

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 21st, 1893.

The seventy-fifth meeting of the Institute was held this date at 12 West Thirty-first Street, and was called to order at 8.30 P.M., by President Frank J. Sprague.

THE SECRETARY—At the dinner of the Institute, which took place last May, on the occasion of the Annual Meeting, it was voted that an annual dinner be made a regular feature of the Institute, and in accordance with that voted the Council has to-day appointed Messrs. Phelps, Hamilton and Pickernell as a committee on the dinner to take place on the occasion of the Annual Meeting May 16th.

At the Council Meeting this afternoon the following Associate Members were elected :

Name.	Address.	Endorsed by
BUTLER, WILLIAM C.	Monte Cristo Mining Co., Everett, Washington.	Leo Daft. Chas. H. Davis. John W. Howell.
CHISM, GEORGE F.	Standard Engineering Company of North America, 92 State Street, Albany, N. Y.	T. D. Lockwood. V. M. Berthold. I. H. Farnham.
ELY, WM GROSVENOR, JR.,	Edison General Electric Co., 226 Union St., Schenectady, N. Y.	Frederick Bedell. Edw. L. Nichols. Ernest Merritt.
GOLDSBOROUGH, WINDER E.	Adjunct Professor of Electrical Engineering, Arkansas Industrial University, Fayetteville, Ark.	Harris J. Ryan. E. L. Nichols. Harold B. Smith.
HARTMAN, HERBERT T.	Assistant Engineer, Canadian Gen- eral Electric Co., 69 Front St., Toronto, Ont.	J. H. Vail. Chas. Hewitt. A. E. Winchester.
HEATH, HARRY E.	Chief Draughtsman, Eddy Electric Mfg. Co., Box 189, Windsor, Conn.	H. S. Rodgers. Wm. R. C. Corson. Ralph W. Pope.
KEILHOLTZ, P. O.,	Superintendent, U. S. Electric Lighting Co., Baltimore, Md.	Cary T. Hutchinson. T. C. Martin. Joseph Wetzler.
MACKIE, C. P.	Manager, Electric Selector and Sig- nal Co., 45 Broadway, New York City.	H. L. Webb. Joseph Wetzler. T. C. Martin.

McCLUER, C. E.	Superintendent, First District, So. Bell Telephone and Telegraph Co., Richmond, Va.	G. A. Hamilton. F. A. Pickernell. Thos. D. Lockwood.
MOTTRAM, WILLIAM T. M.	Electrical Engineer, New Orleans Traction Co., 102 Canal St., New Orleans, La.	Wm. J. Hammer. Francis R. Upton. Oscar T. Crosby.
ROBERTSON, A. C.	President, The A. C. Robertson Co., Electrical Engineers and Contractors, Wilkesbarre, Pa.	M. J. Wightman. H. Bergholtz. Ralph W. Pope.
SPENCER, THEODORE	Assistant in Mechanical Department, American Bell Telephone Co., 2 Craigie St., Cambridge, Mass.	John C. Lee. H. V. Hayes. Thos D. Lockwood.
STORRS, H. A.	Professor of Electrical Engineering, University of Vermont, Burlington, Vt.	Geo. A. Hamilton. Geo. M. Phelps. F. A. Pickernell.
ZIMMERMAN, L. J.	604 West 46th Street, New York City.	Townsend Wolcott. A. A. Knudson. Jas. B. Williams.

Total, 14.

Transferred from associate to full membership.

PERRY, NELSON W.	Editor <i>Electrical World</i> , New York City.
GUTMANN, LUDWIG	Electrical Engineer, Cleveland, Ohio.
Total, 2.	

REPORT OF MEETING OF BOARD OF EXAMINERS.

MARCH 15TH, 1893.

Present—Messrs. W. B. Vansize, *Chairman*, E. T. Birdsall, G. A. Hamilton
C. O. Mailloux and E. P. Thompson.
R. W. Pope, Secretary, present *ex officio*.

	Approved.	Disapproved.	Laid over for Further Consideration.	Total Considered.
Applications for Transfer Re-considered.	9	1	1	11
New Applications for Transfer Considered.	4	5	4	13
Totals,	13	6	5	24

THE PRESIDENT:—I take pleasure in announcing that the paper of the evening is by Dr. Charles E. Emery on "The Cost of Steam Power produced with Engines of different types under Practical Conditions; with Supplement relating to Water Power." Dr. Emery needs no introduction to his associates; he has been for a long time one of the leading members of the American Society of Mechanical Engineers, and a Vice-President,

and is one of the best known steam experts in the United States. That he should after going through the ordeal of attaining that enviable position, have taken up electrical studies and become a member of the Institute is, I think, a matter for congratulation. The paper which he will read to-night is on a subject elaborated some years ago by him in a paper of now international importance. I am sure that those who hear it will be fully impressed with the results at which Dr. Emery has arrived.

[Dr. Emery then read the following paper :

THE COST OF STEAM POWER PRODUCED WITH ENGINES OF DIFFERENT TYPES UNDER PRAC- TICAL CONDITIONS; WITH SUPPLEMENT RE- LATING TO WATER POWER.

BY CHAS. E. EMERY, PH. D.

1. The paper of the writer on "The Cost of Steam Power," published in vol. xii, *Trans. Am. Soc. C. E.*, November, 1883, seemed to supply information desired on the general subject by many engineers not practicing in that branch of the profession, and the writer has often been urged to modify the paper to suit more recent conditions. On investigation it appears that the original paper is still substantially correct for the particular purposes to which it was originally applied. It was designed to show the capitalized or present value of steam power in different units maintained forever. The cost of the power in pounds of coal was for the larger engines based on testimony taken relative to large sized condensing engines operating regularly at Fall River, Mass. This was distributed by judgment to the amount of water evaporated in the boilers per pound of coal and required by the engines per horse power, but such distribution evidently did not affect the final results. The prices of engines and boilers employed were higher than the ruling prices to-day, but these form a small percentage of the total capitalized values. The price of coal employed was also higher than the ruling prices in many localities at present, which directly affects the results, but it is evidently impossible to assume any price for coal which will apply to all locations. For these reasons it is believed that the table can still be employed with advantage by any one sufficiently familiar with the subject to make the necessary corrections for different conditions.

2. It has been decided at the present time, instead of revising the former tables, to compare the cost of developing a given amount of power with several of the different kinds of steam engines now in general use. A unit of 500 net horse-power has been selected for the purpose, though some of the comparisons are on the basis that several such plants are in the same station. In order to make the comparison at the same speed, it is assumed in all cases that the power is delivered at a speed of 250 to 350 revolutions per minute, corresponding to the jack-shaft speed of slow engines and the actual speed of high speed engines.

3. It will be attempted in this presentation to examine all the principal causes which affect the cost of steam power in engines of different types operated under practical conditions, but the substantial equalization of the cost of the power developed with engines of different types and different degrees of economy, when expenses independent of the coal consumed are considered, will necessarily form a prominent feature of the discussion, for the reason that such expenses have frequently been neglected or inadequately discussed, so that their very important bearing on the results is not generally understood. It will be shown that such additional expenses are fairly constant, independent of the type of engine, and that without considering interest or dividends they will in some cases equal the cost of coal. It will be seen, therefore, in comparing two engines both of which are good, so that one, for instance, will only effect a saving of coal compared to the other of, say, $12\frac{1}{2}\%$, making the relative costs of fuel as 8 to 7, that, if additional costs equal to the former be added to *both*, the relative economies will be as 16 to 15, and the saving reduced to $6\frac{1}{4}\%$ simply by the summation of costs. If then we assume that all expenditures should pay 10% interest or dividends on capital invested, and 10% of the difference in first cost of the engines equals an amount which represents a saving of $6\frac{1}{4}\%$ of fuel, then the cost to the owner of the steam plant will be exactly the same in the two cases, since in one case he will pay in additional interest or dividends on the capital invested the same sum as he will pay for additional fuel if he uses the cheaper engine.

4. In general it will be found as in the above illustration that the mere cumulation of costs, other than for fuel or interest, has the greatest effect in reducing the percentage of saving due to a more economical consumption of fuel, and that a consideration

of interest and dividends may simply neutralize or reverse percentages that were already made very small from the first named cause.

5. The original cost of the plant is evidently of great importance, where on one hand money is dear, or on the other coal is cheap or the work irregular. When the interest or dividend charges and others akin thereto are duly considered, it will readily be seen that the number of hours an engine operates in a year has a very important influence on the question of first cost, as such charges for a given steam machinery will be exactly the same whether the latter be operated one hour per day during part of the year, or 24 hours per day for the entire year, and the interest will also be the same whether the coal used cost \$1.00 or \$10.00 per ton. The saving in the total cost of coal consumed, either during the short hours or at the low price per ton, will evidently not be such as to warrant the adoption of high priced steam machinery.

6. It should be observed that various conditions in addition to those previously named operate to equalize the total cost of different kinds of steam machinery. For instance, with more economical engines smaller boilers are required, so the saving in the cost of the boilers partly compensates for the higher cost of the engines. Again, coal is at the present time cheap compared with former prices, and this is true also of steam engines of ordinary construction, which facts tend to maintain former conditions. On the contrary, steam machinery designed to secure economy, though lower than formerly, is still relatively high. It will be found that a consideration of all the facts available imposes very important conditions in relation to the selection of particular types of steam machinery for a particular duty and location.

7. Principally to obtain uniformity of expression we may preliminarily state, on a somewhat elementary basis, that steam engines at the present time may be divided into two general classes, distinguished as high speed and low speed engines, and though most low speed engines are operated at higher speeds than were employed years ago, there is still a definite distinction, although in many cases the gradations not only appear to reach, but perhaps cross each other. The high speed engines are best distinguished by the fact that they are of comparatively short stroke, and develop approximately the same piston speed as long stroke engines by an increased number of revolutions.

8. We have also simple, compound and triple compound engines of both the high and low speed types, and either of them may be horizontal or vertical. Most low speed engines of the power proposed are of the Corliss type, or at least have much the same general proportions, and some means of automatically cutting off the steam by the action of the governor to produce regulation of speed. There have been so many high speed engines brought out during late years of both the simple and compound type, and triple compound engines are being developed by so many builders, that it will be invidious to mention one name rather than another, though doubtless some engines possess advantages which others do not. In most high speed engines the steam is both distributed and cut off by a lap valve operated by a governor revolving with the main shaft, which acts to move the center of the eccentric in a line transverse to the crank at a distance from the center of the shaft equal to the lead. The effect is to modify the cut-off, substantially as with a link motion, by reducing the throw so that the angular motion required to move the valve through its double lap forms a greater or less proportion of the whole motion and therefore varies the angle of steam admission while the lead is maintained substantially uniform.¹

9. Either of the above engines may also be operated with the steam escaping into the atmosphere or to a condenser, and in the latter case an air-pump may or may not be used. The first class of engines can no longer be distinguished as "high pressure engines." They are referred to herein as "non-condensing engines." Those of the second class are called "high pressure condensing, without vacuum," while the term "condensing engines" is a general one applied to those in which the steam is condensed and a vacuum formed.

10. Table I, submitted herewith, shows in detail the cost of one horse-power per year developed in engines of different kinds

1. While it is true that small high speed engines have been known for a long time, it is believed, and in relation to one of the principal forms it is known, that the present revival started with a discussion of the subject by the writer for a circular of the Novelty Iron Works about 1863, which, notwithstanding the closing of the works, was preserved to the profession by the late lamented Prof. W. P. Trowbridge, then Vice-President of the Company. See tables and "Formulæ Relating to Non-Condensing Engines," W. P. Trowbridge, N. Y., 1870. The present general adoption of the fly wheel governor revolving with the main shaft is undoubtedly due largely to the late lamented J. C. Hoadley, when at Lawrence, Mass. His successors were messrs. Armington & Sims. See p. 152, Report Judges Group XX., Cent. Exh. 1876.

when operated for 10 hours per day for 308 days in the year and for 20 hours per day for every day in the year, with columns showing the results in each case for coal costing \$2, \$3, \$4 and \$5 per ton. The results are at first presented on the basis that the power required is comparatively steady so that no surplus machinery is required. A second presentation shows the results for electric light and other plants in case 50% surplus machinery be provided to supply the maximum power during certain portions of the day, and the power for the remainder of the day is sufficiently low to maintain the average.

