DISCUSSION ON "POWER PLANT ECONOMICS," AT NEW YORK.
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E. W. Rice, Jr.: In analyzing the losses that take place in the conversion of a pound of coal into electricity in a steam electrical plant, Mr. Stott makes use of the method that has been so successful in increasing the efficiency of electrical apparatus. Twenty years ago efficiencies of 75 or 80 per cent. were considered entirely satisfactory for electrical generators; but by careful attention to the core losses, iron losses, bearing losses, and other details, the efficiency has been increased to 95 or 98.5 per cent. For large units this efficiency is now considered standard. In these matters the electrical engineer has fortunately been greatly aided by the ammeter, voltmeter, and wattmeter, which have been evolved to assist him. Unfortunately, similar instruments do not exist for the examination of steam engines or steam-engine cycles; if the steam engineer had the equivalent of the ammeter and voltmeter, I feel confident that the efficiency of the steam-engine plant would have been very greatly increased.

At this point it is interesting to note the large saving that can be effected in item 3, "Loss to Stack," in Table 1, by intelligently following out the indications given by the CO₂ recorder, a most useful instrument. The author shows quite conclusively the high efficiency of steam auxiliaries. This naturally follows from the fact that the latent heat can be usefully employed to raise the temperature of the feed water. It is evident that in a case where the heat of exhaust can be usefully employed, the mechanical power can be obtained at high efficiency by using steam in a steam engine between boiler pressure and atmospheric exhaust. A familiar illustration of this is to be found in the use of exhaust steam from high-pressure engines to heat buildings. During the period and to the extent that such exhaust steam can be utilized for this purpose, or for manufacturing purposes, mechanical power can be obtained at high efficiency by the use of simple or compound engines operating from boiler pressure down to the pressure of the exhaust. In this case the engine may be considered as a simple reducing valve, reducing the pressure.

From the standpoint of convenience, simplicity, reliability, and avoidance of unnecessary steam pipes, no doubt there is much to be said in favor of electrically-driven auxiliaries, but they cannot compare in heat efficiency with steam-driven auxiliaries. It is unfortunate that no way is known at present of overcoming the losses, some 60 per cent., of heat units rejected to the condenser. This emphasizes the importance of working with the highest possible vacuum. Before the introduction of the steam turbine, there was no demand for a vacuum greater than 26 inches. The steam turbine is so admirably adapted to working over the lower ranges of pressure, that immediately a demand arose for the use of higher vacuum,

and it is now common to find vacua of 28.5 to 29 inches the barometer being assumed at 30.

Mr. Stott calls attention to the large increase in output and the improvement of efficiency which results from interposing a turbo electric unit between the exhaust nozzle of the reciprocating engine and the condenser. In Philadelphia there are two 800-kw. turbo generators operating exactly according to the plan proposed by the author of this paper. One of these units has been in operation for the last two months, and the other is, I believe, just started. As a result, there has been added to the power plant a capacity of from 1 600 to 2 000 kw. without any additional consumption of coal or appreciable addition to the labor. If enough turbines were placed in operation in such a plant to utilize all of the exhaust steam, the output could be easily increased by some 66 per cent. The increased investment would possibly be but one-half of the original investment in such a power station.

In view of the higher efficiency of the steam turbine as compared with the reciprocating engine in the lower ranges of pressure, it will be found profitable to employ a steam turbine for even a smaller range of pressure than that between atmosphere and 28.5 inches; in other words, a steam turbine may be inserted in the exhaust between the low-pressure cylinder and the condenser in almost any reciprocating-engine plant. In this case a steam turbine would work over a range of, say, between 20 and 28.5 inches of vacuum, corresponding in absolute pressures to between 10 lb. and 0.75 lb.

