korea* (North Korea) with 4.79 million metric tons in 1961, a nearly fourfold increase over 1955. *Japan's* reserves are next in order to those of India, and annual production is over 1 million metric tons. *China's* reserves approach 5000 million tons, made up of about 1000 million metric tons in the Northwest, 2700 million in Inner Mongolia, over 1000 million in the Southwest, and smaller quantities in the Central Southern region (22).

In *Africa* no production of lignitic coal is reported, and the only resource of any consequence is an unusual one, in Nigeria, consisting of drift coals of high hydrogen content, rich in spore remains, and yielding abnormally high yields of hydrocarbon-rich, waxy tars.

Mining (1,25,26,32). Nearly all the lignitic coal now mined is by open-cut (strip mining) methods, which are now highly mechanized, even in places where labor is cheap. The overburden (sand, gravel, clay, etc) is first removed and the exposed fuel won by draglines and shovels in smaller scale production and as a subsidiary method in large cuts, where dredgers are mainly used. Machines have been developed which allow the working, at one operating level, of deposits which are up to about 30 ft thick, this depending, however, on stratigraphical conditions. To improve the quality, selective mining is sometimes practiced, for example, by working thinner cuts, rejecting the intercalated layers of mineral matter.

Mining conditions vary enormously. Thick seams occurring over large areas and with relatively shallow overburdens are particularly favorable (eg U.S.S.R., East Germany, Czechoslovakia, Victoria). The stripping ratio (that of thickness of overburden to seam in mining practice) acceptable for working depends, as has been seen, also on the quality of the fuel and on a number of other factors. Thus, not only does this vary widely as between different areas, up to about 10:1 where the coal is of high quality and/or other conditions are favorable, but the ratio for a particular place can change, for example, with the working out of the better resources, improved productivity or usage, and expansion of markets. Future plans for Federal Germany envisage ratios of 4:1 for lower grades of brown coal, as compared with the present figure of 1.5:1.

Special mining conditions are sometimes met which have to be accommodated in working plans. Some deep open-cuts are subject to underground water pressure: drainage, adding to the cost of working, is necessary, and the batter slopes of the cuts must be appropriately designed (eg as in the Most and Sokolov basin developments in Czechoslovakia). In the Neyveli development in India continuous pumping out of the artesian water below the fuel is necessary to prevent flooding of the workings. A more general difficulty in mining is the great oxidizability of the coal, giving rise to a fire hazard against which stringent precautions must be taken. Dry, hot, and windy conditions, as in Victoria, exacerbate the difficulties, as compared with conditions in the more equable European climate.

Storage (33,34). Because of this liability to overheat, and hence to deteriorate on storage, the attempt is often made to adjust the rate of mining to that of usage, keeping only a limited amount in reserve, for example, in feeding a power station. This sometimes gives rise to difficulties in synchronization of the two. Where larger quantities must be stored, as is frequently the case, oxygen absorption can be cut down by stacking uniformly, avoiding segregation of sizes, and then packing the finer material on the outside. In this way, although the temperature within the stack rises, actual ignition may be prevented, although this sometimes occurs when the stack is dug into. Reheaping of stacks after some oxidation has occurred, and before the temperature has risen too high, increases subsequent safety in storage. Where large amounts are to be stored, the stack may be built by putting down a thin layer at a time, compacting it with earth-moving equipment before repeating the procedure with another layer. Observation of two piles, each of 5000 tons, made up in increments of less than 1 ft deep, showed no sign of overheating over five years. Care was taken to maintain the side slopes at 14° or less to prevent segregation and facilitate compaction. The smooth surface of such piles minimizes differential wind pressures. One of the biggest stockpiles in the U.S.A., of 4 to 6 million tons of lignite from the Garrison Dam in North Dakota, used such a compaction method.

Spraying of the pile with cold water can be most effective. For example, four Hungarian stacks, covered with 10 cm layers of straw, and sprayed periodically with water for ten months, showed a decrease in heat value of only 0.4 to 6%, but of 6 to 20% if untreated. Underwater storage is occasionally practiced, especially in unfavorable climatic conditions and with highly oxidizable fuels, both of which are found in Australia. The storage of briquettes and carbonized briquettes presents no special problens, by comparison. In the former, the structure is less permeable to air; in the latter, it is less oxidizable.

Uses

Much lignitic coal is used in the raw state, especially in power stations, but a large proportion is upgraded before use by removal of part of the nonfuel components (especially of water and, where necessary and possible, of mineral matter), by size-grading, and by briquetting. Thermal drying is carried out, largely as an essential preliminary to briquetting, by contact with superheated steam or by convection drying with flue gas, or by combination of the two, in either order. Cleaning (often unnecessary, and not always possible if much of the mineral matter is in the inherent form) is carried out in the same way as for the coals of higher rank, often in very large washeries, eg in Czechoslovakia (36) and Yugoslavia.

Briquetting (11,35,37,38). Briquetting of brown coal appears to have been first practiced in Bavaria in 1858 using an extrusion press, originally used in Ireland for peat, in which prepared material is forced through a channel of suitable dimensions. This type of press has survived, essentially unchanged, for the production of more than nine tenths of all briquettes made from lignitic coals, but many improvements in design have been made, including the provision of multiple stamps, special press channels and feed devices, and various kinds of drive, all contributing to increase greatly the output of a press. Production in Germany rose from the first annual million tons in 1885 to 60 million in 1943, the latter high level being called for by the need to process briquettes by low temperature carbonization for the production of high yields of tar oils for hydrogenation, to produce a substitute for crude petroleum. A marked postwar trend has been the great development of the domestic market which takes 80% of the total, the rest being used industrially. In 1958, Federal Germany turned one-third of her production of lignitic coal into briquettes (output, 16 million tons), the Democratic Republic, about 45% (output, 53 million tons). In Australia, output has also risen steadily from that of the first experimental factory making 320 tons per day in 1924 from Yallourn lignite. The four factories later built at Morwell now turn out 2.6 million tons annually. A large plant at Neyveli, India, has recently started production, planned to be over 700,000 tons annually.

The briquettability of a coal without a binder is dependent on the adhesion of suitable surfaces through the operation, mainly, of van der Waals forces; two essentials are a high enough degree of plasticity (12) and the presence of an optimum amount of water.

Suitable ways to briquette different kinds of lignitic coal have been established. A useful guide is as follows:

a. The more common, "earthy," less mature coals, of higher degree of plasticity and lower elasticity, are briquetted, without a binder, by the extrusion method.

b. The harder, often more mature, coals of lower plasticity and greater elasticity, are briquetted at higher pressures, with a binder, in ring-roll presses, which are also used when a stronger, carbonized product is wanted.

The latter process was responsible for the larger share of the total output when much of it went for the production of synthetic oil, for the hard, Bohemian lignites gave the greatest yields of tar. As the emphasis in low temperature carbonization has now shifted to the production of a hard, lumpy coke for use domestically, and in chemical and metallurgical industry, the former process now predominates.