11. In column *b* of Table I will be found the designation of the several types of engines compared, arranged by the amount of fuel required to produce one horse-power. Distinguishing letters are provided at the left in column *a* for convenience of reference. In general the kind of engine employed will be understood from the names at a glance. There are presented on different lines of the table, simple high and low speed engines, both condensing and non-condensing, compound high and low speed engines, both condensing and non-condensing, high speed triple compound engines, condensing and non-condensing. There are also three lines devoted to low speed condensing triple compound engines. Of these, line *J* shows the probable results with machinery designed to secure economy in construction rather than the highest economy of fuel. Line *K* refers to a low speed triple compound engine more expensively constructed, for which the economy is assumed lower than in the other case and for which the results are believed to be the best that can be secured under ordinary average practice even with the best machinery. There has, however, for comparison, been added another line, *L*, assumed to be operated at still lower economy by the use of boilers of unusual economy and careful attention to the details of operation, for which purpose \$1 per day is added to the labor account. The results shown in this line are believed to be the maximum which can be obtained under the conditions of unusually good practice with the best care available.

12. It is assumed that the details and proportions of the different types of engines are of a kind which have proved reliable in practice, so that no large allowances are necessary for breakdowns or important repairs.

13. Column *c* shows the indicated horse-power required to produce 500 net horse-power. As previously stated the net power

is assumed as delivered to a shaft revolving at a speed of 250 to 350 revolutions per minute, such for instance as the main shaft of a so-called high speed engine, or the jack-shaft of a low speed engine, consequently the indicated power of the latter must be increased sufficiently to overcome the frictional resistance developed in transmitting the power to the jack-shaft. The total loss due to the friction of the engine and jack-shaft of the slow speed engine is considered to be 10% without reference to its distribution, which is substantially what has been obtained by experiment under average conditions. The friction of the high speed engines is fixed at 8%, which may appear somewhat high for such large engines, but is believed to be warranted by the short stroke, large bearings and high velocities necessarily employed, although it will undoubtedly show smaller in particular engines. In this way 542 is fixed as the indicated horse-power of the high speed engines and 556 as the indicated horse-power of the low speed engines.

14. Column *d* shows the assumed steam pressures as shown by gauge. The pressure regularly carried has been somewhat increased of late years, so that none of the engines are assumed to operate at a less pressure than 100 pounds, and for all the triple compound engines the pressure is assumed to be from 150 to 170 pounds.

15. Columns *e* and *f* relate to the feed water per indicated horse-power per hour; column *e* showing the probable limits within which the feed water required will vary for engines of the types stated, when constructed by different manufacturers or operated under different conditions. The lower limit is believed to have been fixed in each case at the minimum result which has been obtained by reliable experiments with the class of engines referred to; these figures are therefore too low for average practice. The larger figures in column *e* represent results which in the opinion of the writer may be obtained under less favorable but practical circumstances, and of course still larger costs would result from the use of apparatus imperfectly designed or improperly operated. Column *f* shows the feed water per indicated horse-power per hour assumed for comparison. The figures in this column are not intended to be averages of those given in column *e*, but those which can be safely depended upon under conditions of practice, with the load varying between considerable limits, thereby affecting somewhat the economy. It should be stated that the

desire to have these figures decrease progressively where possible has somewhat influenced the values selected, as well as the above considerations, which should be borne in mind in making the comparisons. In cases where the conditions are especially favorable, the results for a type of engine written in one line may be taken from the line below, or by an average of the results written opposite the name of such engine and those on the line below. It is believed, however, from a careful consideration of all the evidence available on the subject that the figures given are all that can be depended upon under average conditions of practice. Engines operating cotton mills or large numbers of small machines of any kind under conditions securing a substantially uniform load will necessarily give nearer the minimum results shown in column *e*, but engines generating electric current for electric railways, or subject to variable loads of any kind will rarely show economies as low as has been assumed for comparison in column *f*.

16. Column *g* shows the commercial horse-power of the boilers required to furnish steam to engines of the indicated power shown in column *e*. The power of a boiler is really represented by the quantity of water it will evaporate under normal conditions. Its rating should not be based on the maximum quantity it will evaporate, for in such case the steam pressure would fall during the operation of replenishing or cleaning the fires. There is really no such thing as an absolute boiler horse-power, for the reason that the quantity of feed water evaporated required by different engines varies through such wide limits. It is, therefore, necessary to arbitrarily fix the rating for boilers based on the evaporation of a definite quantity of water under definite conditions. In the report of the Judges of Group XX, Cent. Exh., the writer called attention to the fact that for economical engines the boilers were generally designed as part of the plant; that for portable engines the boiler and engine were generally attached together, and he suggested that the rated horse-power of a boiler could properly be fixed by the quantity of water required for engines of a class then most largely in use, to wit, automatic cut-off high pressure engines of 80 to 100 horse-power. He therefore, based the calculation relating to the tests of boilers at the Exhibition on the basis that the Commercial Horse-Power of a boiler should be fixed at 30 pounds of water evaporated at 70 pounds pressure at a temperature of 100 degrees. This rating

was adopted by the Judges at that time and has since been adopted by a Committee of the American Society of Mechanical Engineers. The increased duty required by the boiler to evaporate the water at an increased steam pressure is small and may ordinarily be neglected. The assumed temperature of feed water, to wit, 100° , can be readily obtained even with condensing engines, so the commercial horse-power of boilers for the different engines has been found by simply taking the product of the several indicated horse-powers in column *c* and of the water per indicated horse-power in column *f* and dividing each by 30, or the number of pounds of water per horse-power assumed for the rating of boilers. It will be interesting to observe that the high speed non-condensing engines in line *A* require 596 boiler horse-power to produce 500 net horse-power, and that the power of the boilers continually diminishes with the reduction in feed water per horse-power, so that for the case last named, line *L*, only 259 boiler or commercial horse-power is required.

17. While on the subject of boilers we proceed at once to the cost of the boilers given in column *i*. As shown by the heading, the prices stated not only include the original cost of the boilers proper, but the erection and connection of the same, which may add a considerable sum to the original cost, particularly where the work is of such character that steam pressure must be maintained either on one boiler or another at all times during the hours of operation as is desirable in all kinds of manufacture and necessary where public interests are at stake, as in electric work. All steam apparatus needs more or less repair. Stop valves will get off the stems occasionally or obstructions get upon the seats so that they cannot be shut; packing will blow out here and there, joints will become loosened and leaky; in fact, there are numbers of petty difficulties that are likely to arise which will require a particular boiler to be shut off pending repairs, independent of the regular suspension of operations for the purposes of inspection and cleaning. To provide for such contingencies it is necessary to insert plenty of valves in the pipes so that one boiler may be shut off independently of another. As accidents are likely to arise at the valves themselves so as to require shutting off main steam pipes occasionally, the writer felt that it was warranted when building the plant for the New York Steam Company to provide duplicate connections to each boiler so that the main steam pipes themselves could be repaired without suspend-

ing operations. It was done in that case by the use of smaller pipes for the duplicates and during the time they were used exclusively, the steam pressure was carried higher. Very many electric light plants have, however, been made since that time, in which every connection has been duplicated of full size, and valves placed in every branch where it was possibly thought any difficulty would arise likely to cause a suspension of operation. In such case the water feed pipes are also duplicated in the same way. In the work of the writer above referred to, the duplication of the feed pipes was provided for by arranging blow-off valves which could also be used as check valves, by leaving slack in the connection of the stems to the valves and then making connections from the pumps to the blow-off pipes. This arrangement answered the purpose perfectly and in fact proved of greater importance than the auxiliary system of steam pipes. It will be interesting to mention that the latter were kept in operation all the time, and used like what is called the "donkey system" on board ship to supply the pumps and auxiliary connections.

18. There has been some embarrassment in selecting a type of boilers for this comparison on account of the very considerable difference in cost. It has been decided to use a price sufficiently high to cover the cost of the better class of what are termed "safety boilers" or those in which the water is contained in tubes, small chambers or comparatively small shells of unusual strength compared to the large shells of ordinary boilers. Tubular boilers either of the horizontal or vertical type are undoubtedly cheaper in the first place, and since, with equally good combustion in different cases, the economy obtainable is increased slightly by increasing the heating surface available for a given power, ordinary tubular boilers are selected when large ratios of heating surface to grate are desired or boilers of the sectional type employed with economizers at the base of the chimney. Increased surface in tubular boilers chokes the draft. It follows, therefore, that generally the tubular boilers do not have the surplus power of the better class of boilers of the sectional type and that therefore when the power varies greatly and the machinery is to be forced for several hours per day to its utmost, as in electric railway work, a greater H. P. of boilers of the tubular type must in general be provided than of the sectional type. Again, some forms of tubular boilers, although showing high

TABLE II.—Showing the effect on the comparison, in Table I., due to reducing the cost of the boilers \$5.00 per Commercial Horse Power.

a	b	H	H ₁	L	L ₁	P	P ₁	T	T ₁	a
TOTAL COST PER NET HORSE POWER PER YEAR.										
FIRST CASE.										
No Surplus Plant, Coal \$3.00 per ton.										
SECOND CASE.										
50 per cent. Surplus, Plant Coal \$3.00 per ton.										
DESIGNATION.		10 hours day.		20 hours day.		10 hours day.		20 hours day.		
		H From Table I.	H Reduced.	L From Table I.	L Reduced.	P From Table I.	P Reduced.	T From Table I.	T Reduced.	
A B C D E F G H I J K L		Dols.	Dols.	Dols.	Dols.	Dols.	Dols.	Dols.	Dols.	A B C D E F G H I J K L
		36.17 34.20 30.86 30.39 27.49 26.77 26.36 25.53 24.85 23.27 25.32	35.23 33.35 30.12 29.70 26.87 26.19 25.79 25.07 24.37 24.80 24.88	70.89 65.55 59.61 57.43 52.82 50.25 49.99 47.27 45.03 43.25 44.43	69.95 64.70 58.87 56.74 52.20 49.67 49.42 46.81 45.45 44.78 43.99	41.82 40.28 36.12 36.28 32.07 31.24 31.33 30.92 30.17 30.20 31.44 32.07	40.48 39.08 35.06 35.30 31.43 32.07 30.52 30.17 29.51 30.78 31.44	76.54 71.64 64.87 63.32 57.65 55.55 54.72 52.66 51.01 51.42 51.18	75.20 70.44 63.81 63.34 57.65 55.55 54.15 52.66 50.59 50.76 50.55	
L	Do. For Probable Maximum Results	24.19	23.78	42.17	41.76	30.81	30.22	48.79	48.20	

economies under the special condition of steady work and careful attention, are not calculated from their construction to run for a considerable time without attention, and any emergency which prevents regular cleaning, chokes them up so that their performance is very much reduced and inadequacy of boiler power soon becomes evident. This is particularly the case with the cheap and, under certain conditions, very efficient vertical boilers with small tubes. In the earlier form of sectional boilers all parts of the boiler were composed of tubes or small sections which would leak at the joints and relieve the pressure much below the explosive limit of the sections. This kind involved difficulties in the way of disengagement of steam, and were inconvenient to repair, so that in the more recent modified type, selected for comparison, all the water exposed to the direct heat of the fire is contained in tubes or small cells and disengagement of the steam takes place in drums at some distance from the fire. With this form of boiler, dangerous explosions are impossible, even when the water is low, and the cost of maintenance has proved to be very much less than for the ordinary types of boilers. It is thought, therefore, that though boiler explosions are rare, the small risk of an accident is sufficient, particularly when repairs are considered, to warrant the use of an apparatus with which a general disaster is impossible. A comparison is, however, made in Table II for cheaper boilers, which shows that the final result is not due to the price of the boilers selected. It has been assumed that sectional boilers for pressures not exceeding 125 pounds can be purchased and erected in place complete with necessary attachments, furnaces, brick walls, connections to chimney, steam and blow pipes and other connections, with fire tools and fire room fittings in place ready for regular use for \$22 per commercial horse-power; similarly the price for boilers erected and connected complete to carry regularly 150 pounds and upward has been fixed at \$25 per commercial horse-power.

19. In column *i* the above prices have been reduced to the prices per net horse-power by multiplying the ratio of the commercial horse-power given in column *g* to 500 net horse-power by \$22 or \$25 in the several cases, when, as would be expected, it will be seen that the price per net horse-power reduces as the economy increases in the same proportion as the commercial horse-power of the boilers required.