I am not quite sure that Mr. Stott recommends the combination of reciprocating engine and steam turbine in the exhaust as something to be considered in planning a new station. If so, it seems to me that the advantages gained by such a combination would not offset the added complexity. I believe, however, it is a most excellent means of increasing the economy, by adding to the output, of existing reciprocating-engine stations. In considering the application of steam turbines to the lower range of pressures, I have found the following table of value:

Number of ft.-lb. per lb. of energy in steam between 175 lb.

absolute and 0.75 lb. absolute, or 28.5 in. vacuum	262 000
Between 2 lb. absolute, or 26 in. vacuum, and 28.5 in.	226 600
Between 5 lb. absolute, or 20 in. vacuum, and 28.5 in.	157 000
Between 14.7 lb. absolute, or atmospheric pressure, and 28.5 in.	139 000

It will be observed from the latter figure that some 53% of the total available energy in steam, between 175 lb. absolute pressure and 28.5 in. vacuum, exists in the so-called vacuum portion, and that some 40% of this energy remains between 20 in. vacuum and 28.5 in. vacuum.

It is also important to remember that if the vacuum can be increased from 28.5 in. to say 29.4 in., the ft. lb. available are increased about 12 per cent.

The author's suggestion of a new type of plant, to obtain the benefits of the gas engine and unite that with the well-known flexibility and overload capacity of the steam turbine, is certainly interesting. The gain in total efficiency is so remarkable as to warrant careful and respectful consideration. I cannot help being surprised at the low estimate of the relative cost of maintenance and operation of a gas-engine plant as compared with the estimates for reciprocating engines or steam turbines, aside, of course, from the item of coal. I was not aware of the existence of sufficient data of this character to warrant such figures.

A word as to the original investment, in considering the relative investment of a plant consisting of reciprocating engines, whether gas or steam, particularly the steam type, as compared with the rotary engine of the steam-turbine type: I think it pertinent and important to consider that reciprocating engines have been built for many years, that the methods of design and manufacture are familiar, and that the cost of manufacture has, probably, therefore been reduced to a minimum. It is hardly reasonable, therefore, to look for any future material reduction in the price of such reciprocating units. The steam turbine, however, is of a comparatively recent date, and it is reasonable to expect, looking forward five or ten years, that improvements in methods of design or manufacture will result in a very material reduction in cost. Furthermore, I have been informed that the cost of reciprocating engines of large size reaches a minimum at sizes of units even below those which are now used in large stations, and the cost may be expected to increase with any material increase in size. On the other hand, the steam turbine shows no such limitations, as there are now in course of manufacture turbine units of 8 000 or 10 000 kw., nominal rating, capable, of course, of the usual 50 per cent. overload, or even double load momentarily. The original investment becomes a most important factor in the operating cost of a power plant, as interest, depreciation, maintenance, are, other things being equal, substantially proportional to the first cost.

It seems to me that while we cannot ignore any substantial increase in the efficiency of conversion of coal into electricity, the central station designer must in the future, even more than in the past, give due heed to the important questions of simplicity and reliability. The plant should have the highest practicable degree of working efficiency, but it must above all things be reliable. I believe that in simplicity and reliability the steam turbine will outdo all rivals. I cannot help feeling that the modern station has developed into a very complicated makeup. I would like to see the units reduced to the fewest

practicable number, not only the generating units, but the boilers, auxiliaries, steam pipes, switchboard appliances, etc. The safety devices and instruments should be as simple and as few in number and variety as is consistent with reliable operation of the station.

Charles E. Lucke: I think that the author of this paper has evidently sought to find a place for the reciprocating engine, the steam turbine, and the gas engine. His main conclusion is, that for economy of power generation in cost per kilowatt-hour, including manufactured cost, with interest, depreciation, and other establishment charges, the gas-engine plant offers, in the present type of steam-power plant, much greater economy, twice as much, in fact, as the reciprocating-engine plant; and that with the combination of a turbo-generator and a gas-engine generator, there are still greater economical advantages. In this connection it is necessary to remark that of all the power used throughout the United States, the number of horse power generated in high-efficiency central stations is but a very small percentage. The arguments which apply to stations similar to the station indirectly referred to by the author would not necessarily apply to all power stations under all conditions. There are conditions for every installation which will undoubtedly determine its type, and these are very seldom considerations of high economy or thermal efficiency. If exhaust steam is needed in large quantities—in works where evaporating is to be done, or boiling, or washing, or heating of a building—there can be no discussion of power costs, and the power station simply becomes a question of what steam engine units can be bought and kept in repair for the least money. Steam economy is a matter of no consequence in this case. If property is extremely valuable and the current generated can be sold at a good profit, no matter what the price, then undoubtedly turbines must be selected. If there is an enormous quantity of gas available, as in a blast-furnace plant, then everything points to the selection of the gas engine.

