DISCUSSION ON "POWER PLANT ECONOMICS," AT PITTSBURG,
PA., FEBRUARY 13, 1906.

P. M. Lincoln: In regard to electricity-driven versus steam-driven auxiliaries, it seems to me that the two considerations which should govern are: first, economy; secondly, reliability.

I agree with Mr. Stott that the economy of the steam-driven auxiliaries is greater than that of the electricity-driven auxiliaries. The only objection that can be raised is the extensive steam piping required by the steam-driven auxiliaries; this piping will have considerable radiation which cannot be avoided, and if the steam piping to the auxiliaries becomes too extensive, the loss from this cause may be greater than the amount of inherent economy. Any operating engineer will take the type of auxiliary which is most reliable. As between reliability and economy the operator will invariably choose reliability.

As to direct-versus independently-driven exciters, I will mention only the most salient points. The considerations which should govern are those of economy and reliability. As far as economy goes, there are three ways of driving the exciters; one is to connect it directly to the generator shaft, a second is to drive it by a separate prime mover; and the third is to drive it by a motor which is driven by the main prime mover. These methods differ in economy by as much as the main prime mover differs from the auxiliary prime mover.

As far as reliability goes, one point is that of regulation; on that point the motor-driven and the direct-connected exciters are at a disadvantage, because any variation in speed of the main plant is reproduced in the exciter, which alters the voltage of the exciter in a ratio faster than the speed alters in the main generator. This causes a variation in the voltage of the main plant considerably greater than the original speed variation.

W. E. Moore: Power station design does not depend on coal economy only or even on operating cost, but on the very important factor of total cost per unit output as determined largely by the fixed costs on investment. These are a constant expense regardless of the plant load-factor, resulting in a variable cost per unit output decreasing with an increasing load-factor and becoming a minimum when the load-factor reaches 100%, or when the plant carries a full load for every hour in the year. It is therefore obvious that the character of the plant must be governed largely by the load-factor.

According to Mr. Stott, there are delivered to bus-bars 1 452 out of 14 150 B.t.u., or 10.3% thermal efficiency. It is interesting to note that the regenerative recovery in the entire plant is 3.1% credited to the feed-water heater, and 6.8% to the economizer. Ordinarily there should be some heat recovered through the feed-water taken from the hot-well, but in this

case none seems to be considered, probably because the injection-water is brine and city water is used exclusively for feed.

I would call attention to the demand for larger boiler units caused by the introduction of the steam-turbine, whose relatively small floor space makes a compact boiler of great desirability. It is not to be forgotten that the smaller the number of boiler units, the less attention they require; and the cheaper their cost of installation, piping, and maintenance becomes. Mr. Stott calls notice to the equal efficiency of all types of boilers when worked under like conditions. In getting at the results of bad firing it is only necessary to analyze the stack gases with one element in view, CO_2 , and the nearer the approach to 14% the better the firing becomes. Take a boiler with a given amount of heating surface, and pass the gases over with a given velocity, the same efficiency is obtained no matter what the type of boiler.

Boilers are especially desirable which are simple to repair and clean and which will give dry steam. Wet steam is a common evil of the power station. For each 1% moisture in steam the efficiency of turbines is reduced about 2% and the capacity more than correspondingly reduced, while in the case of engines the economy is not so much reduced but the lubrication of internal parts is much more costly, to say nothing of the greatly increased danger from accidents.

The almost universal adoption of water-tube boilers brings with it the corresponding disadvantage of more moisture in steam, and if for no other cause than this, the elimination of moisture from steam would demand the installing of superheaters in the modern steam power plant, especially for turbine work.

There has recently been brought out in the United States a new form of steam boiler of the water-tube type especially adapted for units as large as 1 000 h.p. This new boiler seems to eliminate troubles from differential expansion of its various members, and is peculiar in that it is practically self-cleaning so far as internal scale is concerned. Being adapted for firing from both ends, there are no size limits determined by grate area.