A typical process (Fig. 1 shows this schematically) involves the following stages: crushing and screening of wet fuel; drying and cooling; pressing and cooling; loading onto trucks or storage. Dust extraction—collection, separation, and disposal—is an integral part of the various stages. The quality of a briquette will depend on the type of lignite; the size-grading of the powder; the reduction of moisture content to an optimum value; the pressure used in briquetting and its duration; and the care taken in the cooling stages and in subsequent handling.

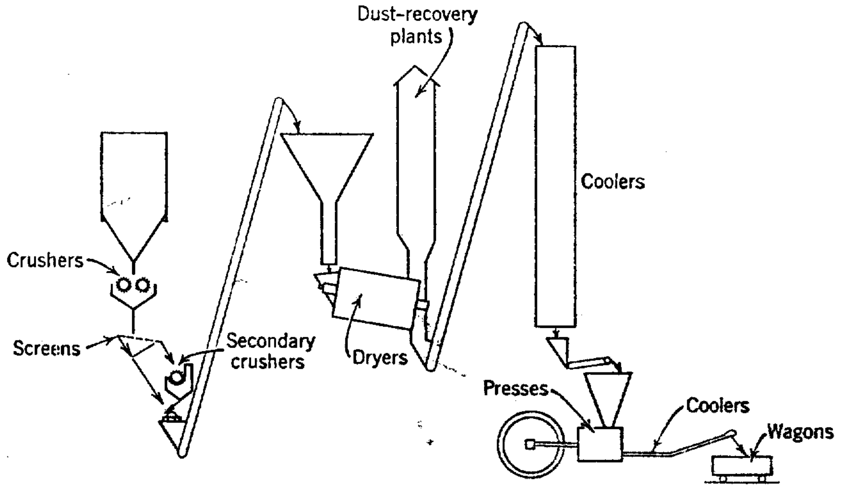

Fig. 1. Schematic drawing of a brown-coal briquetting plant.

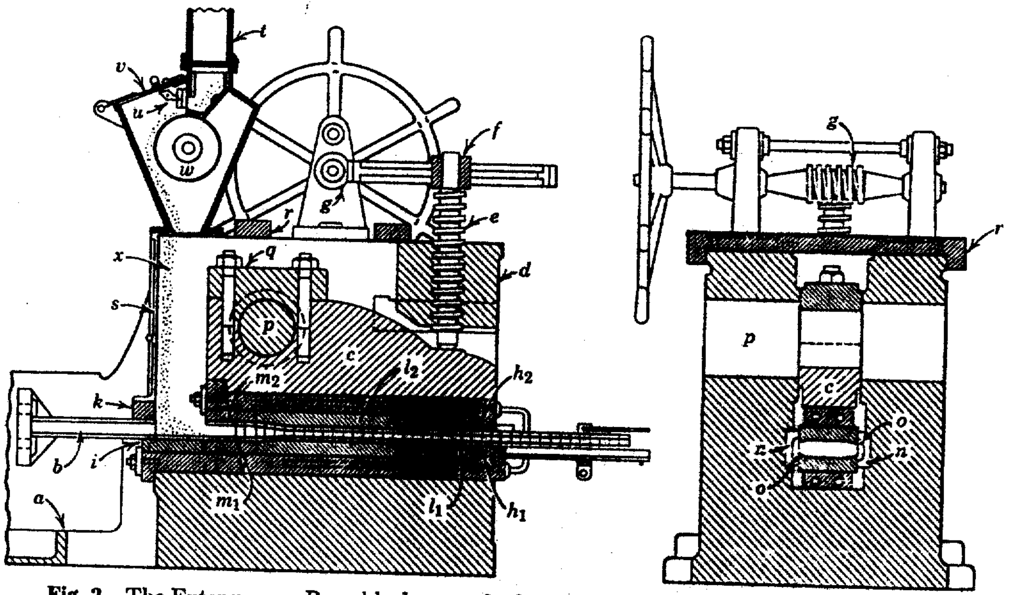

Fig. 2. The Exter press. Press block, press feed, etc, of an old type single press. *a*. Press frame; *b*. stamp; *c*. tongue; *d*. press block part with spindle female thread; *e*. tongue-adjusting spindle; *f*. gear wheel; *g*. worm drive; h_1 and h_2. form books; *i* and *k*. lower and upper guide pieces; l_1 and l_2. lower and upper long molds; m_1 and m_2. working pieces; *n*. side wedges; *o*. packing strips; *p*. tongue belt; *q*. bolt cover; *r*. ties; *s*. door; *t*. feed pipe; *u*. damper; *v*. cleaning door; *w*. feed roll; *x*. coal inlet shaft.

A typical size-grading of the wet powder is 40% of 1–4 mm and 60% below 1 mm. The proportion of fine powder is controlled, the coarser coal (above 4 mm) often being used for steam-raising in a power plant. The optimum value for moisture content in briquetting varies with the coal, but lies between 12 and 18%. If the water content is above the optimum value, the briquette shrinks and cracks on reaching equilibrium with the atmosphere; if below, the briquette may swell and become weaker. After drying, cooling takes place in a separate vessel to the optimum temperature for briquetting, 100–150°F, also giving the necessary time for the remaining moisture to become more evenly distributed, by transfer from the larger to the smaller particles.

In the extrusion press (Fig. 2) the powder falls into the briquetting channel on the backward stroke of a reciprocating ram. The forward stroke both compresses it and pushes the briquettes along the channel for discharge. The pressure attained and the rate of its development depend on a variety of factors, in particular the frictional force between the coal and the channel walls, the temperature, and various features of design, such as the dimensions of the channel and the pattern of ram movement. The last-named is usually controlled by a simple crank linkage, but toggle linkages have been used more recently. The "buckel" or hump in the nozzle at the far end of the channel helps further to distribute the moisture evenly in the already formed briquette, and thus to improve its quality. The final, gradual cooling is necessary as the temperature of the briquettes rises during the process by as much as 30°C, and by even more at the surfaces.

To avoid mechanical stress and breakage, care must be taken in their transfer to trucks or onto storage piles. Dump storage is most commonly used, preferably into sheds for protection, using launders suspended from the roof, with or without portable conveyors. Handstacking of household briquettes has also been practiced, for example in Germany until the Second World War, with a notable preservation of quality and increase in weight stored in a given space. On removal from storage, they are often screened to remove disintegrated material formed.

Properties of Briquettes. The main improvements effected are an increase in heat value and in mechanical strength. The former is usually in the range 4000 to 5600 kcal/kg, because the water content has been lowered. The compression strength is about 100 to 200 kg, using 3 cm diameter faces; bending strength is 12 to 15 kg/cm^2. International test methods are being formulated, as those in use vary considerably.