The average small power station for electric generation, when operated by steam, has a very much lower thermal efficiency and a very much higher power-cost, than have these large highly refined stations. If, as proved by the author, power-costs by gas are less for the highly refined station, and if, as is the fact, the gas-engine station does not fall off in efficiency, nor rise in power cost as its size decreases, then it must inevitably follow that the small gas-engine plant for electric generation will have a higher relative value than the large one, compared with steam. The author shows by some very excellent curves that the economy or efficiency of the whole plant will vary with the load, and that for a steam plant the variations are probably the largest and most controllable in the boiler room. He also shows that the boiler economy is very much poorer at high, forced loads than under light loads, and

that the only way to guard against this is by eternal watchfulness.

Corresponding to the boiler in the steam plant, there is a gas-producer in the gas plant. The gas-producer is much less sensitive to changes in load, resulting in changes in economy, than the boiler plant. This, I think, is a strong point in favor of the gas-producer plant. Again, there is practically no electric station running on a steady load. The load changes are of two kinds: a steadily-rising load from hour to hour during the day, and a correspondingly decreasing load; also a momentary fluctuation, a sudden rise and an equally sudden drop. The hour-to-hour changes are to be handled in a central station by putting on more units, or by taking them off. This means that in the boiler room there must always be a certain number of fires banked or in reserve, or both. Now, it is also true that the same conditions will prevail in the case of a gas-producer plant, but the coal consumed by banked fires or reserve fires in the gas-producer is very much smaller than for the same horse power of steam boilers. This is another point in favor of the producer gas. The ash loss, which is small in any case, becomes almost zero in the case of the gas-producer; because in the producer there is always left a bed of ash in the bottom, so that coal immediately after being burned does not fall through the grate bars as in the case of steam boilers.

The author calls attention to a load economy curve for a gas engine, and draws the conclusion that a gas engine having this curve should not be used at anything less than half load, because its efficiency falls off very much indeed toward no load. The conclusion is entirely justified with respect to the engine that produced this particular curve, but it is not justified with respect to all gas engines. The reason for the economy of a gas engine varying with the load is to be found in the governing mechanism. This results when the governor of the gas engine acts as a throttle on the mixture; in such a case, for the entire suction stroke of the engine the piston must work against the constantly increasing vacuum clear to the end; that is, there will be a loss due to working below the atmospheric line. If the lost work of the engine, as effected by the governor action, is eliminated or reduced to a minimum, the economy load curve will be perfectly flat. The curve presented becomes then not a criticism of the gas-engine economy, with load, but a criticism of that particular type of governor which, I am confident, will disappear in time.

The superior efficiency of the gas-engine plant is acknowledged, but not so often as it should be. The reciprocating engine has been a long time in reaching the efficiency it has today. For years nothing was done to increase the efficiency of gas engines; and it is only within the last five or six years that there has been any marked activity in improving gas engine efficiency, reliability, and regulation.

It is well known that the efficiency of such a unit depends on the compression, and, therefore, other things being equal, the greater the compression before ignition, the greater the increase in efficiency. Theoretically, there is no limit to the compressing; practically there is, but I am confident that some of these practical difficulties will be overcome in time. At the present time mixtures of air and gas are being used in practically correct chemical proportions, and the compression pressure now used is determined by the temperature of ignition of such a mixture. If such a mixture were diluted; that is, if much excess air or neutral gases or internal cooling were used, then this mixture could be compressed very much more without pre-ignition, and a corresponding gain in efficiency would result. This has not been done up to the present time, simply because no one has yet designed a proper proportioning valve for keeping the mixture constant for all conditions, and because no one has yet designed instruments that will indicate at a glance on a dial the proportions of air to gas, the percentage of dilution of mixture, the B.t.u. per cubic foot of gas, the B.t.u. per cubic foot of mixture, the mean effective pressure, and other similar information.