Mr. Stott shows that 3.1% is recovered by the feed-water heater. He therefore concludes that the auxiliaries should all be steam driven so as to obtain sufficient exhaust to heat the feed-water. This brings up the question of steam- versus electricity-driven auxiliaries. I do not believe that either system will prevail to the exclusion of the other. The ideal arrangement seems to be direct-acting steam-boiler feed-pumps and possibly centralized vacuum-pumps with all of the smaller and scattered auxiliaries such as service-pumps, oil-pumps, hot-well pumps, circulating-pumps, coal- and ash-conveying machinery, etc., driven by electric motors. The power supply for the motors to be furnished by separate steam-driven ex-

citer sets of sufficient capacity to carry the excitation plus the motor load, and exhausting into feed-water heater along with the boiler feed-pumps and centralized steam vacuum-pumps. For reliability and low first cost, nothing is better for boiler feed-pumps than a direct-acting steam-pump, and the same statement applies to centralized vacuum-pumps. These, with exciter sets, can be located near the boilers and feed-water heater so that there will be a minimum of steam and exhaust pipes to and from them.

It is hard to explain the expense of a piping system for a small steam plant; a steam pipe when it is once installed has to be kept hot all the time, has to be kept drained, and every steam-supply pipe must have an exhaust pipe, so that the trouble is far greater than the expense.

The motor-drive for the other auxiliaries permits of direct connection to centrifugal pumps, making very compact, cheap, efficient, simple, and easily maintained sets, and entirely eliminates the maze of hot steam and exhaust pipes which permeate the ordinary power-plant basements and which are such a continuous source of trouble and expense to keep covered, drained, joints tightened, etc. Motor-driven sets also do away with the necessity for cylinder lubrication, oil-cups, and nearly eliminate the small stuffing-box and packing expense and resulting slop from steam-pumps. Since the exciter sets must furnish the power, there is no diminution in the supply of exhaust for feed-water, and since the power is direct current there is every opportunity for efficient speed regulation to meet all variable load demands. Therefore there seem to be very valid reasons why steam-driven auxiliaries should not be used exclusively, but rather to use motor-driven auxiliaries in the larger number of cases.

My opinion seems to be directly contrary to the opinion of Mr. Stott, but I think his opinion is probably based on some accidents that occurred at the Manhattan plant. I understand that when the plant was first started they put in motor-driven boiler feed-pumps, and on one occasion a short circuit resulted in the closing down of the plant; before the engines could be started up the boilers had evaporated all the water out of the valves.

With reference to the use of superheated steam, it should be said that superheat causes no additional lubrication expense on the turbine, such as is necessary with high superheat in engines.

The author calls attention to the turbine's much flatter efficiency curve, which means better all-day efficiency, and to the fact that the turbine set's first cost is 33% less than that of the reciprocating-engine set. These two features, as will be seen later, have a very marked bearing on the total cost of the unit output, especially when the plant works on a low load-factor. It should be noted in this connection that the ordinary power

plant works on a load-factor of about 50% or less, usually less, frequently as low as 25%.

It is often charged against the turbine that it must have an expensive surface condenser with auxiliaries using larger amounts of power to maintain its necessarily better vacuum for maximum efficiency. Practice has, however, in some of the more recent constructions, shown both ideas fallacious, as high vacua are easily maintained in turbine plants with ejector or barometric condensers, and there is far less air leakage into the turbine exhaust. Which type of condenser to install is determined in nearly every case by the suitability of the available water for boiler-feed. The surface condenser can be used with advantage on turbines more often than on reciprocating engines, as the turbine introduces no oil into the exhaust, and the condensation is therefore most suitable for feed water.

Mr. Stott estimates that the combined engine and low-pressure turbine plant would use 23% less steam per unit output. Such an increase of economy in practice appears to be improbable. It would seem that a plant containing such combination sets would be much more complicated, more expensive in first cost and maintenance, and that a lower total cost per unit output would probably result by the installation of a straight turbine plant.