20. We now return to column *h*, which shows the cost of engines erected and connected ready for operation. It has been somewhat difficult to obtain satisfactory information for this column. Circulars were issued to different engine manufacturers, and although all responded, and some took special pains to furnish all the information in their power, the resulting data was nevertheless very incomplete, for the reason that few of the makers were prepared to manufacture high speed engines of 500 horse-power, and none of them could give prices throughout the whole list. Again there appeared to be a difference of opinion among the manufacturers as to the *kind* of prices which should be given for such a purpose. Some undoubtedly added a percentage to those for which they regularly sell the same engines in the market, while others evidently stated prices lower than would be furnished under strict specifications. Few of the manufacturers replied to questions as to the cost of erection, stating that such cost would vary greatly with conditions at each location. In some cases, however, the costs of plants complete, including erection, have been obtained which checked well, with estimates made up in detail in substantially the following manner: The costs of the engines at the shop, as furnished by manufacturers, were arranged in order, and the shop price adopted fixed not only by averaging different prices for engines of the same power, but by comparison with prices for engines of different sizes, and in some cases of different types, it being attempted to make a gradation in price from one type to another as nearly as the circumstances warranted. This method is the only practical one, for one manufacturer will quote prices for the same engine to develop either 400 or 500 horse-power, and perhaps in another case at lower pressure or reduced speed even for 300 horse-power. Several engines of different sizes are in some cases made by using the same frame and general details and simply changing the size of the cylinder so that the cost is not greatly modified for quite a range of power. In some cases it was necessary to consider double engines to produce 500 horse-power. The price of engines at the shop had therefore to be derived by digesting all the data based on the several conditions. To these prices were added the cost of foundations as calculated from drawings in some of the circulars, and an allowance was made for pipes, felting and the numerous incidentals which are always required in erecting an engine. The final results, though more

accurate on the average for different parts of the country than would be obtained by a less careful study of the subject, cannot be depended upon for special conditions. It would be the business of any engine manufacturer to claim that he would furnish machinery of a given kind for less than stated, and he could do it by using smaller engines or higher speeds than is customary, or in a variety of ways. The difference in price between an engine at the shop and one fully erected, and in operation, should in all cases be duly considered, and when a large number of engines are grouped on one system of piping for steam and another for exhaust, with condensing apparatus, air pumps and perhaps circulating pumps, the several items of cost mount up quite rapidly. There has been added to the cost of slow speed engines the cost of the main belt and a certain portion of the jack-shaft, so as to put the high and low speed types on the same basis. The allowance will not, however, include the expensive clutches frequently employed. The prices for high speed non-condensing engines with boilers complete, check very well with those collected by Mr. Wm. M. Schlesinger for a book he is preparing with Mr. T. C. Martin, of the *Electrical Engineer*, of which advance sheets have been kindly loaned me. Mr. Schlesinger gives the prices of six plants, varying from 250 to 1200 H. P., with high speed engines of various kinds and tubular boilers of various sizes. The total cost varies from \$50.40 to \$61 per H. P., and averages \$53.70 per H. P., which checks well the \$58.90 given in Table I for such engines with sectional boilers. A comparison for lower priced boilers is however given in Table II. The price given for triple compound engines with boilers, buildings and details complete, checks well with prices kindly furnished by F. S. Pearson, Esq., engineer of the West End Railway, Boston, for the large plant erected by that company. Mr. Pearson considers that \$75.00 per H. P. will be sufficient to complete that work which includes surface condensers not considered in the table.

21. Column *j* shows the approximate cost per net horse-power of the chimney and the buildings required for the steam machinery. These have been based upon the actual cost of various chimneys in actual practice and upon the cost of comparatively cheap buildings to cover the engines and boilers. The prices could be reduced by using very cheap wooden buildings, but are insufficient to provide for elaborate buildings designed to secure architectural effect.

22. Column *k* shows the aggregate cost per net horse-power of the engines, boilers, buildings and chimney as given in the three previous columns.

23. Column *l* shows the amount in column *k* augmented $2\frac{1}{2}\%$ for inspection and 6% for loss of interest during construction, a total of $8\frac{1}{2}\%$, which is designed to cover the expenses of the kind indicated and other contingencies incidental to the construction of a large steam plant or other important work. In starting a company there must be an organization formed in connection with raising the money, procuring the charter and initiating the construction, involving the salaries of several individuals. The engineers to take charge of the work must also be selected before the work is completed and in general very much of the expense must be incurred a considerable time before the plant is put in operation; and even after operation commences, a long time intervenes before everything is working on a sufficiently large scale to secure economy in operation and a return therefrom. Frequently these items are not considered in making estimates. Some of them are of a kind which are not necessarily included in those made by an engineer. Eventually, however, all these expenses must be charged in some way on the books and will usually be placed in the construction account, and it is, therefore, proper to make this charge of $8\frac{1}{2}\%$ in excess of the ordinary preliminary charges for designs naturally included in construction, with the belief that it will in rare instances be sufficient to provide for the several contingencies referred to.

24. An inspection of column *l* shows unexpectedly small differences in the total cost of steam machinery of different types when everything is considered. It is a curious fact that the machinery which as a whole costs least originally is that of fairly good economy. The total cost of non-condensing steam machinery is, on the basis of performance assumed, higher than for more economical condensing engines, on account of the increased cost of the additional boilers, buildings and chimney made necessary by such reduced economy. If it be considered that the feed water per indicated horse-power per hour for the non-condensing engines is higher than would be obtained in particular cases, a comparison with the minimum quantities in column *e* shows that an assumption of the best possible results will not equalize the total cost of non-condensing and condensing engines of similar construction. The more economical engines near the bottom of

the table are comparatively so high priced that even when the reduced cost of boilers is considered, the total price is greater than for the steam machinery of reasonable economy shown near the middle of the table.

25. In column *m* is shown the weight of water which it is assumed will be evaporated per pound of coal. The assumption is $8\frac{1}{2}$ pounds, except in the last case where it has been fixed at $9\frac{1}{2}$ pounds. Although 9 and $9\frac{1}{2}$ pounds evaporated can be obtained under actual conditions readily with boilers of good proportion and construction, it is thought that $8\frac{1}{2}$ pounds is as much as can be depended upon in average practice. It is in fact greater than is obtained in most cases, though less than is claimed in exceptional ones. This rate must be considered somewhat in relation to the price of coal. If cheap coal is to be used which will not give $8\frac{1}{2}$ pounds evaporation, the results must be sought in the column of the table applying to coal of a higher price.

26. Column *n* shows the coal per indicated horse-power per hour, which is simply deduced by dividing the feed water per horse-power, column *f*, by the feed water evaporated per pound of coal, column *m*. We notice that the coal per indicated horse-power per hour decreases from 3.88 to 1.47 lbs., which is about what should be expected for the various conditions heretofore discussed.

27. We next have in columns *o* and *p* the number of tons of coal, of 2240 pounds, required under the conditions stated; column *o* referring to a working day of 10 hours and column *p* to a working day of 20 hours, with coal for one hour added in each case for starting and stopping fires.

28. We have next in column *q* to *x* inclusive, the cost of coal per horse-power per year at the rates of \$2, \$3, \$4 and \$5 per ton; first on the basis of 308 days of 10 hours each, and second on the basis of 365 days of 20 hours each.

29. We have next in columns *y* and *z* the cost per net horse-power per year of supplies and average repairs. There has been allowed 12 cents per day of 10 hours for supplies and 29 cents for repairs, or 41 cents total for a 500 H. P. slow speed engines. These costs are based on testimony in the Fall River suit mentioned in the paper previously referred to. This amount has been increased to 48 cents for the high speed engines, which will probably be insufficient in many cases, but has been assumed correct for the better types.

30. We next have in columns *A* and *B* the cost per net horse-power per year for wages based on \$3 per day of 10 hours for an engineer and \$4 per day for 500 commercial or boiler horse-power for fireman and the labor incidental to passing the coal and disposing of the ashes. The latter amount has been entered fractionally, for although this would be impossible for a single unit it is the only way to obtain a correct progression when considering each unit as a part of a much larger plant. The cost amounts to \$4.77 per day for simple engine in line *A* and \$2.22 for compound engine in line *K*.

31. In column *C* is given the cost of insurance, taxes and renewals per horse-power per year. This is obtained on a basis of $\frac{1}{2}$ of 1% for insurance, which is too low for an electric light plant, and in fact too low for other manufacturing operations except those insured on a mutual plan. Taxes have been assumed at \$15 per thousand on three-fourths of the total cost, equivalent to 1.2%. The renewals for engines, boilers and buildings all averaged together have been assumed at 3.3%, making a total of 5%. The several percentages are believed to be low for general practice, but have been used in the first part of Table I so as to keep within bounds, the influence which quantities proportioned to the cost have on the result.

32. We have in column *D* the amount per horse-power per year to be provided for interest and dividends which has been fixed at the moderate rate of 10% on the capital invested. It should be realized that the interest account should not simply cover the interest on money borrowed or invested to do the work, but a percentage sufficient to pay expected dividends on the capital; in fact, interest and dividends must be considered together. In this country, at least, active business men demand at least 10% on their investments. It may be that they will borrow the money actually required to do the greater part of the work at a comparatively low rate of interest, say 5% to 6%, which the business is expected to pay in addition to a dividend of an equal or greater amount to recompense the promoters for their trouble and responsibility in the matter, so that 10% allowance for interest and dividends is none too much in a growing country. Indeed, it is altogether too small for operations in which the actual value of the plant is represented by a greatly increased face value of securities. Evidently the payment of 5% interest on a bonded issue equal to the cost of construction and 5% dividends

on an equal amount of stock to control the company, or any similar financial scheme based on the same total, is equivalent to an allowance of 10% for interest and dividends, which is the basis assumed for comparison, and this percentage must of course be paid on all expenditures including everything relating not only to the purchase, but the erection of the various details of the steam machinery.

33. Columns *E* and *F* merely sum up the cost per horsepower per year of all operating, current and interest expenditures, except coal, and include therefore the cost of wages, columns *A* and *B*; cost of insurance, taxes and renewals, column *C*; and the interest or dividends, column *D*.

34. We next have in columns *G* to *N* inclusive the *total* cost per net horse-power per year on the basis shown in the previous columns, for coal at \$2, \$3, \$4 and \$5 per ton, first for 308 days of 10 hours each, and second for 365 days of 20 hours each. An examination of the several columns shows clearly that for cheap fuel and short hours the engines of fair economy and least cost give the most economical results when both the cost of fuel and collateral and interest charges are considered. Such a result would be anticipated in comparison with non-condensing engines, but *it is somewhat surprising to find that the compound engines of comparatively moderate price show better economy, everything considered, than the higher priced triple compound engines*, if we reject the results shown in the last line, which, as already stated, it is believed cannot be obtained in average practice. For the 10 hours day, with coal at \$2 per ton, the lowest result is, for the assumed conditions, shown on line *I*, referring to special triple compound high speed condensing engines. Unfortunately more conditions have had to be assumed in relation to this type of engine than for any of the others. They are being made specially for electrical purposes of extra weight and with extra length of bearings, and the prices available would with proper allowance for erection give prices higher than stated. However, the result is very little different from that shown in lines *G* and *H* for compound engines high and low speed, or even for the simple low speed condensing engine line *F*, on the one hand, or the triple compound, lines *J* and *K*, on the other. This similarity in final cost is certainly very interesting, and examining columns *H*, *I* and *J*, referring to coal at \$3, \$4 and \$5 per ton, we find that although the total cost per year in-

creases, the relative cost for engines of different kinds varies but little. At the \$5 rate, the high speed compound engine, line *G*, has fallen \$1.43 per horse-power per year behind the low speed compound engine, line *H*, and \$2.67 behind the high speed triple compound, line *I*, on basis assumed, but the latter with its lower assumed original price and higher coal consumption is holding its own substantially with the higher priced compound engine, line *J*. The same relations practically hold for 20 hours per day with cheap coal, and it is not until we reach column *N* for 20 hours per day and coal at \$5 per ton that the higher priced engines (rejecting as before line *L*) show any decided superiority, and even under these circumstances the difference is comparatively not great.