As designed at present the gas engine can never regulate as well as the turbine. There are gas-engine builders who insist that they can do as well in this respect as turbine builders, but the contention is ridiculous. The gas engine can, however, regulate alternators in parallel sufficiently well for most ordinary work, but the turbine can do even better. In Germany, last summer, I found gas engines as high as 4 000 h.p. single units running on dirty gas and on clean gas, on rich gas and on poor gas, and giving perfect satisfaction, chiefly because they were properly designed and properly handled. I found large units in blast-furnace plants, operating 24 hours a day, for eight weeks without a stop or shut-down of any kind, and more than that, doing something which required most positive certainty of operation. These furnaces were absolutely dependent on an air blast running exclusively on gas engines, and, in more than one case, without a single spare unit. Thousands of dollars were involved in the certainty of the blast, and all went right on from year to year. In spite of sensitiveness to proper handling, some gas engines will run under extremely adverse conditions. In one place in this country I have found the gas very imperfectly cleaned, containing a great deal of grit and dirt that was finally carried into the engines in quite large quantities. Grit and dirt in a gas engine cause trouble; they grind out the pistons, interfere with the valves, and clog the governing mechanism. But though all these things happened in this instance, the engines are still running. Recently I took a gas valve out of one of these engines, and scraped off 20 pounds of oil, ore dust, and coke dust. The valve had been in two months. The engine was still running, and doing its work

reasonably well. These are little facts which point a great moral.

The gas engine has a maximum load capacity proportional to its piston displacement, and so has the steam engine. The steam engine is ordinarily operated at less than its maximum load, and is, therefore, said to have an overload capacity. The gas engine is said to have no overload capacity, because it is intended normally to operate at nearly its maximum load. Now, if a gas-engine plant were to be handled as the steam plant is, then there would be considerable difficulty about meeting the load from this lack of overload capacity or the refusal of the gas engine men to operate their machines normally at part load; but there is another way out for the gas engine which has not been mentioned and which ought to be, and that is the possibility of cutting in and out of spare units on short notice. I know of seven units each of 2 000 h.p. capacity, that have been repeatedly, the whole seven, put on a load in three and a half minutes. There is no cylinder condensation to worry one. All one has to do is to pull the handle for the compressed air, give a twirl to the water valve, open the gas valve, and then carry load and obtain synchronism by the usual methods.

This method of handling the plant will not, however, take care of momentary wide fluctuations; the best method of doing this is, I think, that proposed by Mr. Stott.

C. C. Chappelle: There seems to be some difficulty in obtaining accurate information regarding the comparative operating costs of steam-turbine plants, the chief reason being that a large number of the turbines now in use form additional units in reciprocating-engine stations. I have in mind a plant of about 15 000 kw., the operating conditions of which are comparable with those in the large central power stations of New York city. This plant shows a record of 4.6 mills per kilowatt-hour for all operating and maintenance costs. To those familiar with the cost of power in large reciprocating-engine plants in New York, it is apparent that this figure practically coincides with Mr. Stott's deductions.

Though the combination of reciprocating engine and exhaust turbine makes a favorable showing, yet I believe that Mr. Stott's conclusions are based on rather an abnormally low result for a non-condensing engine, as this result comes within 85 per cent. of the theoretical consumption of a perfect steam engine operating between these temperature limits. Assuming 19 pounds of steam per indicated horse power as a fair cross-compound non-condensing engine performance, and 28 pounds of steam per indicated horse power as the performance of a low-pressure turbine—which approximates that shown by shop tests, with the moisture in the steam included—the net result approaches that obtained with a condensing turbine. The combination, however, possesses great advantages for enlarging ex-

isting engine stations, and for placing them on a more economical basis. It has already been adopted for a number of installations of this character.

While the gas engine has received less encouragement than the steam turbine, its development, nevertheless, has been no less progressive and, as indicated by this paper, it promises even greater things in generating power. A 500-h.p. gas engine was once looked upon as about the maximum limit for this class of prime mover; this is now considered quite an ordinary size unit.