The accompanying chart plotted on the same scale on a basis of total plant efficiency in B.t.u. per kilowatt-hour for steam-engine, steam-turbine, and gas-engine sets shows clearly the relative economical capacity range of the three types of prime movers cited by Mr. Stott. While the gas-engine curve is not so flat, it should be remembered that the economical capacity range of the producer and auxiliaries for a gas-engine power plant is much broader than for steam boilers with the usual steam power plant auxiliaries, which tends to flatten out the curve for economy of producer-gas engine plant at various capacities.

The economy of the gas-engine plant is so much better than that of the steam plant that a far greater variation from maximum economy with change of load can well be allowed and still keep the plant duty far higher than any type of steam plant.

There seems to be an error in Mr. Stott's assumption that the entire 30% waste heat in gas-engine exhaust, minus 5% loss to stack, can be converted into steam. The engine exhaust-gases being at a comparatively low temperature (as compared with ordinary boiler furnace temperature) cannot impart even the ordinary percentage of heat to the boiler; therefore more than the usual loss of heat to stack must be allowed. This would probably reduce the proportion of heat saved from exhaust gases below 15%. Neither is it proper to assume that the 7.1% of jacket-water heat could be used in the turbine

end of the combination plant at a thermal efficiency of 35.1%, for almost the exact temperature of feed-water is available in the condensed steam from turbine so that the warm jacket-water would scarcely be used for the boiler-feed.

The recoverable heat could not therefore amount to 37.1% nor could the efficiency of its conversion run so high as 35.1%, nor could the thermal efficiency of the turbine end of the combination plant approach 25%, as stated by Mr. Stott; especially since the turbine end of the plant would be carrying a very variable load which would decrease its steam economy correspondingly.

FIG. 1.

There seems good prospects of our having at an early date a commercial gas-engine that will have overload characteristics approaching those of the steam-engine and will therefore show much better average efficiency on the customary load variation.

The Otto cycle gas-engine exhausts its gases at a terminal pressure, say 40 lb., when carrying from 50 to 100% load. The ideal gas engine cycle would seem to embody a design in which the terminal pressure would vary with the load, as in a steam engine, and the combustible mixture would be varied in volume according to the load; at light loads a stratified cushion of air being first admitted next to the piston to make up a constant cylinder volume and therefore a constant compression irre-

spective of load. The compression space or clearance to be much smaller than usual, so that the usual high compression would be maintained with the intake gases following the piston, say half the stroke. The full-load engine capacity would then be so proportioned as to expand the burnt gases down to say 5 lb. before exhausting, while at the overloads the governor would admit sufficient explosive mixture to maintain the terminal pressure much later so as to exhaust at, say, 40 to 50 lb. per square inch. Thus the terminal pressure would vary with the load much as is the case with a steam-engine. This in contradistinction to the variable compression pressure with load changes in the ordinary Otto cycle engine. In a gas-engine of the type suggested the temperature of the exhaust at average load would be lower, and less heat would therefore be available for steam raising, possibly not more than would be necessary for steam supply to producers and auxiliaries of the gas generator room, so there would be no reason for mixing gas-engines and steam-turbines in one station. The plant-duty of a station of this type should be far greater than that of a mixed plant, not to mention the simplification of operation and maintenance.

I think it is a very important matter not to mix the equipment in any power station. As Mr. Stott has pointed out, it is difficult to maintain a state in the boiler room where the stack losses are kept as low as 22%; as a matter of fact it runs over 30% in this district, instead of down as low as 22%. Mixing equipment means simply reducing the chances of keeping it down to that point, and furthermore, there is every reason why a plant should be kept uniform.