Combustion (26,39,40). *Significance of Lignitic Coal Properties for Combustion.* The high moisture content sets a ceiling to the efficiency of combustion by loss of sensible heat in two ways: by increasing the weight of combustion products due to steam, as compared with dry coal, and by raising the dew point of the waste gases, so that their temperature must be kept high to avoid condensation. An efficiency, based on gross heat value, of as high as 80% is possible if the moisture content of the fuel is not above 25%, assuming a reasonably low flue-gas temperature of 350°F, a 13% CO_2 content of flue gas, and a loss of 5% due to radiation and unburnt carbon. For a moisture content of 60%, the efficiency is less than 70%, dropping by nearly 1% for each 1% increase in moisture up to 70%. Thus the rate of consumption of this fuel is usually high because of this and its low heat value, so that grates are used only for smaller or medium outputs; larger sized boilers generally use mill firing of the pulverized fuel.

As furnace temperatures tend to be lower due to this loss of sensible heat, the extent of cold surface drawing away heat (eg water tubes) permissible in the furnace is more limited than for hard coals or dried lignitic coals, and is directly dependent on the moisture content of the fuel. Enhanced heat transfer rates, mainly due to the high figure for water vapor radiation, only partly compensate. The selection of fan equipment is affected; the volume of flue gas from coal with 60% moisture passing through an induced-draught fan will be half as much again as with dry coal; forced-draught fans also must handle large air volumes. The ignition of wet lignitic coals requires about five times as much heat as for hard coal and must be taken into account in furnace design, eg by provision of preheated air and control of air supply, use of pre-ignition grates as in chain-grate stokers, arrangement of radiation heating surfaces, and in firing technique.

The requirement for efficient combustion that a fuel be made up of evenly sized and distributed lump coal, to allow uniform flow of air, is the most difficult for lignitic coal. Even if fines are absent, its tendency to disintegrate, especially on heating, inevitably results in mixtures of lump and fine coal, often forming compact air-resistant masses. The lack of uniformity of the bed increases as combustion proceeds, and efficiency falls further. In some lignitic coals such as the German, the ash may form a "skeleton" and thus help to maintain the integrity of the pieces; in others, such as the Victorian, the small amount of friable ash does not help.

The lower moisture and regularity of size of briquettes make their combustion similar to that of bituminous coal, but their mechanical properties are variable, those with "poor standing power under combustion" tending to disintegrate. Too low an ash accentuates this condition and, in lignitic coal and briquettes, as for hard coal, is also a disadvantage if protection of grates is necessary during combustion. Above this minimum (6 or 7%), ash has the usual undesirable effects.

The high organic oxygen and volatile matter diminish rapidly during the combustion cycle of a given charge; thus, the achievement of the correct ratio of primary to secondary air is more difficult than for hard coal.

Combustion on Grates. The difficulties in the design of suitable apparatus and the establishment of appropriate techniques in the burning of the raw coal have been overcome to the extent that no great disadvantage need be felt in its use. Conditions have even been met of providing, during the transitional period in turning from hard to brown coal, as in Victoria, equipment versatile enough to burn both. In Germany, raw brown coal has been burnt for over a century. Fixed step-grates or trough-grates were originally used, the demand for higher outputs being met by increasing grate areas. Forced-draught fans and air-preheat gradually became general after 1924, thereby achieving increased outputs of up to 40%. The main developments, thereafter, were in enlargement and improved design of combustion chambers, and in the mechanization of all but the smallest apparatus. By 1931, firing rates were comparable with good practice in hard coal burning, and grate-fired, power-station boilers could have an output of 350,000 lb of steam per hour. Chain-grates with a preignition stage are common; spreader stokers adapt well and are capable of high ratings (more than 400,000 Btu/(hr)(ft^2)). Dust trapping equipment is general, and particularly necessary at the higher ratings.

Pulverized Fuel Burning. The first practicable system was patented by Kramer in 1933, based on the unit- or mill-firing system. Coal up to 1½ in. in size is fed to a mill, in which it is both partly dried and crushed, whence it is injected directly through a burner into the furnace. (The earlier-established bin-and-feeder system, relying on central storage of the powdered fuel, which was connected by pipes to a number of burners, was impracticable for lignitic coal, because of its great susceptibility to oxidation in the finely divided state.) In the Kramer system, the rapid surface-drying of the fuel in the mill, effected by preheated combustion air with, for a very wet material, admixture of flue gas, causes disintegration, especially of the common, soft type, thus relieving the mill of too heavy a duty. Because of its easy ignitibility, a coarser size than for hard coal is quite adequate, eg 40% on 0.008 in. and 70% on 0.0035 in. aperture screens. The velocity of the mixture of coal and flue gas (5–6 ft/sec at normal loads, or up to 9–10 ft/sec at higher loads) is sufficient to carry the powdered fuel into the furnace.

Other systems (eg the K.S.G.) attain a greater flexibility of performance and are able, by finer grinding and more complete drying, to use material of high mineral-matter content. A preliminary drying and partial gasification is effected in a shaft into which high temperature flue gas is drawn, before the fuel falls into the mill chamber, where further drying takes place. A classifier at the mill discharge enables fine coal of a size suitable for the firing conditions to be piped to the burner, the oversize being returned to the mill for regrinding.

The main use of powdered coal is in steam-raising in power stations, but it has also been used in locomotive firing and cement manufacture, although difficulties have sometimes been experienced in these two applications.

Electricity generation in many areas bearing lignitic coal has been made possible. The low heat value of the fuel requires the station to be sited at the mine, and there is an increasing tendency for mining and power plant and their operation to be planned as a coordinated venture, also taking into account the lowered output from the mine required as the power plant ages. Pulverized fuel- or grate-burning of the lignitic coal, or sometimes, of its char from carbonization, are practiced.

Carbonization. Because of the excessive shrinkage and size degradation on heating the raw fuel, it is now usual to carbonize briquettes. Chars or cokes are, at present, the main products; the gas is neither produced in sufficient yield nor rich enough (the carbon dioxide content may be as high as 25–30% in commercial processes) to be used other than for heating the retorts, for steam raising, or for other works' requirements. The yield of gas may be increased by cracking the tar, but this requires a high fuel consumption in heating the retort as the reactions involved are more endothermic than for hard coal.

Low Temperature Carbonization (11,38,41–44). In the production in Germany of low temperature tar during the two decades up to the end of the Second World War, the briquettes made from the hard Bohemian lignites of 15% tar yield on the dry coal basis, were carbonized in Krupp-Lurgi retorts—narrow chambers, heated externally by flues built into the walls, in which the fuel gas was burnt. The hard, lumpy coke thus made was a valuable by-product. These plants were almost entirely destroyed during the war. The Lurgi-Spülgas process was used from the early 1930s onwards and became the main one, especially for the production of a smokeless reactive lump coke for domestic and industrial purposes.

