

- (1) பக்கங்களின் எண்ணிக்கை 24
 (2) புதுக்கித் திருப்பிய நாள் 11/91
 (3) ஆதாரங் குறிப்பவர் சுருக்கொப்பம்

தமிழ்நாடு ஆவணக் காப்பகம்.

தமிழ்நாடு அரசு

பிரதமர் அலுவலகம்

அரசாணை எண்.	2593.14	அச்சகம்
மு. கோப்புத் தாள் எண்.		பலவகை
நாள் :	13.10.1893	199

86

மடிக்கவோ கண்டபடி கையாளவோ கூடாது.

India Office,
London, 24th August 1893.

Public Works,
No. 6.

To His Excellency The Right Honourable The Governor
in Council, Fort St. George.

MY LORD,

Report of the Committee appointed to consider the question of the utilization of the water power derived from the Periyar Irrigation Works.

In accordance with the request contained in your Public Works Letter, No. 14/3472, dated the 20th December 1892, steps have been taken in this country to obtain the best available professional opinion on the subject of utilizing the water power which will be available on the completion of the Periyar Irrigation Works.

2. A Committee composed of the following gentlemen was appointed to consider the question :—

Professor W. C. Unwin, F.R.S.
" G. Forbes, F.R.S.
" W. C. Roberts-Austen, C.B., F.R.S.
Colonel J. Pennycuik, R.E.

3. This Committee have submitted a report, which I now forward for your Excellency's consideration, and for such action as may be possible in the development of this important undertaking.

4. In consideration of the work which has been thrown upon Colonel Pennycuik in connection with this matter, I have authorised his being placed on duty for one month of his furlough on two-thirds of his Indian pay and allowance.

I have the honour to be,

My Lord,

Your Lordship's most obedient humble Servant,

(Signed) KIMBERLEY.

ENCLOSURES.

No. 1.

Report of Committee on utilisation of Water Power Periyar Works.

It is clear from the facts laid before the Committee that on the completion of the works for the diversion of the Periyar river a large amount of power will become available for industrial purposes, and that the development and utilization of this power will be of the greatest importance to the Government of India from an administrative as well as from a financial point of view.

The subject naturally divides into two main branches, firstly, the development of the power at the site of the works by suitable hydraulic apparatus, and, secondly, its utilisation on the spot, or transmission to distant places at which it may be more effectively utilised, and the Committee are of opinion that the best method of dealing with these questions will be by separate notes, drawn up by the individual members of the Committee, whose technical knowledge and previous experience best qualify them to deal with the separate branches of the inquiry.

Unfortunately, at the last moment, Professor Unwin, being on the eve of his departure for America, thought it better to withdraw from the deliberations of the Committee, and has only been able to report very briefly on the hydraulic arrangements for the development of the power at the site of the works, a subject with which he was eminently fitted to deal, and an additional note on this point has therefore been drawn up by the Chairman of the Committee, Colonel Pennycook, R.E.

The notes of individual members are attached to this report, and a reference to them shows that the development of the power at the site of the works would not cost more than 4% per horse power for the hydraulic apparatus alone, and that the electrical apparatus for its transmission to Madras would not cost more than 35% per horse power delivered at that city, while for the towns of Madurai and Trichinopoly the cost would be not more than 23% and 17% respectively, the most important item of the cost of transmission being that of the conductors, which depends directly on the distance.

Making due allowance for interest on first cost, and depreciation of plant, it appears that power can be delivered in the three towns named at an annual cost per horse power of 3%, 2% and 1% 10s. respectively, and, comparing this with the cost of steam power, there would seem to be every probability that a large portion of the available power can be profitably used in the towns in question, as well as in the smaller towns on the road thereto.

The most obvious, and probably the most profitable, mode of utilising a large portion of the power would be for the lighting of the towns within reach. The Committee understand that none of these towns are supplied with gas, and that in Madras especially the cost of lighting by oil lamps forms a considerable portion of the municipal expenditure.

The information before the Committee as to the nature of the corundum deposits of Southern India is insufficient to enable them to form a positive opinion as to the advisability of using any large amount of power in the manufacture of aluminium, but it is certain that the estimates contained in Mr. Chatterton's original memorandum were over sanguine.