In conclusion, it is evident that we cannot longer, under ordinary conditions, afford to install steam-engine electric power plants; for turbine plants are more efficient and cheaper in both investment and operating costs, though producer-gas engine plants are far cheaper than either in operation but not in first cost. There is, however, good prospect of lower first cost and better overload characteristics in the near future.

Low investment cost is an essential for plants operating on a low load-factor, but it does not seem advisable to mix gas-engine and turbines in the same plant, but rather to encourage manufacturers to develop a gas-engine operating on a cycle that will permit of developing at least 50% overload, the engine being rated at its most economical load.

Rudolph Wintzer: A large number of electrical central stations in Europe are owned by municipalities, as are many of the city gas-works. In early years the gas-works frequently furnished gaseous fuel to small gas-engine driven plants, the charge for gas having run as high as 85 cents per 1 000 cu. ft. But during the last five years several large central stations have been established, using producer-gas engines. Scheveningen, a bathing resort in Holland, will ultimately be equipped with

six 350 h.p. Nurnburg gas-engines driven by anthracite producers of the suction type.

The largest power plant using producer-gas is located in Madrid, Spain, furnishing light and power to the entire community. It is equipped with six 1 250 kw. (2 000 h.p.) Nurnburg gas-engine alternators operating in parallel, supplied by a Mond producer-gas system using low-grade slack coal. Recovery of by-product, including tar and ammonia, is practised at this 12 000 h.p. plant.

The gas-engine is used to a very great extent with suction producers, in water-pumping stations for small cities and counties, especially in western Germany. "Braunkohle" (corresponding to our peat) and lignite in the form of briquettes are largely used in these small plants, and with excellent results.

The greatest development of the gas-engine on the continent has taken place in connection with blast-furnaces and the coaling industry where the waste gases from furnaces and coke-ovens are largely used for power. A large enterprise of this character is now being carried out near Essen in Rheinland. Essen is the Pittsburg of Germany. Within a radius of 40 miles occur most of the largest coal mines and iron and steel works of that country. Most of the existing electrical central stations in the district have been acquired by the steel syndicate, which is erecting large central stations driven by blast-furnace and coke-oven gas to furnish this whole industrial section with electricity for lighting, power, and traction. Some customers in the territory have requisitioned as high as several thousand horse power. These central stations will be erected at the various steel mills and mines, and will all work in parallel.

Typical gas-power stations using blast-furnace gas, are now working at the following plants: John Cockerill Co., Seriang, Belgium, 3 000 kw. United Iron and Steel Works at Hoerder, Westphalia, 3 500 kw. Schalker Iron and Steel Works, Gelsenkirchen, 4 000 kw. Rombacher Iron Works, 3 000 kw. A typical plant driven by coke-oven gas is located at Eschweiler mines in Alsdorf, where a central station of 2 800 kw. is in service, using Otto coke-ovens with recovery of by-products. This plant furnishes current for driving 3 000 h.p. main hoisting engines, pumps, fans, compressors, coal-washing plants, etc., and for electric traction service in the neighborhood. No steam is used at these works, and a producer-plant is available as a reserve in case of necessary shutting down of the coke-ovens. In a short time this plant will work in parallel along high-tension transmission with a hydraulic plant 40 or 50 miles distant, installed by the Ruhr River Hydraulic Development Company.

While formerly the practice was to drive large rolling-mills directly with large gas-engines, the present practice is rapidly tending to motor-driven rolls, supplied with power from a

central station. At Differdingen, in the steel and coal works of the Germany & Luxemburgh Steel & Mining Company, it has been found by careful experiments that for every 1 000 h.p. maximum required at the main rolling-mill, with engine-driven rolls, only 600 h.p. capacity is required at a central station. A number of units are provided, giving flexibility of service, and 40% is made on the first cost of the gas-engines installed.

TYPES OF GAS-ENGINES IN USE.