In this process (Fig. 3), the fuel descends in vertical retorts, countercurrent to hot combustion gas, made separately by burning part of the carbonization gas and introduced at two levels: in the dryer (upper) and in the carbonization chamber (lower). In the dryer, or preheating zone, the moisture is reduced to 1% at temperatures of up to about 150°C. The carbonizing zone below is at 600–850°C. The char made is cooled in the zone below this by the circulation of cool product-gas, and is then with-drawn at the bottom. It must be carefully stored, as its reactivity increases on aging. From the normal brown coal the yields by weight per ton of dried briquettes are: char 45%, with a volatile matter of 10–12%; tar, 12.5%; and gas, 4600 cu ft with a gross heat value of 225 Btu/cu ft. Of the char, 50% has a size of 6–20 mm and is mainly used in gas producers; 20% is less than 6 mm, for steam raising and gasification; and 30% is above 20 mm, as a domestic fuel and in central heating plants. A bigger proportion of large-sized material can be made by selection of suitable coals.

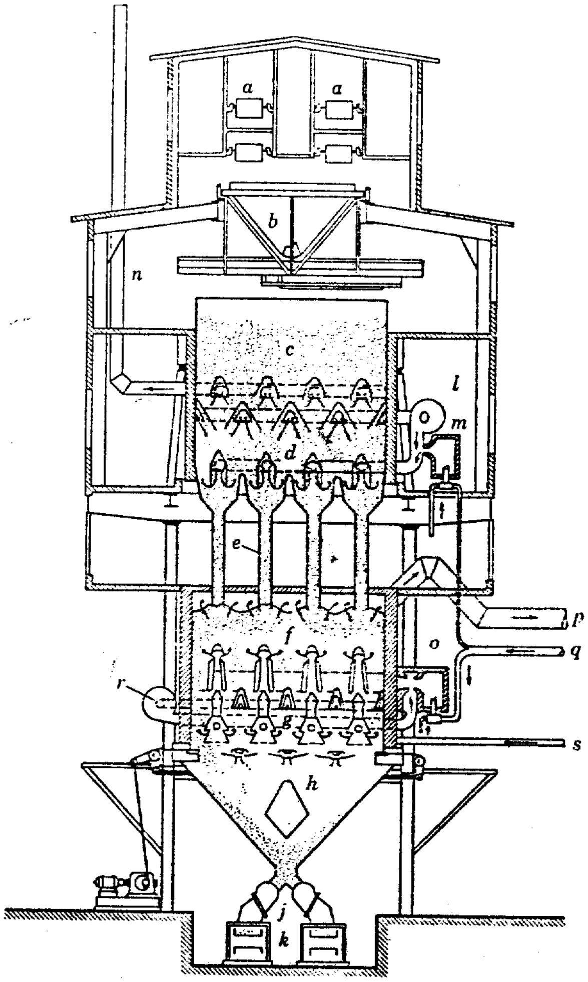

Fig. 3. Diagram of large Lurgi "Spülgas" carbonization plant. *a.* Coal conveyer; *b.* movable distributor; *c.* coal bunker; *d.* drying zone; *e.* connecting shafts; *f.* carbonization zone; *g.* coke cooling zone; *h.* coke extractors; *j.* coke hopper doors; *k.* coke conveyer; *l.* circulation fan for drying zone; *m.* combustion chamber for drying zone; *n.* stack for waste gases from drying zone; *o.* combustion chamber for carbonizing zone; *p.* offtake for mixture of carbonization gas and "Spülgas"; *q.* intake for tar and oil free cooled "Spülgas"; *r.* fan for gas for coke quenching.

It is claimed that about 270 Lurgi-Spülgas units, with a capacity of more than 100,000 tons per day, have been installed. They are mainly in operation in Germany and the Eastern European countries, Australia (Victoria), and India (Neyveli).

Smaller installations exist elsewhere, for example in North Dakota, at Lehigh in Stark county, where 200–300 tons per day of briquettes are carbonized, producing 750 lb of char per ton of lignite. Large-scale developments are being considered in other countries, eg Yugoslavia.

Fluidized carbonization of lignitic coal has been extensively studied up to the pilot-plant scale in a number of countries including Australia (Victoria), U.S. (on the Rockdale lignite, Texas), France, Japan, and Poland, but no process appears to have reached large-scale operation yet. The objectives vary: In the U.S. and Canada, the char has been considered for use as pulverized fuel in power stations, with the tar as a source of liquid fuels and chemicals; elsewhere the emphasis has been on producing a low volatile char for blending with coal for the production of metallurgical coke or for sintering iron ores.

Entrained carbonization, in which the finely divided coal is carried in a stream of gas through a carbonization retort and into a separator, has been tried on the Rockdale (Texas) lignite, using the Parry process, to produce char for a new power supply, the boiler installation of which was built to cope with it or dried lignite. A prototype carbonizer has been in operation since 1953.

High Temperature Carbonization (42–44,46). The main interest here is in those countries where there is a dearth or complete absence of metallurgical coking coal, or where it is of poor quality, and where a coke or char could be made from lignitic coal which is not too reactive, for the reduction, particularly of iron ores. The only commercial process of note at present, is in the German Democratic Republic. Briquettes made from partly dried brown coal of less than 1 mm size are further dried in chambers situated above the vertical carbonization retorts of silica, six to each dryer, and then carbonized for 12 hours, reaching a final temperature of 950°C; the slow heating minimizes disintegration.

The carbonized briquettes are discharged into skips below the retorts, conveyed to a dry-cooling unit (wet-quenching would disrupt them), and, finally, screened at sizes from >45 mm to <3 mm. The retorts are heated by producer gas, the waste gases from which, with the addition of gases which have passed through the dryers, flow through a recuperator and, thence, heat the dryers. A battery consisting of 24 retorts has an output of 125–130 tons of dry coke per day, representing 42% of the dry coal. The coke has a volatile matter of 2.5% and ash of 12%, porosity of 25–35%, and bulk density of 620 kg/m^3. More than half the coke consists of the largest screen size (>45 mm), sufficiently strong (M_{40} index is up to 65) for use in low-shaft furnaces (see below). The rest is used in gas producers, lime kilns, and carbide furnaces. The purified gas from carbonization has a heat value of only 310 Btu/cu ft owing to its high nitrogen and carbon dioxide contents.

The >45 mm size (and sometimes, additionally, the 30–45 mm size) is used in Calbe low-shaft furnaces, usually in conjunction with conventional hard coke (in 1961, the proportion of lignitic coke in the total coke feed to such retorts was 55%), for smelting iron ore. The ash has a favorable CaO/SiO_2 ratio and there is, thus, a saving in the amount of lime needed for slagging. The lignitic coke has also been used in cupolas to replace some of the hard coke made from bituminous coal.