35. We next examine columns *O* to *V* inclusive, which show the total cost per net horse-power per year for electric railroad and other variable work requiring 50% extra plant to obtain on the average 500 horse-power. That is, it must be supposed that a 750 horse-power plant, or the larger portion of the same, leaving one unit, perhaps, for emergencies, is employed during the times of heavy traffic, and that at other times the power is less than 500 horse-power so as to maintain the average. In making this comparison, the cost of fuel and labor per average horse-power has not been increased. Very great variations of load would certainly change these items, but as all conditions cannot be provided for in one table, it may be assumed that the charge for fuel in the first part of the table is rather high for uniform loads, and that charges for both fuel and labor have not been exceeded for the conditions involving surplus plant in the second part of table. The insurance in the latter case has, however, been increased to $1\frac{1}{2}\%$ as an average on engines, boilers and buildings. The engine renewals have also been increased to 4% and the boiler renewals to 5%. These latter allowances are believed to be more nearly correct than those first assumed for many kinds of work. There are individual cases of boilers and engines lasting a long time, but in many cases the necessary changes in the character of the work done, requires a change of steam plant, so it is safer to charge off for renewals a sufficient sum to provide for conditions other than the actual wearing out of the apparatus. In any case we think it will be granted that these allowances are none too large for electric light plants. The comparisons are as before on the basis of coal costing \$2, \$3, \$4

and \$5 per ton, first for 308 days of 10 hours each and second for 365 days of 20 hours each.

36. Examining columns *O* to *V*, we are surprised at once to find that, although the costs have necessarily all been raised, the general relations for the different engines have been very little modified. For short hours and low priced coal the medium priced engines show, if anything, still better results than on the previous basis, and the higher priced engines only show to advantage for long hours and high priced coal, as shown in column *V*. The results even in this column for the engines referred to in the last four lines (excluding *L* as before) are remarkably near uniformity.

37. Before drawing further conclusions, it is desirable to ascertain the effect that will be had on the results by the use of cheap boilers. As has been stated, it is well known that boilers are to be had in the market at a cheaper rate per horse-power than the safety boilers which have been assumed. A mere examination of quoted prices would make it appear that such boilers can be purchased for \$10 less per horse-power than the safety boilers, but the better types of the latter have much more surplus power than ordinary types of boilers, so much so in fact, that no allowance has been made in previous calculations for a greater boiler power than is required to supply engines with steam, as it is believed that the better class of safety boilers have so much surplus power that in large plants one or two can be laid off for cleaning purposes and the others take up the load. Even less than the rated power can be purchased in starting a plant, and no injury follow from forcing such boilers so as to obtain the power desired. When, however, boilers with small tubes, which furnish heating surface very rapidly at reduced cost, are employed, in general a higher rated horse-power must be furnished for a particular case, either originally or soon after operations are started. Moreover, the cost of extra steam and water connections and valves will be as high as in the previous case, and in general higher, for the reason that the units for such boilers are customarily smaller. It has been decided to make the comparison shown in Table II. on the basis that boilers will be employed costing \$5 per horse-power less than those referred to in Table I. and from the modification thus shown, the effect of a further reduction if found possible can be estimated.

38. Table II. shows in columns *H*, *L*, *P* and *T* the total costs

per horse-power per year shown in columns of corresponding numbers in Table I., all being on the basis of coal at \$3 per ton ; the first two named being for the 10 hours and 20 hours day without surplus power, and the last two named being for the 10 hours and 20 hours day with surplus power. In connection with these columns and distinguished by the same letters marked sub-1 are corresponding columns showing the costs per net horse-power per year with the interest and other charges affected by the first cost reduced proportionally to a reduction of \$5 per commercial horse-power on the original cost of the boilers. An examination of the parallel columns shows at once that the effect has been to favor the engines, requiring the use of most fuel, for the evident reason that, as they require more boiler power for a given net power, the reduction for them is proportionally greater than for the higher priced engines. The differences are comparatively not great, but sufficient to show the effect of reduction in this direction. The same effect would result from reducing not only the cost of coal as previously stated, but the cost of handling and firing the same.

39. Evidently, however, any decrease found possible in the cost of engines or of the numerous attachments and appurtenances necessary or claimed to be necessary in connection with a steam plant, and which do not increase in cost proportionally to the commercial horse-power, will decrease the interest charges in a higher proportion for the more economical engines and thus secure economy both by saving of fuel and by saving of interest. These considerations, though not governing ones, since interest is only one item of expense, show the desirability of exercising careful judgment in the details of a steam plant. There will be no economy in selecting poor material or in hurrying matters so as to secure cheap work. Everything must be of the best in the sense of being the best adapted for the purpose. The tendency to put in numerous details, each by itself of small cost, needs, however, to be checked, as such items amount in the aggregate to a large sum. It is recommended that the purchase of the various devices which are being urged upon the owners of steam plants should not be consummated unless they will surely save, say, 25% of their cost annually. It will be observed that the columns of the table foot up a percentage proportioned to more than two-thirds of this, and as the attention and repairs of miscellaneous apparatus is great, the additional percentage is not only

thought to be warranted but to be perhaps insufficient in some cases.

40. The rules adopted for calculating the various columns of Table I are shown by algebraic formulæ the notation being in terms of the letters designating the several columns.

41. The comparison shows the non-condensing engines inferior at every point to condensing engines, and even if better results be obtained for the former in certain cases, still, as has been referred to before, the principal difference will be found by causing the quantities in column *f*, Table I, to approximate more nearly to the minimum quantities in column *e*. Some forms of engines undoubtedly accomplish this, but it is believed that the quantities stated are nearly correct for average good practice, with variable loads. Non-condensing engines are wasteful of fuel when heavily loaded on account of low expansion and at light loads the back pressure forms a large proportion of the total resistance, whereas condensing engines will maintain their economy through a wider range on account of the reduction of the back pressure. The back pressure must particularly affect the economy of the new triple compound engines when used non-condensing. It does not seem possible that such engines used non-condensing can for irregular loads show any economy over well designed compound engines operated non-condensing, unless the steam pressure is carried to 200 pounds or upward, and the size of the cylinders carefully proportioned to the average load.

42. It may be claimed that it is unnecessary to add 10% for interest and dividends, for the reason that nearly every large owner of steam machinery can borrow a large proportion of the money required to construct the plant at a much lower rate of interest. This reasoning is good in some cases and not in others. If the manufacturer can in his regular business pay 10% or more on the capital invested, it is more economical for him to use his credit and borrow money to extend his business than to put such money into a steam plant at a lower rate. For such conditions there is no question but that every expenditure should be charged at 10% or upward. The case is different with municipalities which can borrow money at 3% and 4%, but this after all will not make a great difference in the results, as interest is only one of several items of cost independent of coal. If instead of adding 10% for interest and dividends in column *D* we add only 5%, the difference between the amounts so added for different

engines is very small; for instance, it would make only 42 cents per horse-power per year difference in engines in lines *I* and *J*, which is exactly the difference between the total cost per horse-power per year for these engines with coal at \$3 per ton as shown by column *H*. That is, for this particular comparison the cheaper of the two engines is 42 cents per horse-power per year, more economical when 10% is added and of the same economy when only 5% is added. If we compare the engines referred to on lines *I* and *K* in column *H*, we find that the cost per horse-power per year is 47 cents less for the former, with 10% added for interest and dividends, and that the latter is 20 cents per horse-power per year more economical if only 5% be added for interest and dividends.

43. It is true also that the $8\frac{1}{2}\%$ added for inspection and loss of interest during construction, in column *I*, would probably not be expended in making additions to a whole plant, though rather insufficient than otherwise for original construction. The rejection of this item will not, however, make a great difference. It has not been included in ascertaining the cost of insurance, taxes and renewals, shown in column *C* and if 10% of the increase be charged in column *D* it is only 10% of $8\frac{1}{2}\%$ or .85 of 1%, and so would affect the result only about one-sixth as much as the former presentation.

44. A little more careful examination of the table shows, as was substantially stated at the outset, that it is not the interest charges which principally cause equalization of total costs in the operation of engines of different kinds. The principal difference is due to the fact that all the other expenses except coal and interest, are very nearly constant and the interest intensifies the difference by directly neutralizing, so far as it goes, the economy due to decreased coal consumption. This is made more clear by the following tabular presentation:

45. The table shows that the collateral charges, line (2), excepting interest, are substantially the same, and about equal to cost of coal, Col. (1), for the economical engines, and that the slight increase of interest, line (4), for the more economical engines tends to neutralize the slight increase of economy of coal shown on line 1, so that, though the costs for engine *I* still remain less than those for engine *G*, they are also less than for the more economical engine *K*.

46. In conclusion we will say that when this investigation was

	Simple High Speed Non-Condensing	Compound High Speed Condensing	Special Triple Compound High Speed Condensing	Triple Compound Slow Speed Condensing
LINES OF TABLE I.	<i>A</i>	<i>G</i>	<i>I</i>	<i>K</i>
(1) The costs of coal at \$3.00 per ton, Col. <i>r</i> , for a ten hours day are for engines stated in the headings at the right.	\$19.09	\$ 1.57	\$9.84	\$8.91
(2) The collateral operating expenses, ex- cluding interest, are (Line <i>E</i> —Line <i>D</i>)	10.69	9.18	9.06	9.11
(3) The interest charges, Col. <i>D</i> , are - -	6.39	5.61	5.95	7.30
(4) The total costs, Col. <i>H</i> , are - - -	36.17	26.36	24.85	25.32

instituted it was believed, as had indeed been hinted by others and proved for extreme cases, that under some conditions as to the relative prices of economical types of steam machinery compared to price of coal and number of hours operation, the saving in fuel would not warrant the increase of first cost, but it was not known that this would occur within the limits of ordinary practice as the comparison shows. It is hoped that the conclusions and the facts upon which they are based will be very closely examined by engineers and manufacturers, and any facts or reasons confirming or varying such conclusions be fully presented and discussed.

47. This paper should not be considered a criticism of the practice or views of others, or serve to discourage the higher development of the steam engine. On the contrary, an investigation of this kind, whatever the result, is calculated to broaden the view by taking into consideration more of the conditions of the problem, and thereby enabling the engineer to secure the best results for each particular case. The tables do show for short hours or low priced coal, or both, that types of steam

machinery to secure the greatest economy of fuel are not warranted, but by the same tables it is found that for longer hours and the higher prices of coal considered, the more expensive machinery begins to show a commercial advantage which evidently increases as the price of fuel increases. In some cases other conditions must be included for a complete solution of the problem. For instance, in large steamers making long voyages economical machinery secures in addition to the saving in the cost of fuel, a saving in the space required to carry the machinery and fuel, and thus increases almost in a geometrical ratio the efficiency of the ships. This may not be true for vessels making very short trips, or stopping a large proportion of the time in port. The very large expenditures made by some mining companies to save fuel by the use of expensive steam machinery of special design, has been fully warranted by the long hours and and high price of coal. The enormous mechanical operations at the Calumet & Hecla mines gave the profession unequalled opportunities, which have been grasped in the most creditable manner by our distinguished co-laborer in the engineering field, Mr. E. D. Leavitt, who has reared there a series of remarkable monuments of engineering skill with an expense warranted, doubtless, by the conditions. The development of the great West is, however, now so modifying the conditions that a change of policy may be initiated even at the Calumet & Hecla mines in the near future. During a recent business investigation with an electrical outlook, the writer ascertained that the prices of coal in Duluth and Superior, beyond the Calumet & Hecla peninsula, are even now reduced nearly to those ruling on the seaboard, which result has been brought about by the construction and operation of large whaleback steamers which take wheat eastward and coal on their return trips.

48. Until quite recently the construction of pumping engines of special design and expensive construction was warranted, even for locations near lines of communication with coal fields. At present, however, pumping engines of good economy are being manufactured regularly, as a business, at a comparative cost that will make the still more economical but much more expensive machinery less in demand than formerly. The further perfection of the steam engine will not be hindered by these facts, for with the development of our mining industries at great distances from the coal fields, the closest economy in the use of fuel will

secure the best commercial results. In order, however, to secure such results for our growing enterprises, electrical and otherwise, in the cities and towns along lines of communication already established, it is believed that the field will be occupied by cheaper engines of simple construction, which, though not securing the maximum economy of fuel, will so reduce the capital upon which interest and dividends are to be paid, as on the whole to represent not only better commercial policy but better engineering, because based on more complete conditions.

SUPPLEMENT RELATING TO WATER POWER.