For large work three types are represented; namely:

1. The four-cycle, double-acting tandem engines of Nuremburg, Deutz, and Cockerill.

2. The two-cycle, double-acting Koerting type.

3. The two-cycle, double-acting opposed, Oechelhauser engine.

Of these three types, the four-cycle type has become standardized for general power-station work, while the two-cycle types have found their most extensive applications to blast-furnace work. Four-cycle tandem engines are operating up to 2 000 h.p.; that is, 1 000 h.p. per cylinder. Two-cycle engines have also been built from 750 to 1 000 h.p. per cylinder.

Comparing the constructions of the three types for 1 000-kw. units, it is found that the four-cycle engine has one connecting-rod and two power cylinders; the Koerting engine has two connecting-rods, two power cylinders, four compressor cylinders of nearly the same diameter, and two side connecting-rods; the Oechelhauser two-cycle engine has a six-throw crank-shaft, four bearings, six connecting-rods, four single-acting pistons, and two compressor cylinders. In the Koerting engine the exhaust ports in the cylinder wall are uncovered by the piston; in the Oechelhauser engine the pistons uncover both exhaust- and air-ports so that no valves are used. This elimination of valves in the Oechelhauser and Koerting types looks at first sight like a simplification, but in reality it involves serious complications in the number and disposition of the principle working parts.

A comparatively new type of engine is being built by a British company. It is a two-cylinder double-acting vertical engine arranged like a cross-compound steam-engine, with generator between cylinders. This is built up to 2 000 h.p. capacity.

European practice has definitely tended toward single-crank units, and the horizontal tandem, double-acting type has become the standard in this respect. By duplicating the tandem arrangement, making a two-crank engine, the economy is not improved. The speed variation of the single-crank type is found to be close enough for alternating-current work. The single-crank units give far greater flexibility in central-station operation; they can be loaded more economically, and there is more opportunity for inspection and repairs. The sizes most frequently used are 1 000, 1 500, and 2 000 h.p.

ELECTRICAL OPERATION.

In regard to the electrical specifications for gas-engine work, Continental firms usually specify a cyclical fly-wheel deviation of $\frac{1}{10}$ to $\frac{1}{80}$ the pole-distance in engines with one impulse per stroke. This condition can easily be met, and takes into consideration occasional irregular working. In a 500 h.p. engine of the vertical, double-acting type, driving spinning machinery at the Hollins Mills, Marple, a cyclical speed variation of 0.2 to 0.4 per cent. was obtained, which was increased to only 1 per cent. when one cylinder was made to misfire regularly. The cyclic speed variation was taken with a very sensitive and well-made recording tachometer. It is a matter of interest that the steam-engine which formerly did the work of this gas-engine showed 8 per cent. cyclic variation, and it is not surprising therefore that the mill tenders had less trouble from broken threads after the gas-engine was put in service.

Troubles from parallel operation are practically unknown in engines above 1 000 h.p. giving two impulses per revolution and 25 cycles.

A type of alternator in general favor, is a combined fly-wheel and generator field in one structure, with the fly-wheel rim outside the rotating field. With the usual speed of periphery of field, this permits a high fly-wheel speed with a short distance between the bearings and good accessibility.

FUELS.

In Germany the cost of hard coal is \$5.50 to \$6.50 per metric ton, (2 220 pounds), according to facilities of transportation. Good bituminous coal costs \$3.50 to \$5.50 per ton, and bituminous slack costs from \$1.50 to \$2.50 per ton delivered at the plant. On a small scale anthracite is largely used, but in very large plants, such as that of Madrid, low-grade bituminous coal is mostly used. The Mond producer system has greatly enlarged the possibilities of low-grade bituminous fuels.

Clean gas is the first consideration for successful running in all power plants using producer-, blast-furnace, or coke-oven gas. Tar in its several forms, must be removed from the gas, also sulphur and dust, to a point where not more than 0.03 grams per cubic meter of foreign matter is present.

ECONOMY.