Research and development work proceeding in many countries on the use of lignitic coal as a metallurgical fuel includes: controlled carbonization of the fuel as lumps or briquettes to make a suitable coke; carbonization of the fuel or of its chars in blends, especially with bituminous coals; its use in direct ore reduction by heating

Table 6. Operating Results on Large Lurgi Pressure Gasifiers

	Rhenish		Morwell	
fuel				
size, mm	1.5		briquettes	
moisture, %	20.20		15.6	
ash, %	4.65		1.6	
volatile matter, %	39.75		40.6	
fixed carbon, %	35.40		42.2	
tar content (Fischer), %	10.00		5.6	
gas composition, vol %	*Crude*	*Purified*	*Crude*	*Purified*
CO_2	32.2	2.0	34.0	4.5
H_2S	0.1			
O_2			0.1	0.1
C_nH_m	0.5	0.5	0.4	0.5
CO	17.4	25.2	14.5	20.7
H_2	37.2	54.0	35.8	52.6
CH_4	12.1	17.6	13.5	19.4
N_2	0.5	0.7	1.7	2.2
gross heating value, Btu/scf	300	435		457

pelleted or briquetted mixtures with the ore to high temperatures; the sintering of iron ore with char made, for example, by fluidized carbonization.

Gasification (47,49). Gasification of brown coal briquettes mixed with hard coal (to eke out its supply) had failed, in Germany, during the 1914–1918 war, in plants designed for the latter, and later adaptation of plants (eg by heavy steaming in carbonization retorts, the tar being cracked by passing it through adjoining retorts) was only partly successful. The need to produce synthesis gas, mainly for the production of liquid fuels, became a requirement additional to the production of town gas. See also Gas, manufactured; Hydrogen.

The Lurgi gasification process, first commercially operated in 1936, became the most firmly established, and the majority of developments stem from it. This is a high-pressure (up to 30 atm) fixed-bed, nonslagging process using oxygen and steam, and thus, by elimination of atmospheric nitrogen, yielding a gas of a heat value approaching that obtained by carbonization with steaming of bituminous coal. The higher yields of methane obtained by the hydrogenation at the higher pressures contribute to this. Among the operational advantages of the process are its ability to cope with small sizes of fuel and the high gasification rates possible, per unit of reactor volume. A cross section of a modern Lurgi gasifier is shown in Figure 4, and operating results for a Rhenish brown coal and Morwell brown coal briquettes are given in Table 6. Information on some plants known to be making town gas by this process is given in Table 7.

Other large Lurgi plants exist in Eastern Europe but detailed information is lacking. A new type of Lurgi gasifier to produce more than 200 million cu ft of town gas from lignite of high ash content has been built at Schwarze-Pump, south of Berlin.

The raw gas, whether for town supply or for synthesis, is purified by removal of dust, tar and light oil, sulfur-containing compounds (H_2S and organic), and carbon dioxide.

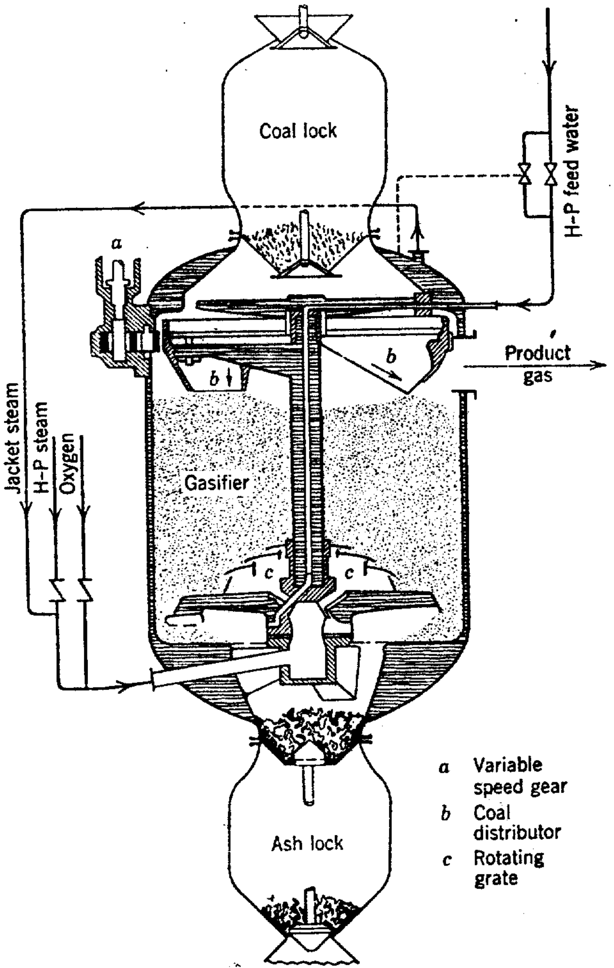

Fig. 4. Lurgi pressure gasifier.

The purifying units and synthesis vessels cost less than those used in operations at atmospheric pressure, because of their smaller size. The gas is available at pressure for long distance transmission (eg 90 miles from Morwell to the Melbourne area).

Fluidized processes have been developed, the first on a commercial scale being the Winkler, in which lignite and lignite char are gasified at atmospheric pressure with air, oxygen-enriched air, or oxygen and steam. Another type of process operating at atmospheric pressure is the Rummel single-shaft, slag-bath gasifier, in which the reactants (fuel of size less than 5 mm, and carrier gas, steam, and oxygen) are injected through nozzles into a slag bath, in which the molten ash acts as a heat storage and heat transfer medium; the iron oxide in it may also act as an oxygen transfer agent through alternate reduction with carbon and oxidation by oxygen. A full-scale plant making 560,000 scf of synthesis gas per hour, containing 84% of carbon monoxide and hydrogen, is reported. The double-shaft version of this process promises, if successful, to provide a continuous process for making synthesis gas, using air.

Underground gasification (46) of coals of lower rank is preferred because of their great permeability to gas, and has been carried out on coals of the Moscow region since

1947 (moisture, 30%; ash, 37%; heat value, 4900 Btu/lb). The coal lies in a bed up to 15 ft thick, but in a bed less than 3 ft thick the coal is not gasified. A shaftless method is used in which the permeability of the lignite is increased, eg by using high pressure air. By 1955, annual production had reached 15.6 billion cu ft of gas (measured at 60°F and 30 in. Hg pressure, saturated) with a heat value of 85 Btu/cu ft. Experimental work has also been carried out in Czechoslovakia.

Chemicals and Liquid Fuels. The most important product made by direct treatment of lignitic coals is montan wax, the derivatives of which have considerable overseas markets. Direct hydrogenation of brown coal to yield motor and aviation spirits has never been the main commercial way of making synthetic liquid fuel; the liquid products of carbonization, especially low temperature tar, have been, together with synthesis gas, the most important source of these, both also yielding a wide variety of other chemical products (see also Coal, Vol. 5, pp. 672–676).