Though the operation of 60-cycle alternators in parallel is not easily accomplished with steam engines, yet there are a number of gas-engine plants of large size in which 60-cycle alternators are operated successfully in parallel. The combination of gas engines and steam turbines possesses great advantages, as Mr. Stott says, and in several important prospective installations it is receiving serious consideration.

W. L. R. Emmet: The use of a low-pressure turbine in connection with the exhaust of a reciprocating-engine plant, or in connection with the waste heat of gas engines, naturally suggests itself to anybody familiar with the characteristics of the steam turbine. In a paper read at the Electrical Congress in St. Louis in 1904, I called attention to both these possibilities, and gave almost the same figures as to possible saving that Mr. Stott has given in this paper.

Among other things, Mr. Stott shows clearly the great saving in investment incident to the use of steam turbines. He gives a performance curve of a steam-engine that indicates an abrupt rise in the rate of steam consumption with increase of load. Capacity to carry the peak load is the controlling factor in the cost of a steam plant, and the reciprocating steam engine, particularly in the case of large units, is undesirable from this standpoint; for the reason that the problem in building very large steam engines is to take care of the great weights involved in the low-pressure cylinders and valves. Very large steam engines have a tendency to be uneconomical at overload, because the engine builder is tempted to make the low-pressure cylinder just large enough to give good economy at certain loads and so get through without mechanical difficulties. If this were a turbine of the good quality shown by another curve, instead of turning up at 4 000 kw., the curve given by Mr. Stott would either move out horizontally from that overload point or else it would turn upward slightly. The result would be that at some maximum boiler output, the turbine would give anywhere from 20 to 25 per cent. more output—more maximum plant capacity—than the reciprocating engine. In short, for so much money 20 per cent. more capacity could be obtained. The plant capacity is costing, in the case of this station, possibly \$150 per kilowatt, 20 per cent. of that is \$30 per kw.; in other words, the increased value afforded by the

turbine in overload capacity is more than the total cost of the turbine. Disregarding operating expenses and considering only first cost, the engine can be scrapped and a turbine put in its place. In this station, then, if 20 per cent. were to be added to the capacity by erecting buildings, boilers, and other parts, the cost would be greater than if all the engines were discarded and steam turbines installed, and there would be no gain in peak-load capacity. And changing from reciprocating engines to turbines would also result in better economy of operation, as shown by the curves.

In regard to using a steam turbine in the exhaust between the engine and the condenser. In this case the turbine performs exactly the functions of a vast third cylinder on the engine, a cylinder of shape and size suited to the load; it receives this load without cylinder condensation, in fact with all the characteristics of an ideal cylinder. It is just another expansion working in the field which the reciprocating engine is incapable of filling, and in that field it can give as good efficiency as in any other field, and that efficiency closely approximates to that of a high-pressure cylinder. There has been obtained experimentally in the lower ranges of pressure, in a single process corresponding to the work of one cylinder in a steam engine, an efficiency as high as 76 or 77 per cent. with saturated steam in a very simple kind of steam turbine; this is as well as the engine does even in the higher ranges of pressure, and four times as well as it does in the lower ranges.

Suppose that an engine station is operated with engines limited in the matter of overload, by congestion in the low-pressure cylinders. Installing a low-pressure turbine between the low-pressure exhaust and the condenser, and assuming that the engine exhausts at a pressure of 20-in. vacuum, then 20 per cent. is added to the maximum output formerly obtained from the station. The capacity of the turbine to do that work is one-fifth of the capacity of the engine; it has no governor; it has only half the number of wheels and processes of the high-pressure turbine—altogether it is a very simple device. The turbine would cost possibly \$35 or \$40 per kilowatt; and the additional power produced, if rated at the cost of increase of capacity of the station, on an engine basis, would amount to something like five times the cost of installing the turbine. Consequently, enlargement by adding low-pressure turbines may cost only one fifth as much as an enlargement on the original line, and for the reasons explained the result is far better. As a rule, this can be done without enlarging the station or the necessity of employing additional men.