It is probable that a substantial amount of power might be usefully employed in the immediate neighbourhood of the works in the driving of wood working and cotton machinery. No cotton is believed to be grown in the immediate vicinity of the works, but large quantities are said to be produced in the neighbouring districts of Coimbatore and Tinnevely, in both of which districts large mills are at work. The advantage of cheap power would probably more than cover the cost of carriage of the raw material to and from the site of the works.

The Committee concur in the opinion expressed by the Chief Engineer to the Government of Madras, that the water should be brought to the hydraulic motors by means of pipes, a separate pipe being used for each motor, or two motors at most being supplied from a single pipe, and that, with a view of reducing as far as possible the cost of the pipes, the fall should be divided into either two or three stages.

They do not consider that it is absolutely certain that it would not be found possible to convey the whole of the water to the foot of the fall by a single inclined shaft sunk through the rock, and if such a course were practicable its cost would probably be somewhat less than the cost of pipes, but they do not think that the chance of a saving in that cost is such as to justify the heavy initial expenditure involved in the detailed examination of the rock which would be necessary before the construction of the shaft could be undertaken. They also observe that the shaft must be constructed long for all the water quantity of water likely to be ultimately brought into use, while the pipes can be put down from time to time as the utilization of the power is developed.

The Committee also concur in the Chief Engineer's opinion that the construction of a railway from the nearest point of the South Indian Railway to the site of works, a distance of about seventy miles, is a necessary preliminary to the utilization of the power in question. How far such a railway could be expected to pay for itself on the cost of construction from ordinary traffic is a point on which the Committee have not sufficient information to enable them to form an opinion, but looking to the fact that the greater part of the line will pass through country already fertile or about to be cultivated by the irrigation from the Periyar, and that it will connect the second largest town in the Madras district with existing lines of railway, they think it probable that the deficit will be such as to outweigh the advantages to be gained by the utilization of the water power under consideration. Such a railway might be easily and economically worked by electricity, for which it would be especially suitable, as for many years to come it must remain an isolated line, connected with other lines only by the single junction with the South Indian Railway at Changanassery.

In the note of the Chief Engineer to the Madras Government, dated 17th October 1892, it is said that provision must be made for closing the head sluices at the Periyar for a fortnight in every year for the purpose of inspection and repair. Such closing would be a very serious obstacle in the way of the utilization of the power for electric lighting or for the working of railways; whether it can be avoided is a matter for the consideration of the professional advisers of the Madras Government, but the Committee are informed by their chairman that he thinks there would be no serious difficulty in so arranging the sluices that a certain minimum quantity of water could be sent down at all times, and that the cost of such an arrangement would be insignificant as compared with the importance of the object in view.

It does not appear to be within the province of the Committee to offer an opinion as to the exact course to be pursued in order to bring into use the power under consideration. It is for the Government of Madras to consider whether they will themselves construct the whole or any portion of the apparatus necessary for the purpose, or whether they will simply lease the right to the use of the water to one or more con-

tractors having the latter to make their own arrangements for its utilisation.

The Committee would, however, suggest that early steps should be taken for giving the utmost possible publicity to the fact that this power will shortly become available, with a view to the submission of practical proposals for its development.

It must be borne in mind that there is a great probability of new industries being attracted to the district by the mere existence of a source of power, which appears to the Committee to be one of the cheapest in the world.

JNO. PENNYCUICK, Colonel, R.E.,
Secretary to Government of Madras,
Public Works Department.
GEORGE FORBES,
W. C. ROBERTS-AUSTEN.

13th July 1893.

No. 2.

Note by Colonel Pennycuick, R.E., on the Hydraulic Apparatus required for developing the Water-power of the Periyar River, dated 28th June 1893.

It may be taken as certain that the water required for driving the hydraulic motors will be brought to the latter by iron or steel pipes, a separate pipe being provided for each motor or pair of motors, and that no attempt will be made to carry the whole of the water-supply by a single shaft or inclined tunnel sunk in the rock on the sides of the valley down which the water is passed.