Table 7. Some Gasification Plants for Manufacture of Town Gas (48)

Location	Date of construction	Number of gasifiers	Capacity	
			Gas, million ft³/day	Coal processed, tons/day
Hirschfelde, Central Germany	1936	2	1	30
Böhlen, Central Germany	1939	10	25	550
Most, Czechoslovakia	1942	originally 8[a]	25[a]	550
Morwell, Australia	1956	6	15	380

[a] Believed extended to capacity of 85 million ft³/day.

Montan Wax and Other Products Obtained by Solvent Extraction. Strictly, the term montan wax (Bergwachs) (51,52) refers only to the material obtained by solvent extraction of suitable German brown coals, montana wax being the more correct, generic description of similar waxes, regardless of geographical origin. However, those small quantities made outside Germany are commonly referred to as montan, prefixed by the name of the country of origin. See also Waxes.

As judged by German experience, to be of value as a source of such wax a brown coal must yield 10–15% of an extract containing 60–90% of the yellow or pale brown waxy substances. The rest of the crude extract consists of deep brown, resinous (montan resin), and asphaltic substances, the latter partly derived by dispersion of the coal substance; these dark colored substances are often referred to collectively as "resins" or "bituminous resins." The waxy brown coals selected in Central Germany and Treysa (Hessen), sometimes yielding up to 18% of raw wax, normally have the additional advantage of a lower moisture content than the usual commercial brown coals. Woody or resinous brown coals are of little value, even if the yield of extract is high. Thus, the Nigerian lignites, some of which give more than 20% of crude extract with non-dispersing solvents, are unsuitable because of their large content of dark, resinous material. The increased yield of extract obtainable from a waxy brown coal by extraction at pressures much higher than atmospheric is no advantage, as this is due largely to dark-colored dispersion products. Furthermore, the residual brown coal cannot then be briquetted, as it usually can be after extraction at atmospheric pressure.

The approximate composition of Central German, crude montan wax has been given as: esters of waxy monocarboxylic acids, 53%; free waxy monocarboxylic acids, 17%; free monohydric alcohols, 1–2%; ketones, 3–6%; resins, 20–23%; and asphaltic material, 3% (51). The range of carbon numbers for the alcohols and acids, whether free or combined, is C_{22} to about C_{34}, both odd and even numbers being present, but with the latter predominating; C_{26}, C_{28}, and C_{30} are often present in largest amount in many analyses reported. Ketones, lactones, estolides, polyterpenes, and hydrocarbons, mainly paraffinic, have also been found, usually falling within the same range of carbon numbers. In the dark, resinous portion various acids and hydroxyacids, sulphur-containing acids and hydroxyacid esters, terpenes, and sterols are reported (53,54).

Before the Second World War, the annual production of crude wax from the largest works, the Riebeck-Montan at Halle, now in the German Democratic Republic, was 17,000–18,000 tons, of which about 3000 tons was exported in refined form to the U.S. In 1944, German production had risen to 23,000–24,000 tons after the intervening decline, and montan wax had become, once again, the most important European source of hard waxes. The main output of raw wax is still in East Germany, whence it, together with the semi-refined materials, is sent to Gersthofen in West Germany, to be refined together with a smaller quantity of raw wax obtained from West German (Treysa) brown coal.

Production and Refining of Crude Montan Wax. The following is based on the usual procedure used in Germany. Powder-free granules, of 10–12% moisture content, are extracted with an azeotropic mixture of benzene with an alcohol (a common mixture

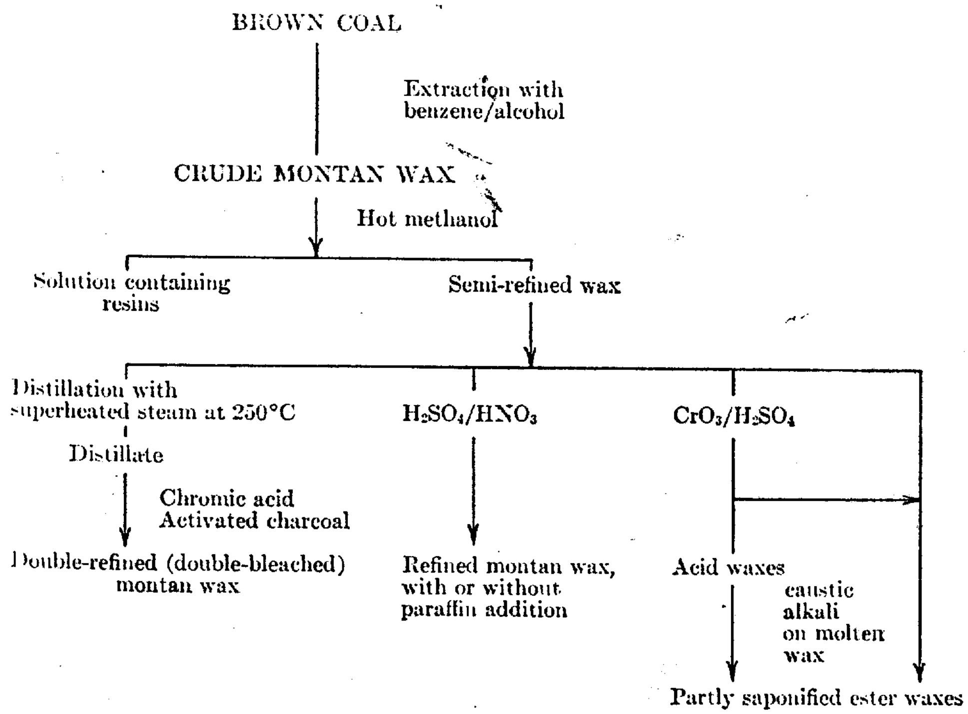

Fig. 5. Refining of montan wax.