With blast-furnace gas the 1 000 h.p. engines at Rombach and Ruhrort have shown a heat consumption as low as 9 300 B.t.u.'s per brake horse power hour at full load, and 12 000 at half load, using the "lower" or "effective" heat value of the gas. It is European practice, however, to rate engines somewhat higher than they are rated in America; the above engines having only 5 per cent. normal overload capacity. High-grade Mond gas-plants in England have shown economies of 1.1 to 1.2 pounds of slack coal per brake horse power hour, including

all standby losses for the balance of a 10-hour working day. In this particular the producer has a very large advantage over steam, and especially superheated steam plants, as the standby losses are almost negligible. At a large European iron and steel works at Essen extensive tests were made to ascertain the standby losses on the steam-piping system which was in fair condition and completely lagged. With no steam used for driving engines it was found necessary, in order to maintain normal pressure, to keep twenty 180-h.p. boilers under full fire.

In well-constructed horizontal gas-engine plants the oil consumption is no higher than in a corresponding steam-engine plant. For instance, a 1 000-h.p. tandem gas-engine requires on an average of 35 to 40 lb. of oil (4.75 to 5.25 U. S. gal.) per 24 hours, 60 per cent. being cylinder oil at 35 cents per gallon, 40 per cent. being engine oil at 20 cents per gallon.

COST OF EUROPEAN PLANT.

For a 2 000-h.p. high-grade gas-engine plant the distribution of cost should be about as follows:

	Dollars per brake horse power
Gas-Engines.....	\$30.00
Foundations.....	2.20
Auxiliaries.....	0.80
Building.....	4.00
Piping and engine outfit.....	3.00
Electrical outfit.....	14.00
Gas-producer plant.....	14.00
Producer house.....	1.50
Total.....	<hr/> \$69.50

or very nearly \$100.00 per kilowatt.

About a year ago high-grade gas-engines sold for about \$25.00 per brake horse power. The present prices are somewhat higher. For high-grade steam-engines using superheated steam the cost is about the same, \$25.00 per brake horse power.

J. R. Bibbins: As the saturation and regulation curves of a dynamo are characteristic of its operation, so do certain curves as definitely characterize the working of a prime mover. Speaking particularly of heat engines, there are three curves which materially assist in determining the suitability of a machine for a particular service; these curves represent: 1, the hourly heat (steam or gas) consumption at various loads with its derived curve of the "water-rate" variety familiar to steam-engine practice; 2, kinetic (absolute thermodynamic) efficiency, with its derived curve of mechanical efficiency; 3, speed regulation, involving, in the case of the reciprocating-engine, cyclical as well as absolute speed-variation. The first determines the rate of input of working medium, steam, gas, air, etc.; the second,

the efficiency of conversion into useful work in the shaft; and the third, the suitability of the machine for operating constant-potential electrical apparatus. In this discussion we are chiefly concerned with the first, and from a purely practical standpoint.

Steam-Engines: In high-speed steam-engines such as the Willans, governing by throttling steam-pressure, the total steam consumption per hour is practically proportional to the load. Plotted in the form of a curve, known as the "Willans"* or water line, it gives practically a straight diagonal line AB , Fig. 1.

The so-called water-rate curve derived from this, $A'B'$, and expressing steam used per horse power per hour is, then, of course, a hyperbola and shows a constantly decreasing water-rate with increasing load. Clearly, then, this type of engine

is able to give its best economy at maximum output. In modern power work, however, this condition is demanded only occasionally to tide over maxima in a fluctuating load; on the other hand, from an economical standpoint, the engine is obliged to work at considerable disadvantage during normal loading.