Obviously, the use of a high vacuum is important in turbine work, and efforts for obtaining this vacuum have met with astonishing success. And, too, a high vacuum is inexpensive to maintain; there is practically no leakage, resulting in a close approach to theoretical or ideal conditions.

Sometimes a reciprocating engine can be run non-condensing economically; but the advantage of condensation is so much greater with the turbine that the only reason for running non-condensing is the need of steam for other purposes. By installing cooling-towers in a non-condensing plant, the output can practically be doubled without adding to the operating cost.

F. E. Junge: Geographical, economical, or governmental conditions must always largely affect the point of view and the judgment on questions that are of common interest in engineering matters, especially when the comparison concerns the divergent practice of countries like United States and Germany.

An illustration of the extent to which electric centralization has been carried in Germany may be derived from the practice obtaining in isolated coal mines, which often possess no prime movers at all for driving the various pumps, hoists, fans, and other machinery. These mines have a transformer sub-station, equipped with motor-generators and fly-wheel sets, serving to equalize the load fluctuations, while high-tension electric current is obtained from a central station sometimes located in a city many miles from the mines. For instance, 50-cycle current of 10 000 volts is transmitted over a distance of 9 kilometers from the city of Essen to the Mathias Stinne Coal Mines, where 2 000 h.p. is used for driving the various machines. One coal mine which supplies good coal for coking purposes has a coke-oven plant attached to it and utilizes the waste gases thereof in a gas-engine-driven central station, while the surplus power is distributed by electric transmission to the sub-stations at neighboring mines.

This possibility of utilizing the energy in waste gases by distributing and selling it for light and other purposes in the neighboring industrial districts, forces the German engineer, in the determination of the commercial economic coefficient for a heat-power plant, to place a more pronounced value on the factor of heat cost than can be imparted to it under the conditions prevailing in this country. How seriously the difference in the valuation of this factor affects the prime mover problem in central stations can best be seen by comparing the estimated calculation made by Iffland to determine the respective merits of various engine drives for a combined coke, iron, and steel-smelting plant, where the coal mines are so closely located as to fall into the commercial distribution radius of the electric central station and are operated from it. The normal power required by all the engines is 42 200 h.p.; therefore the maximum simultaneous capacity which the plant must be able to carry permanently is 21 000 h.p., which is produced from the waste blast-furnace and coke-oven gases.

We shall consider only two cases: first, a gas-engine-driven central station; secondly, a steam-turbine-driven central station. All the auxiliary machines are operated from the central station. On account of the difference in consumption of the

reversible and non-reversible machines, the total capacity of the central station required is found to be 25 000 kw., it being advisable with complete centralization to provide for an ample reserve. The power equipment in the first case consists of eight gas engines, each having 6 000 h.p. normal capacity, and 4 000 effective kw. ($\cos. \phi = 0.8$).

In the second case, of five steam turbines each having 10 000 h.p. normal capacity and direct connected to alternating-current generators of 6 800 effective kilowatt capacity ($\cos. \phi = 0.8$). The normal capacity of the gas-engine-driven central station is therefore 32 000 kw. total, and of the steam-turbine-driven station, 34 000 kw. Most of the machines used on the plant are in constant operation all the year round.

Now, assuming that the waste gases have no commercial value whatever, then the actual cost, including initial capital outlay and operating expenses for generating one boiler horse-power hour, is as follows:

For gas-engine-driven central station.....	44 cents
For steam-turbine-driven central station.....	42 cents

For purposes of comparison, I give the figure that would be obtained with steam-engine drive all over the work. One boiler horse-power hour would then cost 75 cents. In this case, then, the steam turbine would be the most economical prime mover. However, the assumption that the blast-furnace and coke-oven gases are given for nothing is erroneous. The gases must first be cleaned, as this increases their heating capacity and makes them applicable for use in gas engines; but this process requires an expenditure of one cent per 30 000 cu. ft.; moreover they actually have a value as fuel for steam raising. In the plant under consideration, we shall therefore compare the power value of the waste gases when used in gas engines to what obtains when burned under boilers, and so must appraise the gas at a rate corresponding to the reduction of the coal bill. If power can be distributed abroad, the appraising of the gas depends on the disposal of the surplus power and varies with the locality. Now estimating coal at \$2.50 per ton, and assuming that seven kilograms of steam are raised from one kilogram of coal, then the value of the blast-furnace gases which are to be used in gas engines is \$150,000. The value of the blast-furnace and coke-oven gases available for raising steam is \$325 000. With this valuation, the former results are modified as follows:

Gas-engine-driven central station, 54 cents per boiler h.p. hour.
Steam-turbine-driven central station, 66 cents per boiler h.p. hour.