49. It will be impossible in this connection to make a satisfactory comparison of the relative advantages of steam and water power, under different conditions. The cost of steam power has, however, in the previous pages, been considered on a somewhat different basis than has heretofore been customary, particularly by including the interest and certain miscellaneous charges in the operating expenses, making the minimum practicable cost per horse-power per year appear higher than has been stated by others, so if the cost of water power calculated on the ordinary basis were compared with this increased cost of steam power it would cause the water power to show an unwarranted advantage. It, therefore, appears necessary to make a brief examination in the form of an inquiry as to what amount can be paid for the development of a water power in competition with steam power. The average cost of developing a water power cannot be based on locations where the natural conditions are specially favorable, nor on a case like that at the Falls of St. Anthony, where an enormous water power was developed at a minimum expense amid surroundings apparently permanent to those who had not studied former recessions. In due time, however, the water undermined the hard limestone cap defining the falls, which had already been worn through above, and started a new channel through the underlying sandstone, thereby threatening to change the falls into a series of rapids extending miles up stream, when by the intervention of the general Government and the use of large appropriations, on the plea of preserving navigation, with some private contributions, a concrete dike or dam was built in a cross tunnel in the sand rock back of the falls, from a firm foundation up to the limestone cap, and the falls and incidentally the water

power saved. Ordinarily such disasters must be provided for from the accumulations of an ample depreciation account. Information of great value as to the possible cost of the general development of a water power may be obtained from the experience on the Merrimack.

50. Prof. Swain has stated in the Census Reports the costs of several of the principal structures at Lawrence and Lowell, aggregating \$650,000 at the former place and \$752,000 at the latter place. There are wing dams and probably other improvements apparently not included at Lawrence, and the costs of the greater portion of the canals at Lowell are not mentioned. In addition to the above items must be added the original cost of the land and large expenditures which have been made by the several mill owners jointly for works to control and regulate the flow from several large lakes on the watershed and thereby help the low water flow of the stream. The testimony of the mill owners in various suits relative to water power shows that the original costs of development on the Merrimack were so high that it has been customary to gradually "charge off" from year to year a portion of the cost so that the final results would show better interest on the apparent capital invested. It is believed to be safe to assume that the original costs in connection with the Lawrence water power have been about \$1,000,000, which is less than the amount stated to have been originally paid in, and that those for Lowell have been considerably more. The original costs at Manchester could not have varied greatly from those at Lawrence. Additional hydraulic plant has, however, been put in at all these places to utilize "surplus water" or that flowing in excess of the assumed low water capacity of the stream, and steam plants are also employed to keep up the power when the stream is low. The work is principally of a kind that requires steam for manufacturing purposes, independent of power, the year around for slashing, dyeing, etc., and steam also is necessarily required in the winter to heat the buildings. These other uses somewhat offset the cost of a steam plant, while the expenditures for surplus power by raising the average power developed on the stream, really lower the average cost per horse-power of the general expenditures which have been made to utilize it. There were originally sold at Lawrence 128 mill-powers aggregating 8,700 net horse-power and a little more power at Lowell where the fall is higher. The leases permitted the use of the water for 15 or 16 hours per day. In practice, however, but little water is used

during more than 60 hours per week, and the dams are so large that during low water little water is wasted and a larger power on a 10-hour basis is utilized, which fact together with the use of surplus water when available, probably brings the net power available at Lawrence up to 13,000 horse-power on a 10-hour basis throughout the year, and somewhat more at Lowell.

51. On the basis of a cost of \$1,000,000 the general plant at Lawrence has therefore cost about \$77 per horse-power and somewhat more at Lowell. Independent of this, the mill owners have incurred large expenses in erecting turbines and hydraulic connections from the head canals to the lower levels. These costs have been estimated by Mr. Main at \$45 per horse-power, including provision for surplus water, or an average of \$65 per horse-power for the average power utilized.¹ Adding this to \$77, the general cost stated above, we find that the total cost of developing the water power on the Merrimack has been about \$142 per horse-power, which it will be shown is about the limit of cost at which water power can be developed in competition with steam. The Merrimack owners are, however, obliged to add to this cost the greater part of the cost of a steam plant for use when there is no surplus water, which still further increases the capital account.

52. It has long been known that the water power on the Merrimack had cost so much for development, that could the expenditures be recalled it would be more economical to locate where coal can be obtained at cheaper rates, and steam power used exclusively. This was true before mill engines were constructed as economically as at present. Now the preponderance is so great, that unavoidable errors of fact as to the details of the original costs will not change the illustrative value of the presentation. It is true, notwithstanding these facts, that a new water power is being developed at Sewall Falls, near Concord, N. H., but it appears to be limited to the low water flow of the stream, and it is not known whether it will assume part of the original cost of the reservoir systems.

53. The highest allowable cost for the complete development

1. "The Value of a Water Power," by Chas. T. Main, vol. xiii *Trans. Am. Soc. M. E.* The price stated seems high, but should be known to Mr. Main who resided at Lawrence when the paper was written. He has, however, overlooked the items of cost of development referred to above, not mentioned by Prof. Swain, and therefore gives \$130 as the total cost, instead of \$142 stated in the text.

of water power from the dam to the jack-shaft appears to be about \$140 per horse-power utilized on a 10 hour basis. If we consider that accidents are liable to happen to the best constructed hydraulic work, we should charge at least $2\frac{1}{2}\%$ of the original cost for depreciation, say $1\frac{1}{4}\%$ for repairs and about $1\frac{1}{4}\%$ for taxes, or about 5% independent of interest account. If then on the principles above developed we charge 10% to an account for interest and dividends, and allow 2% for operating expenses, the total annual charge becomes 17% of the original expenditure. At an original cost of \$140 per horse-power, 17% represents an annual cost of \$23.80, per horse-power per year, or about the same as shown in the tables with economical engines, and coal between \$2 and \$3 per ton. Generally, however, there will be one company to furnish water power and others to utilize it, which will have the effect of increasing this 17% so as to make the balance in favor of steam somewhat greater. This statement of course only applies to conditions where simply power is required, and no large quantity of water is necessary for purposes other than for power. When the power is used for 24 hours per day instead of 10 hours, a much greater original cost is permissible.

54. When the power of a waterfall is to be delivered at a distance, the allowable cost of actually developing the power must be decreased by that necessary to transmit the power and actually deliver it to a jack-shaft at a given distance. An electric transmission is undoubtedly the most economical for such a purpose. If we add to the cost of the electric dynamos that of the buildings, of the hydraulic connections to the canals, of the turbines, of the line and of the installation, and finally add the cost of the motors, so that the power is according to the assumption delivered to a jack-shaft, the total cost of what may be called the "electrical transmission plant" cannot probably at present prices be put in for \$140 for each net horse-power delivered, so on a 10 hour basis no expenditure could be allowed for the general development of the water power, but only for the simplest hydraulic connections to existing canals, etc. If, however, power can be sold throughout the whole 24 hours, more than double the price can be obtained for the same, and this will warrant doubling the total cost of development unless a greater percentage of income is desired. As the cost of the electrical plant remains the same, the whole allowable increase may be applied to the de-

velopment of the hydraulic plant, thereby entirely changing the conditions.

55. The writer has not hesitated to recommend an original expenditure of \$200 per horse-power for a combined hydraulic and electric plant near large cities, where not only the customary income due to incandescent and arc lighting and the use of small motors at high rates would be available for comparatively short hours, but where the industries were such that large units of power could be sold at remunerative prices on a 24 hour basis. Even higher costs for development would appear to be warranted in some locations, but there is no general rule on the subject. The allowable expenditure in a particular case can only be determined from calculations based on the actual conditions.

DISCUSSION.

THE PRESIDENT:—Members of the Institute, you have heard the very interesting paper which has been presented by Dr. Emery. I think the impression which many of you have received is the same as my own—of surprise that there is so little difference between the total cost of power for the different classes of steam engines. Any one who has been called upon to make a selection of a steam plant and has received from fifteen to twenty bids from different builders, together with the claims for economy made by each, has been much in doubt as to the wisdom of a final judgment. I must confess that I myself have often been confused by the conflicting claims, and I think the paper which has been presented to-night will aid every engineer in settling these oftentimes puzzling questions.

The conclusions which Dr. Emery has reached in the matter of the use of water power in plants for the electric transmission of power is similar to that which I arrived at some time ago. Before I go into any details, however, I shall ask Professor Forbes, who I see is present, and who by reason of his experience and his present connection should be well qualified, not only to give us his views upon steam plants, but particularly upon combined hydraulic and electric plants, to say a few words upon this subject. I see that we have also with us some members of the American Society of Mechanical Engineers whom we wish to hear.

PROF. GEORGE FORBES:—Mr. President, since you are good enough to call upon me to make some remarks I will rise, but I fear that I shall not have a great deal to say that will be of any value. The paper was only put into my hands a short time before I arrived here, and it is one which requires a good deal more attention than from hearing it read or the slight glance I was able to give it before arriving here. But everybody, I am sure, must appreciate, even from hearing the abstract read what enormous importance this paper is going to be to us all. No doubt there are many others here, who have been in the same position in which I have been placed in the course of the last year, who have had to make a special examination of this very question, and all those who have had to deal with the utilization of large quantities of water power, estimating the value which that water power is to those who are exploiting it, must have been forced to do what they could to estimate the value of the horse-power when developed in the most economical means by steam power. I have in these investigations during the last year had the good fortune to be assisted by the experience of some of the most experienced engineers in this country, including one whom we all respect, who is mentioned by the author of this paper, Mr. Leavitt; and I would only say generally that the conclusions which have been come to by myself, and those who have given me their assistance agree

extremely well with the conclusions at which Dr. Emery has arrived. I must say that Dr. Emery has put the case in a much more general way, and much more applicable to a great variety of circumstances that actually do exist in practice than any estimates I have ever seen of the actual cost of the horse-power, and consequently it is possible for us in any particular case that we are considering, to pick out the conditions which most nearly approach what is in the case that we are studying. And while I may say that some estimates I have seen of the cost of a horse-power per annum, especially on a ten hours' a day service come out a little below what Dr. Emery has produced, I must add that in those cases certain items of expenditure have been omitted, and in the cases where a lower estimate has been arrived at, the compiler has been professedly trying to produce the lowest figure which the users of water power would ever have to contend against.

I would feel that it is hopeless, without having given a great deal of time to prepare remarks on this paper, to say anything much to the point. But I would ask the author one or two questions about it. In the first place as to the cost of the coal, I noticed that the heat producing power of the coal is assumed to be the same in all cases. Now I fancy that these tables may lead to a little misunderstanding in the minds of some. I imagine some one taking up this table and saying: "Now what will it cost us at such and such a place to produce a horse-power per annum? There is coal purchasable at this place at \$2.00 per ton. There is also coal purchasable at \$4.00 per ton. He will naturally say: I will choose the coal at \$2.00 per ton. That gives him a certain definite price on this estimate; but, of course, the slack at \$2.00 per ton would only produce about one-half the heating power of coal at \$4.00 per ton. In giving the price of coal it seems to me it ought to be mentioned what the calorific power of the coal is, and I would ask Dr. Emery whether he has in all these cases considered the calorific power of the coal practically the same.

I would ask Dr. Emery whether he considers that 500 horse-power is a sufficiently big amount to be considered. I mean are the standing expenses of a 500 horse-power plant sufficiently divided over the power to make it fair? If you went to 10,000 horse-power, for instance, would the standing charges be less in proportion to the horse-power, or is 500 horse-power sufficient to take up the whole of the value of the fixed expenditure? That is to say; are all the brains, and all the bodies that are at work on the plant fully occupied with 500 horse-power or would a larger unit modify the result?

I will not take up the time of the meeting with remarks which I feel are not of very great value and I will only make a few remarks about the supplementary portion relating to water power. The cost of putting in the plant has been taken at probably \$140

per horse-power without electrical transmission. Now it seems to me it is almost an impossible thing to make a definite estimate like that. The cost of the water power applied, depends so entirely upon the local conditions in the first place, and secondly upon the magnitude of them. Where you have got a large head, the cost is generally very much less than where you have a very low head. When you have to dam up a river, of course the expense per horse-power of the preliminary work is generally much greater than with a waterfall, and of course the cost of the actual turbines is very much greater when we have low heads than where we are using a very considerable head. Another point is that the cost per horse-power in the use of water power diminishes enormously with the magnitude of the works. When you are dealing with 100,000 H. P. the cost for each horse-power becomes very much less indeed. I should say that this \$140 was a price that would be fair for a moderate fall, and for very few thousand horse-power. But when you come to larger amounts I think it would be considerably less.