The side slopes of the valley are such that there will be no difficulty in laying the pipes with a slope of $2\frac{1}{2}$ or 3 horizontal to one vertical, and the average length of the pipes may be taken at three times the head.

The total fall available is a little over a thousand feet, and as a small amount will be lost at each stage if this total fall be divided into two or more stages, the effective head may be taken without sensible error at a thousand feet.

So far as the pipes are concerned, the cost per unit of power is pretty nearly independent of the size of the pipes for any given velocity and head. The power that can be conveyed by a single pipe varies as the square of the diameter, while the cost varies as the diameter multiplied by the thickness, and as the latter varies as the diameter for a given pressure, the cost varies in the same ratio as the power. In reality the cost is rather less for large pipes than for small ones, as the loss of head to produce a given velocity is greater in the latter case than in the former. This difference is not of importance in pipes over two feet in diameter.

The cost of the pipes is, however, very seriously affected by the number of stages into which the total fall is divided. Thus, a pipe three feet in diameter utilizing the fall of a thousand feet in a single stage would require a thickness at the bottom of about an inch and a half, and a mean thickness of seven-eighths of an inch. If the fall were divided into two stages the maximum and mean thickness would be three-quarters and half an inch; for three stages they would be one-half and three-eighths, and for four stages three-eighths and five-sixteenths, showing a reduction of thickness, and consequently of cost, in the proportion of 14, 8, 6, and 5.

On the other hand, there is a certain loss of head at every stage, the cost of the head works and regulating gear is practically independent of the height of each stage, and therefore increases directly with the

number of stages, and the cost of three turbines of a thousand horse-power would be considerably greater than that of a single turbine of three thousand horse-power.

The exact number of stages which would give the most economical result will vary according to the size of the pipe and the velocity allowed, but within the limits with which we have now to deal, it may be said broadly that there is considerable economy in an increase from one stage to two, not much in an increase from two to three, and little or none in any further increase. The further calculations in this note will be made on the assumption that the fall is divided into two stages of five hundred feet each, the pipe for each stage being fifteen hundred feet long.

The velocity of discharge permissible in the pipes exercises a most important influence on the cost of the latter per unit of power, the absolute cost being independent of the velocity, while the power transmitted increases in direct ratio thereto, except that the loss of head required to generate the velocity increases somewhat rapidly in proportion to the latter. Taking as an example, the case of a three-foot pipe fifteen hundred feet long, with a total fall of five hundred feet, the result for different velocities would be,—

Velocity per Second.	Loss of Head.	Effective Head.	Horse-power.
2½	1 foot.	499	727
5	4 feet.	496	1,446
7½	9 "	491	2,148
10	15 "	485	2,829
12½	22 "	478	3,485
15	32 "	468	4,095

the cost of the pipe being the same in each case.

The economy of high velocities is more marked in the case of larger pipes and less so with smaller ones.

So far as mere economy in the cost of the pipes is concerned, velocities of fifteen or even twenty feet per second might be used with advantage, but there are practical objections to the use of velocities much exceeding ten feet per second, and this limit will be adopted in the following calculations.

In Professor Forbes' report on the electrical transmission of power the unit is taken at 5,000 horse-power. To generate this power on a fall of five hundred feet about 120 cubic feet of water per second would be required, which would be carried by a pipe four feet in diameter with a velocity of between nine and ten feet per second. The pipe would have a mean thickness of five-eighths of an inch, and would weigh 392 lbs. to the foot, including an addition of twenty-five per cent. for joints, &c. The total weight would be 262½ tons, and the cost at 20% per ton 5,250%, to which must be added 2,500% for carriage to the site of the works, and 600% for laying, making the total cost of the pipe, 8,250%.

A turbine to generate 5,000 horse-power would cost about 6,000%, and 750% might be added for a proportional share of general expenses, making the total cost of the installation 15,000%, or 3·00% per horse-power.

The annual cost might be reckoned at,—

Interest 4 per cent. on 15,000%.	£ 600
Maintenance	600
Depreciation 6 per cent. on 6,000%.	360
	<hr/> 1,560

or, 0·312% per horse-power.