With steam-engine drive the cost would be 98 cents. It will be seen that the correct valuation of the fuel upsets the former results entirely in favor of the gas-engine-driven central station. Basing the results on the cost of production per ton of marketable goods, of which this plant sells 300 000 tons per year, we arrive at the following:

Gas-engine-driven central station, \$2.00 without, and \$2.48 with appraising the gas.

Steam-turbine-driven central station, \$1.93, and \$3.02 respectively.

With steam-engine drive the cost would be \$3.35 and \$4.42 respectively.

It is seen that the gain effected by the selection of gas engines instead of steam turbines for the central station amounts to 50 cents per ton of annual capacity. The figures are of special significance, as they show how much the whole prime-mover question hinges on the valuation of the factor of heat cost. The conditions change, of course, if a plant possesses only capacity for iron and steel smelting, and has rolling mills but no coal mines attached to it; and they are again different for a steel plant with rolling mills but without coal mines, blast furnaces and coke ovens. It is only in the last named case that gas-engine drive—gas engine-central station and scattered gas-engine auxiliaries—is the most economical method, but it is only by a combination of coal mines, blast furnaces, steel smelting plants, and rolling mills that an efficient production is possible, as we can hereby avoid paying the duty imposed by the protective tariff on raw materials, pig iron, and half-finished goods.

Sight must not be lost of the fact that the results of the above calculation are based on foreign conditions and cannot be used for direct comparison with the corresponding items which for the same plant capacity would obtain in this country. This, however, does not affect their relative value in the least.

Owing to the need of reducing waste in technical methods, and to the geographical and social conditions prevailing on the Continent, which differ from those in this country as regards the distribution and production of mineral and metallic ores, the density and sphere of action of industrial centres, and the cost and reliability of skilled labor that can be secured, we shall—if the surplus power that becomes available by the adoption of economical prime movers can be used in the works, where its value is equal to the corresponding reduction of the coal bill, or if it can be sold to advantage abroad, where its value varies with the local conditions—invariably select the gas engine as prime mover for central stations. Where there is no market for available surplus power, there the steam turbine will always keep its field of usefulness.

Calvert Townley: In connection with the study of economy in steam usage, the conditions affecting a moderate sized plant should be considered as well as those obtaining in a very large plant. In that connection the use of exhaust steam for heating purposes should not be lost sight of.

In the majority of isolated plants, in many electric light stations, and not infrequently in railroad power houses, opportunity could be made, if the plant were originally so designed,

to utilize for seven months of the year a large part, if not all, of the exhaust steam for heating; thus, in effect, turning the generating plant into a heating plant, and using the engines as reducing valves to lower the steam pressure from that generated by the boilers to that required for the heating system.

The B.t.u. in steam at 175 pounds gauge pressure is only 5.45% more than in steam at 10 pounds gauge pressure, so that, given the necessity for a steam-heating plant, the additional coal required to make the steam available for electric generation is comparatively small.

Some unfortunate experiences in an endeavor to utilize exhaust steam for heating, where either the circumstances or the design of the plant, or both, were unfavorable, have discouraged many engineers from the more general adaption of this principle; but there can be no doubt that it is susceptible of wide application, and that the possibilities of saving are very great.

Mr. Stott's Table No. 1 is extremely interesting, as showing a careful analysis of loss distribution. It should be noted, however, in considering this table, that the last column shows the losses in per cent. of the original heat units in the coal, and, therefore, it does not represent a true measure of the relative importance of the losses; for example, the loss in engine friction is given as 0.8%, whereas there has been 38% of the energy lost before reaching the engine, and the engine friction is, therefore, approximately 1.3%. Similarly, the heat units rejected to condenser are given as 60.1%, whereas 29.3% having already been disposed of, the condenser takes over 86%; that is to say, the efficiency of each transformation increases in importance as we come down the line, and, therefore, a small gain in efficiency in a late transformation may be of more value than a considerably greater gain at an earlier stage.