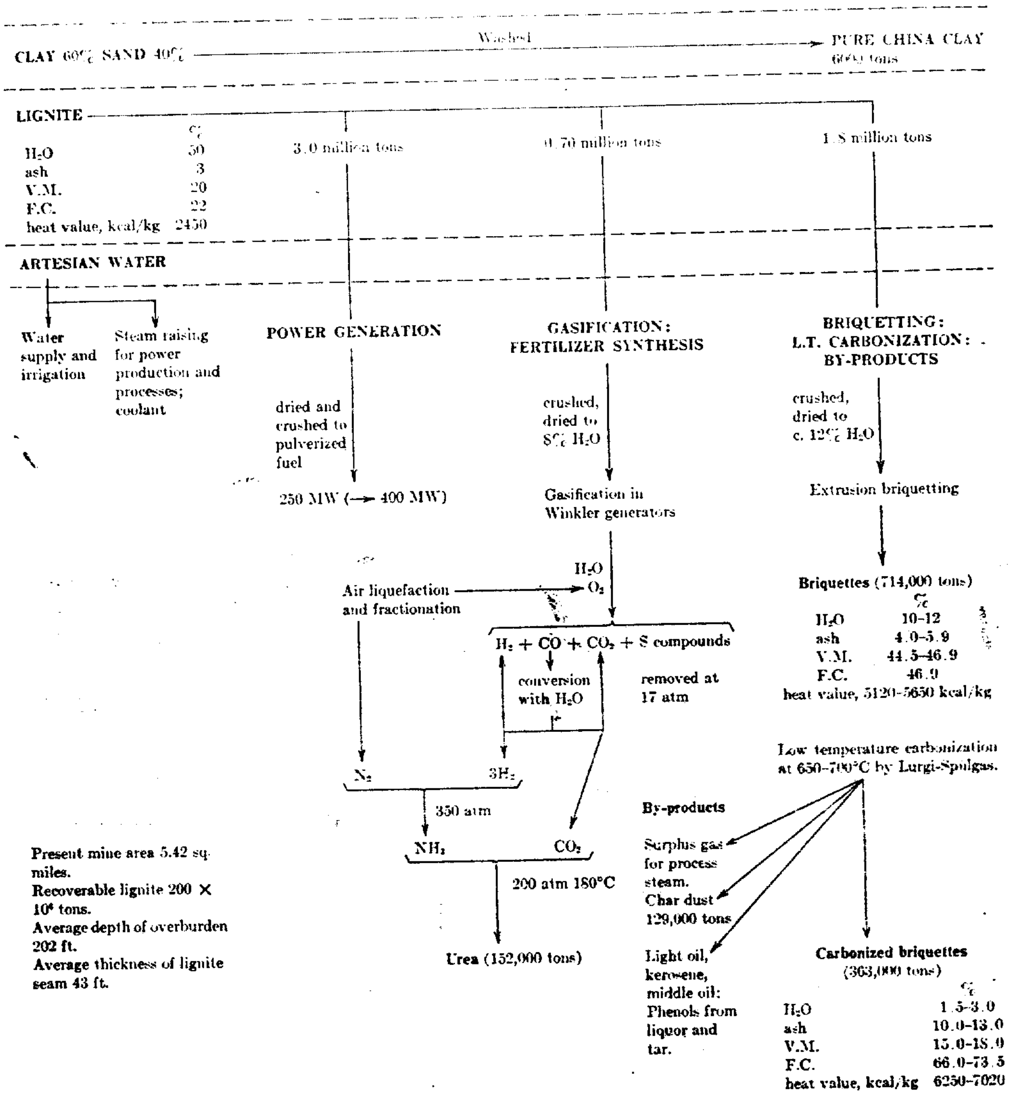

Fig. 6. Neyveli Lignite Integrated Project (showing annual production capacity, not yet reached in each case; V.M. is volatile matter; F.C. is free carbon).

is, by volume, 85% benzene and 15% of unrefined wood spirit, which contains methyl and isopropyl alcohols) at pressures slightly above atmospheric, giving extraction temperatures of 90 to 100°C. Benzene acts as the main solvent, the function of the alcohols being mainly to improve extraction by wetting surfaces and dissolving cell walls. The crude wax obtained by distilling off the solvent is too dark for most of it to be used without refining, which produces a range of lighter-colored waxes of different properties. The more important procedures used are outlined in Figure 5.

Of the chemical reagents used, chromic acid (eg sulfuric acid and potassium chromate) and sulfuric acid/nitric acid oxidize and remove the dark resinous and asphaltic substances; a series of bleached waxes from a deep to a very pale yellow, and of hardness increasing from that of beeswax, is obtained by control at this stage. A completely white wax can be obtained only by "double-refining," which results in decomposition of the esters and other components and further sacrifice of yield (eg to about 30% of the crude). Caustic alkalis on semirefined or acid-treated wax are used to effect partial or complete saponification and further ranges of waxes are obtained by esterifying the products with various alcohols. A synthetic series (I.G. waxes) is obtained from the acids and alcohols separated after saponification, and then bleached and reesterified with other suitable acids and alcohols. Other materials (eg paraffin wax) may also be blended with the refined waxes to modify their properties. In these ways differing hardnesses, compatibilities, solubilities, emulsifying, and gloss-giving properties are produced. Some properties of crude and refined Gersthofen waxes are given in Table 8.

Table 8. Properties of Gersthofen Waxes (52,55)

	Crude, hard, crystalline, dark	Acid wax S, pale yellow, very hard	Ester wax E, pale yellow, hard	Ester wax OP (partly saponified type), beige, hard
sp gr (20°C)	1.02–1.03			
mp, °C	82–90	80–83	78–82	100–104
solidification point, °C	70–84	76–79	73–75	78–83
acid value	29–36	140–155	15–20	10–15
saponification value	68–81	160–180	145–165	105–120
ester value	39–45	20–25	125–145	95–105
unsaponifiable, %	30–36			

Other Montan Waxes. Czechoslovakian crude montan wax contains about twice the amount of the dark, nonwaxy substances as does the Riebeck crude. The following properties are for a crude wax extracted with benzene from a brown coal from the Josef Jan mine at Pila, near Karlovy Vary (formerly Karlsbad): resin, 45%; asphaltic material, 5%; acid value, 36; saponification value, 89; ester value, 53; mp, 73–75°C. A small quantity was imported by the U.S. after 1945 when the German wax was not available.

The most suitable lignites for wax production in the U.S. are those from California, giving a yield with benzene of about 7% (air-dried coal basis), and from Arkansas, of similar yield. Most lignites from other states yield less than 2%. Higher yields are obtainable using benzene–alcohol, but mainly by extracting more resins and asphalts. A plant at Buena Vista, extracting 25 tons per day of lignite from Amador county with petroleum naphtha, produced "American montan wax" containing 48–68% of resins and 3–7% of asphalts, and having acid value, 36–46, saponification value, 81–112, and ester value, 41–68.

Extraction of Lignitic Coal for Other Products (56). Electrode carbon was made commercially in Germany during World War II from an extract obtained above 350°C in a plant processing 5.3 tons of lignite per hour to yield 3.7 tons of an almost ash-free product, which was carbonized in conventional coke ovens.

Wood-staining, alkali-soluble materials have been made in North Dakota from an extract obtained from leonardite, a naturally oxidized lignite.

Liquid By-products from Low Temperature Carbonization (56–58). The composition of low temperature tars can vary widely, depending on the conditions of carbonization and on the type of coal (59); subsequent processing must take this into account. Thus, the total amount of phenols is largest in tar from humic coals (up to about 50% by wt), and of hydrocarbons, including aliphatic waxes, greater and of phenols less, in those from coals high in hydrogen (eg spore-rich coals).