Now in a steam-engine governed by a positive cut-off, the water-line is decidedly curved, CD , due to a variety of causes, giving a water-rate curve $C'D'$ of more pronounced curvature. Two important results have, however, been achieved; first, the engine gives its best economy between three-fourths and full load where it is normally working a greater part of the time; and secondly, by lengthening the cut-off a very large overload capacity is available. On the other hand, the cut-off method

* "Willans Law" first expounded by P. W. Willans. See *Transactions British Institution Civil Engineers*, 1890.

compares less favorably at light loads and heavy overloads, the water-rate increasing rapidly in either direction.

Steam Turbines: Manifestly a combination of the two systems should yield the characteristics most to be desired; these characteristics are: *a*, maximum economy at normal loading; *b*, large overload capacity with fair economy; *c*, good economy at light load; *g*. These have fortunately been realized to a large extent in the steam-turbine.

A steam-turbine of the well-known pressure type gives a practically straight water-line, *EF*, Fig. 1, up to about full load with a somewhat higher inherent efficiency than the steam-engine, in most cases exceeding the cut-off engine even at the best load. By the use of a "secondary" admission of steam to lower stages in the turbine, its power may be increased to

as high as double the normal rating and with but small loss in economy. Supposing the secondary or overload valve comes into action about full load, *F*, the water-line abruptly changes direction, *FG*, resulting in a compound water-rate curve, *E'F'G'*. At the point of opening, *F'*, the steam consumption begins to increase, but as the overload increases the turbine tends to regain its original efficiency. Furthermore, the prime mover and generator are better matched in regard to efficiency than in the cut-off engine, both doing their best work at normal rating.

These characteristics are well illustrated in the accompanying curves, Fig. 2, showing tests upon a 1000-h.p. Westinghouse-Parsons turbine. From one-half load to 100% overload the water-rate varies but little over 10%. The same characteristics appear in the non-condensing tests, except that the turbine

is unable to sustain as heavy a load, being guaranteed only for full load non-condensing and 50% overload condensing.

Low-Pressure Turbines: If we represent in curve form, Fig. 3, the work available in steam expanding from 150 lb. initial pressure to atmosphere, the fact is apparent that there has been used only about one-half of the total work available at a vacuum of 28 in. This at once explains the possibility of the

low-pressure steam-turbine working on vacuum alone, and it is interesting to note that the water-rate of such a turbine is about double that of a similarly constructed turbine working through the entire range of pressure. Thus a 750-kw. Westinghouse-Parsons turbine below atmosphere has given a water-rate of 25 lb. per brake horse power with high vacuum, corresponding to about 13.5 lb. per brake horse power-hour for the total pressure-range. Moreover the total water-line is practi-

cally straight as in the normal turbine, showing that steam is used with uniform efficiency at all loads. Professor Rateau of Paris has done much along these lines of low-pressure turbine work. The low-pressure turbine is of interest in providing a means of nearly doubling the output of a non-condensing steam plant with but little increase in operating expense. Cooling-towers are, of course, of assistance where water is costly.

High-pressure turbines, working down to atmospheric pressures, are, on the other hand, frequently used in district heating systems, half of the energy in the steam being converted into electrical energy, and the remainder into heat. Usually, a condensing turbine is employed running non-condensing during cold, and condensing during warm weather.

Internal-Combustion Engine: Curiously enough, the gas-engine presents the same characteristics as the throttling steam-engine; namely, a nearly straight Willans or gas-line, $A B$, Fig. 1, and a continually decreasing rate curve of gas consumption, $A' B'$. It possesses, however, nearly double the efficiency of heat conversion or kinetic efficiency* of the steam-engine. An engine of good design is capable of delivering from 25% to 30% of the heat of the gas in the form of work at the shaft, while the corresponding kinetic efficiency of a large steam-unit usually runs from 12% to 15% and of a steam-turbine 15% to 22% of the heat input. As a machine, its mechanical efficiency is nearly the same as a high-grade reciprocating steam-engine.