Hartley Le H. Smith (by letter): In discussing the operation of hand-fired and stoker-fired boilers, Mr. Stott in Figs. 6 and 7 illustrates various items as a function of the draft, which is presumably the draft at the boiler downtakes, although he does not explicitly say so. The values of draft are so much lower in Fig. 7 than in Fig. 6 that it is not quite certain whether the draft was measured at the same place in the two cases. In Fig. 6 the maximum economy is attained at only 77% of the standard rating, and the economy at the standard rate of evaporation shows a falling off of 13% from the maximum value. As these conditions are rather extraordinary in a boiler rated at 600 horse-power, in which the ratio of heating surface to grate surface is usually high, it would be interesting to know in what manner the variation of draft at the downtake caused the draft immediately above the fire to vary, and also the corresponding variation of CO₂.

The variation of reciprocating-engine steam consumption shown by Mr. Stott in Fig. 8 is extremely interesting and im-

portant. A feature even more significant than the rapid rise in the most economical steam consumption, is the very great extravagance in steam consumption which results from an engine with its load equally divided between the cylinders, and the extraordinary rates at which this consumption with such adjustment increases from a point representing a little over 80% of the rated load. In Mr. Stott's illustration the equal division of load between the cylinders makes the consumption at rated load 3.5% higher than the most economical adjustment, and at 35% overload the equal division between the cylinders consumes 9.5% more steam than the most economical adjustment. Mr. Stott might have stated which cylinder was doing the most work, and in what manner the ratio varied throughout the range of load he has illustrated. The natural inference is that the most economical working was obtained by putting the larger share of the work on the high-pressure cylinder, for the avoidance of the large cylinder condensation losses at heavy loads in the low-pressure cylinder. A hint in this direction is given in speaking of the reciprocating engine with a low-pressure turbine on its exhaust, that the reciprocating engine should be run high pressure where relatively it is most efficient. It seems probable that a good many operators of reciprocating engines should take Fig. 8 with considerable seriousness, as there are probably many more engines operating with the load equally divided than unequally divided in such manner that the minimum steam consumption results.

There is another factor of some moment; namely, if it is not assured that engines are working with the most efficient valve adjustments, it would not pay in a large system to operate large units at excessive overloads during the periods of maximum demand rather than smaller units at rated load in older stations held normally as reserve equipment.

The author says that the apparent saving of 13.5% in steam consumption when a turbine is operated with steam superheated 200°, means an actual thermal saving of only 6.6% due to the greater total heat of superheated steam. It seems essential to add that if the superheating is obtained with internal superheaters, as is usually the case, there is an almost inevitable increase in the heat loss escaping to the stack, due to the increased temperature of the gases; that this increased heat loss may easily become of serious moment may be seen in Fig. 5. In the absence of economizers it is conceivable that this item might wipe out the saving due to the use of superheated steam in the turbines.

In Mr. Stott's treatment of a high-pressure reciprocating engine with a low-pressure turbine on its exhaust it is difficult to see how the giving up of 165.3 B.t.u. per pound of steam is connected with the expansion of steam from the absolute pressure of 190 to 14.7 pounds per square inch, except that as

the generator has an efficiency of 98%, and the engine a mechanical efficiency of 93.65%, the over-all efficiency is 91.75%, which

would require $\frac{3412}{0.9175} = 3718$ B.t.u. in the engine cylinder per

kilowatt-hour. When this is increased by 13.5% to allow for radiation, incomplete expansion, and similar losses it becomes 4215 B.t.u. per kilowatt-hour, which when divided by 25.5 pounds, gives Mr. Stott's figure 165.3 B.t.u. per pound of steam. The thermal efficiency represented by the expansion of steam between the limits of 190 and 14.7 pounds per square inch absolute pressure is 19.7 per cent.