The concluding paragraph of the paper I most thoroughly agree with, as to there being many cases where \$200 per horse-power would be not too expensive in order to start work for the combined hydraulic and electrical plants in large cities; also, I agree with the writer's remarks that every single case must be computed from the beginning, and the comparison made depending on the particular conditions of the particular place.

THE PRESIDENT:—I wish to say a few words concerning the transmission of power by electricity over long distances with water power as the prime source of energy. I have always tried to avoid being over-enthusiastic in dealing with a commercial question of this character. The habit is too common to assume, now that electric transmission is a possibility, that possession of a water power is necessarily something of a bonanza, and that all that is necessary to convert it into tangible wealth are a few electrical adjuncts. Both the economies and the possibilities in electric transmission are overstated, too many conditions are overlooked, too many possibilities of failure ignored. I made the statement some years ago that it was very questionable whether in an ordinary case, transmission from a water power to a city 20 to 25 miles away with reconversion in a sub-station and re-distribution for lighting or power purposes, was an attractive commercial enterprise, and that if a man wished to distribute power in a manufacturing district he would probably do better to put in a well equipped steam plant of large size, well located with regard to railroad facilities, with supply of coal at reasonably low rates, and distributing at a constant potential of 500 to 600 volts, than he would to attempt to replace the steam plant by a system of electric transmission with water power behind it 20 miles away. I believe the general statements which Dr. Emery has given here to-night confirm this conclusion, and that we should avoid expecting too

much from the transmission of power by electricity. I am not authorized to make any statement concerning the intentions of the promoters of the enterprise with which the last speaker is connected, but I believe that I am safe in saying that this great development of water power of Niagara Falls, which is so interesting from the standpoint of the hydraulic engineer, is not designed so much for transmission of power to a distance as it is for local transmission, and for the local development of manufacturing industries requiring large units of power. The electric railway engineer is frequently called upon to pass upon the question whether for railroad purposes it is possible to use water powers even 10 or 15 miles away from the centres of distribution, and he cannot but appreciate the lack of sound information upon that subject, and the folly of many of the visionary assumptions made by railway managers with regard to this problem.

PROF. FORBES:— Might I say, as a sequel to what you have just stated, of course the question of the cost of the work at Niagara, we have worked out very fully and I think I may say that we know what it is going to cost, both the electrical transmission to Buffalo and everything, but you will readily see that it is hardly possible for me to speak very freely about that just at the present time. But as to the question of transmission to a distance, although it is naturally the desire of those associated with it to develop the power in the immediate vicinity, in the meantime the extra cost of transmission to a distance of 15 or 20 miles is almost insignificant. When the details of these plans are published you will be astonished to see what a very little difference that really does make when we come to the actual machinery that will be put down.

THE PRESIDENT:— Perhaps I do not make myself sufficiently clear in that matter. Take the case at Buffalo for example; let us see how electricity is used there. There are, generally speaking, the arc and incandescent light plants, the stationary power service and the railroad systems. The arc lamps run on constant current circuits with varying potential. Some of the incandescent lights probably run on alternating current circuits; others run on 110 and 220 constant potential circuit. Railway motors run in a 500 volt constant potential circuits. These various systems of distribution are distinct in themselves. They have practically but one thing in common, that is, they are driven by steam engines. The moment you leave the belt of the steam engine or its coupling and go to the dynamo, the character of the transmission is changed. Now to operate these various systems from a distant source of power there is only one thing that is practically possible, that is to substitute for the boilers and engines in the several stations represented by different financial interests, or in some common station controlled by all, motors driven by the electric plant 20 miles away, which is in turn driven by turbine wheels. The substitution of the secondary part of this plant

is not practicable; it has a character determined by the local demands and conditions. There is undoubtedly a field for the transmission over long distances of large units of power for special purposes, and also under conditions where the cost of coal is prohibitory and where perhaps it cannot be obtained at all, but I think that from a general commercial standpoint the statement I have made will be found correct in practical experience.

I appreciate that Professor Forbes is in a somewhat delicate position in speaking of what is to be done at the Niagara plant, and perhaps I ought not to have suggested so plainly that he was somewhat better posted than most of us as to the actual cost of transmission for the distances in question, and for the larger units.

I understand that Mr. McElroy is present. If so, we should be glad to have the pleasure of hearing from him.

MR. SAMUEL MCELROY:—To an engineer who has been a long time in practice, a paper like this, replete with the study of a profoundly analytical mind, comes not only as a most valuable contribution to its subject matter, but as a characteristic index of the professional progress of the day.

The time when many professional men were much troubled with petty personal jealousies, and with the idea that their shop secrets were their most valuable stock for employment, has happily been changed. The advanced progress of science, keeping step with, but always in advance of, the material progress of the country, and the beneficial results of society life, have done much to improve the systems of mutual help, and to broaden the standards of professional service, and the result, as one of various indications, is shown in papers which condense in a few columns, a wide range of experimental and practical research and result, for the direct benefit of professional brethren.

We have then, rising above the class which is content with a low standard of work, and adds little to the general fund of information; and the class which dwells continuously in the confined atmosphere of school-boy mathematics, rapidly developing into splendid, aggressive life, the men of true professional dignity; who neglect no details which involve principles, but give principles their true rank. These are the burners of midnight oil; men who love their work for its own sake, and not for what it pays; who are too high-minded to waste time in personal jealousies; students too ardent to turn aside for common places; and ever ready to put their most valuable acquisitions at the service of their professional brethren, as such papers as this illustrates.

One of the specially valuable features of this paper is its careful condensation into a brief space, of a wide range of experimental practice, and how a wide grasp of such practice simplifies apparently contradictory or complicated conditions, every experienced engineer learns, the more he learns.

In the feverish spirit of the day, which for want of just this balance of forces, tends to run to excess after every new theory,

very great waste of time and money is made, which better habits of concrete analysis would have corrected. We go through spasmodic public excitements often, which are only spasmodic. Not so very long ago, the whole railway world was astir over the merits of the "broad gauge" railroad track, and trunk lines like the Erie and others, must have six and seven-foot gauges. Some years after, the same fever ran to a three and-a-half feet gauge; and it is only lately that common sense has brought our general railway system into standard gauge, and even this, the pedagogues of the profession, are continually tampering with.

The question of cost of steam power, in itself, and as developed by different classes of engines adopted, or now being adopted, is here carefully analyzed in its proper commercial condition. Steam power, we see here, means something more than a boiler, a cylinder and a line of shafting. It means not only boiler plant and cost, with all the accessories; not only engine plant and attachment; engine house, chimney, and appurtenances; coal supply, combustion rate, and cost; but other conditions are important. There are daily operation as to running time; relative engine friction; pressure economy; feed water temperature, evaporation, spare pipes and valves; repair, depreciation, supplies; interest on construction and plant; inspection, insurance, taxes, dividends, surplus power and like conditions, which enter into the general problem of use and cost, and are here carefully analyzed and tabulated.

As to these analyses, their basis of arrangement is so clearly explained that special corrections for special cases can readily be applied.

As, in my own expert practice, I have frequently been required to demonstrate the economy, fitness, and special value of water power, if I should venture any opinion on the valuable analysis here made, of comparative steam and water power, it would be to say only this:

That it is quite certain that water falls and flows to the sea, by gravity, much more cheaply than coal can be mined, and is likely to outlast coal; that water power plant is far less expensive, as a rule, than that of steam, and its daily care much less expensive; that at the centres of such power, Lowell, Lawrence, Holyoke, Cohoes, etc., their common annual rental of about \$20 per H. P. (ordinary mill day), has induced the most elaborate outlay of capital, and resulted in very remunerative income.

I think, therefore, that on general analysis, water power does not cost as much as steam. While it must be admitted that very expensive reservoirs and other structures, as at Lowell and Lawrence, aggregate what Dr. Emery's analysis shows; yet at Lowell the Central Pacific mill prefers in low runs to pay \$60 per H. P. for surplus water, to using its own steam plant; that for somewhat large consumption of special power, \$3.00 per week is a common steam power price at Lowell, Boston, New York and other places.

The estimated cost of development on the Hydraulic Tunnel of Niagara is about \$2,238,750 for a capacity of 119,000 H. P., or about \$10.50 per H. P., for slopewalls, cribs, races and gates, and tunnel. The rates, as published, are for 5,000 H. P. or over, \$10 per H. P. per year; 4,500 H. P., \$10.50; 4,000 H. P., \$11, down to 300 H. P., \$21. On the old Hydraulic Canal, powers have been leased as low as \$4 for 600 to 1,000 H. P., and \$5.30 for 250 to 300 H. P. Such leases are, of course, improperly cheap, as are, in fact, the general rates of the new tunnel.

On the Kennebec River, Maine, I found a working power, at Carritunk Falls, under 28 feet fall, of about 7,000 H. P. This river, on its upper basins, has remarkable natural reservoirs of about 229 square miles, with about six feet available storage, in a main basin of 2,860 square miles. A main dam of 80 feet controls the flow, and nature has singularly formed the races and wheel pit; so that the cost of these items is much less than that of Niagara.

In cases like this, then, the superior economy of water power must be conceded; and in pulp mills, as at Carritunk, the large quantity of water needed is also an important item of cost.

These, however, are not criticisms on the elaborate and most valuable paper of Dr. Emery; they furnish modified conditions of use, which no engineer will apprehend and appreciate more thoroughly than he.

THE PRESIDENT:—I notice that Mr. McElroy in his interesting remarks has omitted mention of a rather well-known water power near by, and that is the Housatonic. My attention was called to it a short time ago, and although I have forgotten what the rates given were, my impression is that the price there, is considerably higher than those just given in other instances.

MR. McELROY:—I am not able to say definitely as to that. Of course there are other cases. The company at Paterson, for instance, charges very much more. Their rates are more than double.

THE PRESIDENT:—Is Mr. Holloway of the Mechanical Engineers present?

MR. J. F. HOLLOWAY:—Mr. Chairman, I had no expectation of saying anything to-night, but I read with pleasure the paper which Dr. Emery has prepared, and I wish to say that I agree heartily with my friend, Mr. McElroy, in the complimentary remarks he made about the paper. The paper is one that will be of great value to mechanical, as well as electrical engineers. It is evidently the result of a great deal of study and care on the part of the author, and in its result it is to some extent surprising; and yet after all, it coincides very closely with ideas that I have had all of my life—that this is a world of compensation; that we do not get all the good things in one place, without having to take some other things that are not quite so good.

The results he shows are as between the more common, and

the highly refined engines, and the ultimate results that are shown in his paper, are not so widely different, and that will be, I think, a matter of some surprise to many, until they investigate the matter in the direction and to the extent in which Dr. Emery has investigated it. The common idea is, that to get the best results, you must get the most refined mechanism, and considerable money is often spent in that direction without knowing how much in other respects, the total value of the saving is brought down to the results obtained by the plainer and more common machines.

Referring to the water power question, I know very little about that, except that it occurs to me that it is hardly a fair comparison that Dr. Emery has made between the steam engine and water power, in the location which he has selected. I think it would have been better to have said that he had made the comparison with a place where there would be a good water power if there was water. If you go to all the expense of arranging for using water, and then half the year you do not have water, of course that must add largely to the ultimate cost of water power.

PROF. JOHN H. BARR:—I came down here this afternoon to hear the third reading of this paper. I had the privilege a short time ago of hearing a dress rehearsal of it, and read it to-day on the cars. I hope this, however, is not the final reading as it is one of the things that grows on me. I thank you for the privilege of taking part in this discussion, though Dr. Emery has left little to discuss. The previous gentlemen have expressed their appreciation of this valuable paper to the engineering profession, in which I wish to concur.

I noticed a reference to the condition of affairs at the Calumet and Hecla Mines. My first engineering experience was gained at the Calumet and Hecla Mine, and, while I was there in a subordinate capacity and perhaps not entirely competent to judge of things, I think it quite probable, if not certain, that the conditions have by this time been so modified, that a different policy might be pursued with economy, so far as distribution of power is concerned. The great work done at Calumet by Dr. Leavitt, is of the highest interest to engineers, and if he has kept his eye rather constantly on columns *c* and *f* of the table given in this paper, it can be said that few men have done as much with a pound of coal as he.