The tar and its *distillation* cuts are used as fuel oils and as sources of phenols, and may make a useful economic addition to the production of carbonized briquettes. A promising outlet for the pitch, additional to its use as a binder in briquetting and as a source of electrode carbons, may be in blends with petroleum bitumen for use on roads. The liquor is also extracted to recover the lower, monohydric and a range of dihydric phenols.

Table 9. Some Plants Now Hydrogenating, Cracking, and Refining Low Temperature (l.t.) Tar (57,58)

Plant, location	Fuels treated	Process	Products
Most, Czechoslovakia	l.t. tar from lignitic brown coal	hydrogenation at 300 atm; distillation; extraction	gasoline, motor oils, phenols
Böhlen, East Germany	l.t. tar from brown coal crude fuels from Rositz	hydrogenation at 300 atm	diesel and other oils
Rositz, East Germany	l.t. tar from lignite	cracking; distillation	gasoline and diesel oil
Leuna, East Germany	brown coal and l.t. tar	hydrogenation at 250 atm	gasoline, etc
Zeitz, East Germany	l.t. tar from brown coal	hydrogenation at 300 atm	diesel and lubricating oils, paraffin wax

In *hydrogenation* of the tar to yield liquid fuels, a high hydrogen (also a desirable property of the coal, if this is to be processed) and a low asphaltene (benzene-soluble, hexane-insoluble) content are an advantage. Central German brown coal and its tar of high hydrogen, as used at the Leuna works at Merseburg, require a lower pressure and hydrogen consumption in the liquid phase hydrogenation than do the Cologne coals (formerly hydrogenated at Wesseling at 700 atm) and the Bohemian coals of Czechoslovakia. See also Hydroprocesses.

Of the peak production of about 4.5 million metric tons of synthetic liquid fuels reached in Germany during the war, about 90% came from brown coal, mostly by hydrogenation of the low temperature tar, to yield mainly motor and aviation gasoline, but also some diesel oil. The Leuna plant, the largest, gave an 80% yield of gasoline of octane number 60–70. Originally making synthesis gas for the production of ammonia and methanol, the plant was conveniently adaptable to the production of hydrogen. Integration of processes (see below), in general, has become a feature in the use of brown coal, a further example being the use of the char from carbonization for power production (eg at Böhlen and Magdeburg).

Plants in East Germany and Czechoslovakia now produce increasing amounts of liquid fuels by hydrogenation of brown coal and brown coal tar: in 1956, the production of gasoline in East Germany was about 883,000 metric tons, and of diesel fuel about 830,000 metric tons. Some of the dismantled German plants were used in Siberia in the construction of one with a capacity of 1 million metric tons of aviation gasoline. Because of the interest in the U.S. in assuring a continued, indigenous source of supply of liquid fuels, experimental work on the liquefaction of bituminous and lignitic coal has been proceeding since 1936, both in the laboratory and in demonstration plant. No large-scale production is undertaken at present.

Information on some plants processing the tar in 1958 (two also treat lignitic coal, in addition) are given in Table 9. Other large plants are planned, eg in the Ukraine, for the manufacture of gasoline, fuel oils, phenols, and paraffins from 2 million gallons per year of low temperature tar from brown coal (57).

Thermal and catalytic cracking of the tar becomes more attractive, economically, when undertaken together with that of heavy petroleum oils, as at Rositz in East Germany, where a new cracking unit processes annually 23 million gallons of tar and 20 million gallons of press oils to yield 25 million gallons of gasoline and diesel fuel, together with gas and coke. In the Ukrainian S.S.R. fractions from low temperature tar from Aleksandrovsk lignite have been catalytically cracked, eg a dephenolated fraction of boiling range 200–350°C gave a good motor fuel using aluminum silicate as catalyst in a moving bed.

Ethylene, valuable as a chemical intermediate, is a constituent of the gas formed by thermal cracking of the tar; work in a number of countries has been aimed at finding the conditions for its optimum yield. In the U.S.A., the tar made by carbonization of Texas Sandow lignite at temperatures not above 550°C gave on cracking at 800°C and an "average" retention time of 1.5 sec, per ton of dried lignite: 40 lb of ethylene, 70 lb of methane, 6 lb of benzene, 5 lb of toluene, and 3 lb of naphthalene.

Selective solvent extraction was used successfully during the war in a refinery at Espenhain, now in East Germany, to process 88 million gallons annually of brown coal tar. Gasoline, diesel oil, and soft and hard waxes were obtained by a series of continuous extractions with liquid sulfur dioxide, naphtha, and ethylene dichloride. A full-scale plant planned for Rockdale, Texas, is to use solvent extraction as a preliminary refining stage. A pilot plant of capacity 350,000 gallons of tar per year has been in operation, using hexane and aqueous methanol in the continuous countercurrent extraction of a mobile, crude tar oil (heavy-tar condensate being recycled to the carbonizer), in conjunction with a vacuum still and a topping still. The products made are neutral oils (hexane-soluble), distilling to 200°C, and between 200°C and pitch; hexane-soluble pitch; nearly pure lower phenols (methane-soluble), distilling to 235°C; and higher-boiling methanol solubles.

Products from Synthesis Gases. The composition of the gas, consisting mainly of carbon monoxide and hydrogen, made by oxygen-steam gasification, can be altered to make synthesis gases suited to a number of different purposes after purification (see Carbon monoxide–hydrogen reactions), including the production of liquid fuels and chemicals by the Fischer-Tropsch process and its modifications; the synthesis of methanol and higher alcohols; the production of hydrogen for ammonia synthesis or for hydrogenation of brown coal or its low temperature tar, and of carbon dioxide for urea production or other purposes. This versatility of use of the original gas is turned to account in integrated schemes (see following page).

Other Nonfuel Uses (56,60). Lignitic coals may also be processed to yield lightweight building slabs and other artifacts of a similar nature, in which the main developments appear to be in East Germany; fertilizers and/or soil conditioners prepared, for example, by oxidation or amination; ion-exchange resins made, for example, by sulfonation, after heating (cation-exchange product), by nitration and reduction (cation-exchange), and by treatment with ethylene dichloride and ammonia (anion-exchange); and a range of special carbons, such as activated carbons made from the low temperature char treated with superheated steam, suitable for clarifying solutions and similar uses.

Integrated Projects (41,44,61)

The improvement in the economics of exploitation of lignitic coal brought about by the co-existence in the mining area of various processes for using it, linked together by the products of one becoming the raw materials of another, could be seen first in Germany, later in other countries. With the establishment of such a pattern, necessarily flexible and adaptable to national or local needs and markets, the exploitation today of a favorable new resource starts with an advantage formerly lacking. A recent example, based on modern technologies of winning and use, is well advanced at Neyveli in India, and is one of the most ambitious industrial developments in the Far East (see Fig. 6). Not all sections of it are in full production yet (1966), and plans for the further use of the by-products, especially of the char dust and tar, are still being considered.

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