Could we rate the gas-engine at its maximum capacity we should, of course, obtain maximum efficiency at normal rating, and in European practice this is frequently done; but in American practice some overload capacity is demanded, hence we must deliberately rate the engine below its maximum by the per cent. of overload desired. This is an unfortunate characteristic of the gas-engine; that its maximum power is reached when the cylinder is full of mixture, and it seriously militates against gas power in the minds of those who install a smaller steam-engine with the deliberate intention of overloading it, a more or less universal custom.

The Gas-Engine Generator: Present practice assigns an overload capacity of 10% sometimes of 15% to the gas-engine. Standard generators are, however, capable of sustaining 25% overload continuously within safe temperature limits. It is, therefore, permissible to rate the generator on a closer margin; that is, give it a higher rating for gas than for steam work. This enables the generator to run normally at a slightly higher efficiency, and reduces the cost of the power unit per kilowatt capacity, which is desirable owing to the high cost of gas-engine construction.

* Kinetic Efficiency is defined as:

$$\frac{\text{Thermal equivalent of useful output}}{\text{Total heat input in gas,}} = \frac{2\,545}{\text{B.t.u. per B.h.p-hr.}}$$

Load-Factor: The term load-factor is often used in widely different senses, usually as follows:

a $\frac{\text{Average load on engine}}{\text{Rated Capacity.}}$, during operating period only.

b $\frac{\text{Average load on station}}{\text{Total rated capacity of generators.}}$

c $\frac{\text{Average load on station.}}{\text{Maximum (or swinging) maximum.}}$

d $\frac{\text{Average load on station}}{\text{Average (or steady) maximum.}} = 100 \frac{\text{kw-hr. generated}}{\text{Max. kw-hr.}} (\%)$

By average maximum is meant the maximum shown on the station load-curve plotted from wattmeter readings. This last is the true load-factor and, for 24 hours' service, it alone offers an impartial basis for the comparison of station costs and

economies; although b may be used in comparing the operation of a given plant at different seasons, a is of importance in properly proportioning or "blocking in" engine capacity to suit a particular load-curve, such as Fig. 4, with the best ultimate economy. By integrating both the station load curve and the corresponding engine curve the average 24-hr. load per engine can be readily estimated, and the consequent water and coal consumption of the station approximated.

Much emphasis has very properly been placed upon the effect of load-factor on fixed or capital costs. But in a plant with load-factor varying from month to month, as in a central lighting station, the effect on operating costs and economies is fully as pronounced. The accompanying curve, Fig. 5, shows

average results from a 750-h.p. plant using producer-gas fuel and subject to a variable load-factor during the various seasons. The curve is practically a hyperbola, as it should be, and within the working range of the plant it shows an increase of from 1.9 to 3 lb. of coal per kilowatt-hour, or 27.5% with a decrease of 60% in load-factor. At normal working the plant uses about two pounds of coal per kilowatt-hour.

For a steam plant operating under variable load-factor the general character of the curve is the same. Thus in a 7500-kw. light and power plant using steam-turbines the operating cost was reduced from 0.5 to 0.325c. per kilowatt-hour or 42.5% of the normal, with an increase of only 13% in load-factor. See Fig. 6.

It is therefore apparent that as two factors combine to give the total cost of power; namely, the operating costs and capital or fixed costs, both should be considered in determining the effect of load-factor. As a matter of fact, one is about as important as the other. With a high load-factor, 50% to 70%,

such as occurs in a large railway plant, a small change has a comparatively insignificant effect owing to the flatness of the curve, but in a lighting plant where the load-factor ranges from 15% to 25% the values change with great rapidity. An excellent method of obtaining a clear idea of the total effect of

load-factor is by means of a diagram, Fig. 7, similar to that used by Dr. Mertz, in which capital costs are plotted below, and operating costs above the horizontal axis, the total ordinate giving total costs. The combined effect of the two curves is

very striking, and emphasizes the necessity of increasing the average all-day load upon a power station by every legitimate means. Also of restraining as much as possible the capital cost of a power station necessarily operating on low load-factors.