The Falls of St. Anthony is cited as an exceptional case where nature has greatly favored the locality in water power; and while its water power had a very important influence in the development of the city located near it, I doubt if its present influence is as great as most people think. I believe that steam mills at other places can now compete on very fair terms with the mills on the water power at St. Anthony. The supply of water is so variable that all the more important mills have to have large steam plants—steam plants sufficient to practically run the entire mill. The in-

terest, and all costs except running expenses, go on for this part of the plant, whether the mill is run by steam or water. The cost for labor also is largely maintained whether run by steam or water, because the engineers have to be employed throughout the year in order to have them when needed. The value of land and high taxation, or rent, puts these mills at a disadvantage, largely compensating the gain due to running by water part of the time.

MR. C. O. MAILLOUX:—In using engines for electrical station purposes, the tendency of modern practice, even with slow speed engines is to do away with the jack-shaft and to use the power either by belting from the engine direct or by attaching the armature direct to the shaft. Hence in a large number of cases the power of the engine will all be utilized excepting a very small percentage necessary for its own friction; and one need not, therefore, allow ten per cent. more for loss in jack-shaft or other intermediate transmission. This, of course has a direct bearing on the initial cost of the engine and the cost of maintenance, and indirectly upon the total cost of power per annum.

In regard to the utilization of water power when used to generate electricity to transmit to a distance, there is one factor that appears to me to be of importance, as affecting the question whether a given transmission scheme is financially practicable or not. I refer to accessory machinery and apparatus, particularly that needed for regulation and control, the importance and the cost of which I think is often underrated if not neglected, in making estimates on the cost of machinery necessary to utilize the energy of water power by transmission to distant points. I met a party some time ago who is operating an electric railroad by water power, and was not particularly happy over it, even though the power cost him but little. He said the principal trouble was in the great fluctuation of pressure, the voltage varying from 300 to 600. If several cars happened to start, or to be going up grade at the same time, the voltage would come down to 300, but if some of the cars stopped, the dynamo would raise the E. M. F. up to 600 or more. I asked myself, while thinking over this case, what would be the result when transmitting 5,000 horsepower electrically, from a generator driven by a turbine, supposing the load was suddenly and totally relieved by the circuit being opened through a main fuse blowing out, or a break in the wire, or supposing it were suddenly thrown on, without giving time for the governor to act; or again suppose the load were constantly fluctuating as it does on most railroad circuits. It occurred to me that something would happen of interest to science, and possibly the coroner also. We can hardly have fly-wheels sufficiently large to take care of these fluctuations, as they must be of enormous size. Calculations show just what would have to be their weight and proportions to prevent any serious variation of speed, when the whole load is thus thrown on or off. There are to-day many places where available and cheap water

power is unused for the sole reason that no efficacious and satisfactory regulation has been found to compass the fluctuations of load occurring on railway and power circuits. At Oswego they use a resistance, so that when the load is thrown off from the working circuit it is thrown on an idle resistance, which is not a very economical means of handling the difficulty, to say nothing of its cost. Hence, even assuming that we can overcome all other difficulties, of a financial or engineering character, in connection with a transmission scheme, we must put into our estimate a very liberal allowance for accessories, to enable us to secure a successful transmission and control of the energy, and leave the energy at the other end where it has to be utilized, in such form that it can be used as successfully and as satisfactorily to the customer as the electricity obtained from a central station operated by steam.

I have always found the principal difficulty of electrical transmission projects to be, to dispose of the electrical energy after it is transmitted, and especially to distribute it, or deliver it to the consumer in a satisfactory manner.

PROF. FORBES:—I would say that in the case of the Niagara transmission that question has been thoroughly threshed out and we have got a fly-wheel, not at all gigantic in comparison with the revolving armature, which completely takes care of that. In two seconds the regulator will have acted and the fly wheel will have taken care of it up to that time.

THE PRESIDENT:—I think in the larger plants where five or six thousand horse power units are used, there will be less difficulty possibly than is anticipated, because as a rule where transmitting from a single source of such large units to distributed work for stationary purposes, there is a certain averaging up of the duty which will prevent such sharp variations of the load as have been indicated, and hence I do not think there will be so much difficulty on the large water power transmissions; still, these variations have to be guarded against, and it is more difficult to meet them in a water plant than in a steam plant.

If any other gentlemen wish to discuss the paper we will be glad to hear from them. Possibly some remarks may be prepared by members subsequent to this meeting; if so, I shall try to have them received at the next regular meeting, or they can be presented to the Editing Committee. Dr. Emery will reply to some of the comments which have been made.

DR. EMERY:—I can only say that I feel very much gratified with the complimentary remarks that have been made in regard to the paper and the way in which it has been appreciated by those present. It is unfortunate that the paper is so long that few have had time to study all the points in their different bearings and relations to each other, and I am quite sorry that one whom we esteem so highly as Prof. Forbes should have received

a copy only an hour before the meeting. I should have been very much pleased to have his remarks, excellent as they were, based upon a more thorough study of the paper. I quite agree with him on the point he makes in regard to the quality of the fuel. That matter should be emphasized in every way. At the same time it is not neglected in the paper. I will read Section 25, page 133, upon that point:

"In column *m* is shown the weight of water which it is assumed will be evaporated per pound of coal. The assumption is $8\frac{1}{2}$ pounds, except in the last case where it has been fixed at $9\frac{1}{2}$ pounds. Although 9 and $9\frac{1}{2}$ pounds evaporated can be obtained under actual conditions readily with boilers of good proportion and construction, it is thought that $8\frac{1}{2}$ pounds is as much as can be depended upon in average practice. It is in fact greater than is obtained in most cases, though less than is claimed in exceptional ones. This rate must be considered somewhat in relation to the price of coal. If cheap coal is to be used which will not give $8\frac{1}{2}$ pounds evaporation, the results must be sought in the column of the table applying to coal of a higher price."

The last clause of the quotation, it will be seen, exactly covers the point made by Prof. Forbes in regard to cheaper coals. They will not give $8\frac{1}{2}$ pounds evaporation. The better grades of anthracite coal of buckwheat size, will rarely evaporate over 8 pounds of water from actual pressure and temperature, and for the poorer qualities $7\frac{1}{2}$ pounds or even less can only be depended upon. If, therefore, such coal cost \$2.00 per ton, the results in the table should be mentally interpolated between those for \$2.00 and \$3.00 per ton. A glance at the figures in the two columns will show that any such difference will not appreciably alter the relative performances of the different engines if the same coal be used in all cases. The absolute results for a particular engine would of course be changed.

The next question is, whether or not 500 horse-power is a sufficiently large unit for general consideration. Prof. Forbes did not use the term unit, but I think that will express his meaning. I used 500 horse-power as being more generally applicable than a larger unit. It is in fact much larger than the average, but sufficiently large to secure maximum performance in the engine. The results would not be materially changed if we were to consider larger plants as multiples of a 500 horse-power plant. The cost of fireman would not change at all, and though one engineer on watch might care for an engine of more than 500 horse-power in a large plant, a chief engineer would also be employed at a higher salary, so that the labor account would not be greatly modified. The table is therefore about right for any large plant.

PROF. FORBES:—For how small a plant is it right?

DR. EMERY:—It would be presumptuous to say that it is exactly right for any engine. It cannot be expected that the friction of the engine, the weight of steam or coal used per hour, the cost of

supplies, of wages, of interest, and of fuel will in any particular case exactly coincide with the assumptions in the table. I have attempted to cover a great deal of ground and have been obliged to generalize. I have stated all the details of the generalizations and show at some length that considerable changes in the assumed facts would not materially affect the comparative results for the different engines. Absolute results for any particular case can be obtained by substituting the particular conditions, using for ready reference the formulæ at the heads of the columns. Do not misunderstand me. I have assumed very *probable* conditions, collated by references and by personal recollections based on a very lengthy experience, so that the results are approximately right for average conditions. Recurring to the original question I do not think that the operating expenses of a steam plant of 2,500 horse-power, or containing several units of that size would vary from one of 500 horse-power, or made up of several units of that size, sufficiently to predict in advance which would have the advantage. As already stated, one engineer on watch would take care of more horse-power in large units, but the number of men required to do the overhauling on the spare engine, and the salary of a chief engineer or general superintendent, would balance or more than balance the apparent saving for attention. For electric lighting work the principal saving due to the use of 2,500 horse-power or other large units, would be in the cost of real estate and buildings. In New York City, for instance, the area is limited, land is high priced, and the larger units take less floor space, so that considerably more engine power can be crowded into the same space, and this may make considerable saving in first cost.

Prof. Forbes, in the short time he has had to examine the paper, has not quite understood my first remarks in relation to the cost of water power. Moreover, the preliminary statement in the supplement to the paper is necessarily incomplete, and was rendered much more so in attempting to abstract it. Prof. Forbes says, "The cost of putting in the plant has been taken at probably \$140 per horse-power without electrical transmission." I wished to be understood that \$140 per horse-power was about the maximum amount that could be expended to develop a water power on a 10-hour basis in competition with steam, and I showed that the expenditures on the Merrimack had reached this sum, and that if they could be recalled they would not now be warranted. It was not intended to intimate that water power could not frequently be developed for a less sum. The supplement is directed particularly to the question of allowable expenditure when interest on the first cost is considered. I of course agree with the general statement that the cost of developing water power when there is a high head and no dam to be built is comparatively small. I have simply emphasized the fact that all waterfalls are not thus advantageously located. I recently report-

ed on a large water power 15 miles from large cities where there is over 70,000 horse-power running to waste, during the minimum flow which occurs in winter as in the Alps, and not in the summer. This power will in time be valuable, but it is not immediately available because a fall of nearly 500 feet is distributed through 10 miles, so that on the most economical plan of development there would have to be 10 power plants, some of which would be in gorges not readily accessible. This power may be utilized electrically, by locating a number of generating stations on the river, and transmitting it to the cities. The demand for so much power would, however, have to be created. The lower falls could be utilized at once for present demands, but the whole power must go together and a small development would not pay the interest on the large original first cost of the property. In this case I did not hesitate to recommend the original expenditure of \$200 per horse power for combined hydraulic and electric plant in case the power could be immediately developed and utilized, but this was found to be at present impossible. In due time these conditions must change, but they are governing ones at present. When 100,000 horse-power or more can be obtained at a single location, necessarily the cost of development becomes very much less.

It will be observed that I have not attempted to discuss the details of electrical transmission. President Sprague has pointed out the nature of the difficulties. I, however, desire to call attention to the fact that the method I have adopted is the proper one. The total cost of plant to deliver the power from the waterfall to the work to be done, which I typify as a jack-shaft, cannot, in competition with steam and cheap coal, greatly exceed \$140 per horse-power on a 10 hour basis and \$200 and upward per horse-power on a 24 hour basis. This cost of plant includes, first, the original investment in the general development of the water power, which to the consumer may appear as rental charged by the water power company; second, the cost of installing turbines and dynamos to generate the electric current; third, the cost of the electric line, and, fourth, the cost of the motors which turn the wheels, or the illustrative jack-shaft, at the point of delivery. *The motor must be included in the cost*, as then only is the result comparable with steam power on the basis shown in the table. The comparison is independent of the work done by such jack-shafts, as in either case it can be employed in generating electric current at lower tension for general distribution, or utilized directly to operate large mills or manufactories.

I am pleased with the remarks of Mr. McElroy. Naturally he has had such an extended connection with water powers that his sympathies are in that direction. I have never personally administered the affairs of a water company, but one of the most important of my observations occurred when a brother engineer in charge, had to leave his comfortable office and brave pneumonia in directing the movements of several hundred men

employed in clearing the canals and races of ice. Similar instances are frequent in our severe northern climate, and cheap as water power is under normal conditions, the irregularities due to freshets, droughts and ice must be duly considered in striking a balance with steam power.

Mr. Holloway, of the Henry R. Worthington Company, might have called attention to the fact that it was one of the chief arguments of the lamented head of that firm, that while he built a pumping engine not as economical in fuel as those of special design, the difference in first cost and of interest and repairs afterwards was in most cases sufficient to make his construction more desirable. Recent improvements of the engine under the direction of his son, C. C. Worthington, have had the effect to raise the economy, without materially reducing the simplicity, so that large pumping engines are now manufactured practically in considerable numbers, and the necessity for special designs to secure unusual economy of fuel is less frequent than before.

I am much obliged to Mr. Mailloux for initiating a very interesting discussion in regard to governing water-wheels operating electrical plants, and am also obliged to other speakers, but do not recollect any further question that requires response.

I trust that further discussions may be sent in by manufacturers and engineers, to whom the paper has been sent and will be specially obliged for any information tending in particular cases or under particular conditions to modify the statements as to costs and prices given in the paper as a basis for comparison. I have been assured this evening by the operating superintendent of an electric station, who does not wish to rise, that my estimates of the cost of supplies, repairs and renewals is too low to apply to high speed engines of large size, operating electric plants. This is an important point which I hope will be fully elaborated by those at liberty to talk freely on the subject, as it may show the desirability of using engines of fairly slow speed, rather than the cheaper ones running at high speeds compared with their size. Engines of the old slow speed type are now run much faster than formerly, and it may be that a compromise class of engine will soon be designed to which neither of the common names can be applied, which will be cheaper than the slow speed engine, and yet not run so rapidly as to cause the difficulties which some have experienced with certain types of high speed engines.

THE PRESIDENT:—I had intended to point out, which I will now do very briefly, that it is most important in considering the transmission of power by electricity from original water power plants, that the conditions of construction under least cost should be considered. Some few years ago I prepared a paper which was read before the Franklin Institute which brought up that question. The conditions were given for continuous current transmission, although they would probably need to be modified

for alternating current transmission, and I presume the same general laws will hold.

[COMMUNICATED AFTER ADJOURNMENT BY THE AUTHOR.]

DR. EMERY :—Mr. Samuel Webber, the veteran hydraulic engineer, now residing at Charlestown, N. H., has, since the meeting, written me pleasantly, stating that the steam portion of the paper confirmed, in several respects, views he had held for some time ; but in his first letter he criticized rather severely the costs given for the development of the water power on the Merrimack and, incidentally, the authorities cited in reference thereto. Some of the criticisms were, however, in part due to the fact that at first he did not quite appreciate the method of comparison adopted. The letters are not in shape for publication, but a full abstract is presented, which it is thought will be of great interest and value, although for reasons given in closing, all of his general conclusions are not accepted. He first suggests that probably the cost of land had been included in the total costs which “sold not only for the mill sites, but for offices, store-houses, dwelling houses and streets ; for a complete factory village,” implying, evidently, that but a portion of this cost should be included in the cost of the water power. He then criticizes the addition of about “50 per cent. of cost for additional wheel plant to provide against back water,” a Lowell expression which means, in the language of the paper, the additional plant employed to utilize the “surplus water,” as it is called in many of the places. He says :

“This additional wheel plant has been added, as the original power was outgrown, to enable the mills to use all the water possible, and it is now 19,000 H. P. in Lowell, which is used for a portion of the year.”

He refers to the original comparatively low cost and the later high expenditures at Lowell, adding that “Lowell and Lawrence united, and bought at a moderate cost, the control of the outlet of Lake Winnipiseogee, which, by dredging, they are enabled to draw down six feet in summer. They do not raise the water in the lake. In the long run these improvements have raised the amounts expended to a large sum, but have doubled the original power.”

He then adds:—“I still hold to my often expressed opinion that \$100 per H. P. is an ample estimate for dams, canals, wheel-pits, etc., under 20 feet fall, and in many cases it can be done for \$50.”

He adds: “As to the statement that Lowell will never be rebuilt, it is all bosh. It would be done to-morrow if the power was unoccupied and it would not cost one-half the amount per horse-power which it did in the first place, by using modern turbines, and other improvements.” He then expresses the opin-

ion that the cost of the power at Manchester was not one-half that at Lawrence.

The attention of Mr. Webber was then, by letter, called to the fact, that the paper necessarily dealt with the average power throughout the year, since the power to be made up by steam would necessarily be the difference between the aggregate power required, and the power derived from the water, which latter would necessarily vary at different seasons. He was also asked if he would not kindly furnish a statement of what the actual costs had been as he recalled them. In responding, he regretted the loss by fire of a large collection of his notes and memoranda. He recalls that at the "first regular meeting of the stockholders of the old Locks and Canals Co. at Lowell, Feb. 27, 1822," it was stated that the "property cost for land \$18,339, and for the old dam and canals \$30,217. In 1823, when the price per mill-power was fixed, Mr. Appleton stated that the expenditures up to date were \$120,000 and would furnish 50 mill-powers. These were supposed to net 60 H. P. each, making 3,000 H. P., or \$40 per H. P., on which the fixed rental was \$300 per mill-power, or \$5 per H. P., being $12\frac{1}{2}\%$ on the investment." The mill-powers were gradually sold off, and "in 1845 the capacity of the old canals was over-taxed," and between then and 1875, expensive improvements were made, of which the costs are given in the paper of the writer and referred to hereafter. He recapitulates the costs at Lawrence substantially as given in the paper, but states the cost was greatly increased from the fact that "the town was originally intended to be on the south side of the river, but the agent employed by the original projectors to purchase the land was found to have reserved so much of the most desirable portion of it for his own private property, that the directors voted to build on the north side, where the ground was very uneven, and the cost of the canal increased enormously." The company, however, owned considerable land on the south side, so that the south canal was finally built to enable that land to be sold, though the water could all have been used by the first canal, which, however, should have been at least 20 feet wider to avoid the swift current which causes the banks to cave occasionally."

Mr. Webber adds:—"Old Mr. Samuel Batchelder, now dead, who began with Lowell, and afterwards built up Saco, says, in his 'History of the Cotton Manufacture,' that he estimates the total cost of water power at Lowell, 'including land,' at \$15 per H. P. and he knew much more about it than these 'latter day' figures."

Mr. Webber continues: "Were I to make a rough cast of the cost of a water power, imagined to give 5,000 H. P. on 20 ft. fall, I would allow for a dam 500 ft. long, averaging 10 ft. high near top of fall, base of dam 10 ft. wide, top 5 ft. or $7\frac{1}{2}$ ft. average=75. c. ft. in one linear ft. This $75 \times 500 = 37,500$ c. ft. or 1390 c. yds. This, at \$20 per c. yd. (ashlar in cement), would

be \$27,800. Assume guard gates and waste weir to cost half as much more, it would add \$13,900, making \$41,700. Then a canal a mile long, 100 ft. wide by 12 ft. deep, or 257,000 c. yds., at 25 cents per yard excavation = \$64,250. This makes a total cost of \$106,000. Add to this, facing canal walls with stone, say 1 ft. thick, average, or 4,280 c. yds., at \$5 = \$21,400, and you get dam gates and canals \$127,400, or \$25.48 per h. p. Now add about as much more for land for mill sites, and call this investment \$50 per h. p. Then take Mr. Main's figures for average cost of wheel plant at Lawrence (which is far higher than it would be to-day) at \$45 per h. p. and you get a grand total of \$95 per h. p.

Mr. Webber states further, that the costs in some of the older mill towns "are so mixed up with land purchases and sales which have been very profitable, and furnished the means for great extensions over the original plant that it would be very difficult to separate them." He then refers to the very cheap development of some water powers in Maine, much in the same manner as the subject has already been treated by Mr. McElroy.

In reviewing the very valuable information furnished by Mr. Webber, it should be borne in mind that a writer in making a generalization usually obtains information from various sources, all of which can be considered with reference to the general conclusion. Mr. Webber's statement that the work on the Merrimack could be done now for much less than the actual cost, is of course true, though his remarks emphasize the fact. It is, however true, that nearly all new enterprises start small and then in increasing the plant incur very much more additional expense than if the final development could all have been carried out at one time. It is therefore proper to consider such facts in making a generalization. It is believed that, on the whole, the lesson of the Merrimack as pointed out in an illustrative way in the supplement to the original paper is still as valuable as ever. It was there stated, that changes in values due to more accurate sources of information would not much change the results, but the additional figures given by Mr. Webber rather confirm than otherwise, the rough estimate made as to the total cost at Lowell. The original company bought up an old canal company and probably at ruinous figures, yet the water company had expended \$120,000 by 1823, which for the power then developed on a leasehold basis to the stockholders themselves, was very reasonable, being only \$5 per h. p., but a profit would need to have been added to these figures, if the water had been obtained from a different company. The improvements referred to by Mr. Webber, however, increase the cost on an enormous scale. From the census reports it is learned that a new stone dam was built at the top of the fall, where the height was fortunately only from two to four feet, except for a short distance in a deep place, so although the dam was 1094 feet long it only cost \$114,000. The new canal, which necessarily skirted the river so closely as to re-

quire a very expensive retaining wall for a considerable distance, cost \$551,584, and one of the underground feeders in the city cost \$36,131, making in round numbers the total given in the paper, \$752,000, which with Mr. Webber's \$120,000 gives \$872,000 in definite items. The original work probably cost considerably more than was paid for it, and there is the additional expense of controlling the lakes. Mr. Webber considers that the outlet of Lake Winnipiseogee was purchased cheaply, but the census report shows that there are other lakes also utilized, and Mr. Francis in a prominent report has stated distinctly that the control of the headwaters of the Merrimack was obtained at very great cost. There is testimony in law-suits that part of the original costs for some for the mills have been charged off on the books. The general statement in the paper that the work at Lowell had probably cost considerably over \$1,000,000 is therefore sustained. The rough estimate in relation to Lawrence cannot be very much in error. Mr. Webber, however, does not consider that the works at Manchester could have cost one-half as much, but this is an extreme statement. I now recollect that Mr. Manning, the engineer of the company, once told me that he estimated the total cost at that place as between \$90 and \$100 per h. p. If this meant the total wheel-power, the statement in the paper was approximately correct.

The evident difficulty in obtaining approximate prices at such a location is in distinguishing between the costs per h. p. of the total plant (all of which can only be utilized during high water) and the cost of plant per h. p. based on the average power throughout the year. The average power should be used as the divisor in obtaining the cost of the power, for it represents the quantity to be used in reduction of steam power in a given case. The total wheel power, was doubtless referred to by Mr. Batchelder in the extract noted by Mr. Webber. The \$15 per h. p. necessarily refers to the leasehold or annual cost, not to the total cost. This on a $12\frac{1}{2}\%$ basis, originally fixed upon among the owners, represents a total cost of \$120 per h. p., and if the h. p. meant, is the maximum for which wheels are provided as we suppose, the total cost on the basis of the average h. p. developed throughout the years has been very much more than the \$140 per h. p. assumed in the paper. When it is considered that, in a location like the Merrimack, the mill owners must provide not only the surplus water plant to utilize surplus water, but additional steam plant to do the work of a surplus water plant when the water is low, it will be seen, as briefly referred to in the original paper, that steam power exclusively, would cost much less, if the actual costs of developing the water power were even approximately what has been supposed, and it would need careful study and estimates to determine whether, as Mr. Webber suggests, the work in being done over again could be accomplished enough more cheaply to change the conditions.

THE SECRETARY:—Although electrical engineering is considered quite a modern development of general engineering we are constantly having brought to our attention the researches of some of the earlier workers in the field, and one of our most active members has recently come into possession of some facts relating to the history of the machine that is before you, which as near as we can ascertain was made in the year 1867, by the late Professor Charles A. Seeley. Mrs. Seeley, who is present this evening, has delegated Mr. Wolcott to present some facts in relation to it, after which the machine is to pass into the custody of the Institute and be placed with other historical relics which are gradually accumulating.

AN EARLY DYNAMO.

BY TOWNSEND WOLCOTT.

Early in the year 1867, when the principle of self-excitation in dynamos was new, and in fact practically unknown except to a few of the most advanced electricians in this country, the subject of electric lighting was broached by Prof. Charles A. Seeley to Mr. Horace Greeley. Mr. Greeley became deeply interested, and highly amused at the idea of “grinding out electricity with a crank, and then making light with it,” as he expressed his understanding of Professor Seeley’s description of an arc light operated by a dynamo. Mr. Greeley suggested that Professor Seeley should build a dynamo machine and other apparatus, which were accordingly started at once, and on March 28th, 1867, Mr. Greeley published an editorial in the *Tribune*, entitled “Electric Light.” The scientific points were, of course, furnished by Prof. Seeley, but it is evident that Mr. Greeley understood what he was writing about, as the editorial is interesting reading at the present day, considering the time it was written. I, therefore, quote it in full, as follows:

[From the New York *Daily Tribune* of Thursday, March 28th, 1867.]

ELECTRIC LIGHTING.

The Nineteenth Century is already most conspicuous among the centuries for those great inventions which minister to the wants of mankind. Three-tenths of it still remains; and the leaders of progress in science and the arts are more numerous and active than ever before. It is certainly far from impossible that many who are now living, may witness products of genius yet