The above calculations are for units of 5,000 horse-power, but for most purposes much smaller units would be preferable, and even for the electrical transmission of power I am inclined to doubt whether so large units would be advisable. Professor Forbes' calculations show that the principal item in the cost of transmission is that of the conductors, which is independent of the size of the unit of power, and that the increase in cost of the dynamos and transformers involved in the use of smaller units would not greatly increase the total cost per horse-power.

A pipe two feet in diameter, with a velocity of ten feet per second, would carry thirty-one cubic feet of water per second, and would have an effective head of 476 feet, and generate 1,230 horse-power.

Its mean thickness would be three-eighths of an inch, its weight per foot 110 pounds, its total weight 79 tons, and total cost, including laying, about 2,500%. The turbine would cost 1,500%, and the total cost of the installation would be about 4,400% for twelve hundred horse-power, or 3·67% per horse-power.

The annual charge would be,—

	£
4 per cent. on 4,400%.	176
6 per cent. on 1,500%.	90
Maintenance	200
	<hr/> 466

or about 0·39 per horse-power.

It is clear that whatever units were employed the capital cost would not exceed 4%, or the annual charge about ten shillings per horse-power.

In a former note on this subject submitted to the Government of Madras, I advocated the use of Pelton wheels as the prime movers for the generation of power. The Committee's discussions appear to have established the conclusion that these machines are not, in their present form at all events, suitable for electrical work on a large scale, owing to their want of regularity in speed and the fact that they work on a horizontal axis; the first defect I have no doubt might be got over by the use of an appropriate governor, the latter is fatal unless the machine could be modified so as to work on a vertical axis. In the estimates given above it has, therefore, been assumed that horizontal turbines will be used, but for power to be used on the spot and for purposes for which the extreme regularity of speed required for electrical work is not essential, it might be possible to use the Pelton wheel, and, if so, its simplicity and cheapness would be important advantages.

The calculations of cost given above refer to the maximum power of each motor; as the latter would probably never be worked up to its full power for more than a portion of each day, longer or shorter according to the work to be done, the real cost per actual horse-power would be somewhat greater than that indicated by these calculations. For example, the annual cost of a twelve hundred horse-power machine is calculated at 466%. If such a machine worked for ten hours daily at an average rate of a thousand horse-power at the site of the works would be year, the annual cost per horse-power at the site of the works would be 0·47%, and the cost per horse-power hour (the most accurate way of stating cost) would be about one six thousand four hundredth part of a sovereign or about one four hundredth of a rupee. The cost of a horse-power hour delivered electrically at Madras, Trichinopoly, or Madurai would be one-seventieth, one one-hundredth, or one one-hundred and thirtieth of a rupee.

Inasmuch as the cost of steam power at any one of these places is certainly not less than a tenth of a rupee per horse-power hour the

highest of these rates would leave an ample margin of profit while the price at the site of the works would be so small as to offer every encouragement to the establishment of factories, even at a considerable cost for carriage of raw material and manufactured products.

The question of how far Government should be connected with the operations for the development of this power will need careful consideration. It must, in any case, construct the service reservoir and regulating works for the distribution of the power to the different prime movers, unless the whole power is to be leased to a single speculator, a course which the Government will probably be unwilling to adopt; but the cost of these works, the designs for which can be drawn up by the local Public Works Department, will be trifling, probably not more than Rs. 20,000 for the first ten thousand horse-power and one rupee per horse-power for subsequent additions. On the other hand the Government will probably be unwilling to take any part in the transmission of the power to a distance or in its utilization for industrial purposes, and will either construct the pipes and prime movers and lease the power derived from them, or lease the water direct from the service reservoir leaving the lessees to utilise it as they please.

A charge of sixty rupees in the former case or of thirty rupees in the latter per million cubic feet (with five hundred feet fall) would give a substantial addition to the returns from the Periyar and be almost unfelt by the users of the power. There would be no difficulty in controlling and recording the water used by such factors so as to enable the charges to be properly levied.

It is stated in the report of the Committee that it is proposed to modify the designs of the Periyar sluices so as to avoid the necessity of shutting off the water entirely for examination or repair of the head works. This is a most important point and the alteration will not add more than five or six thousand rupees to the cost of the sluices.

In the note submitted to the Government of Madras to which allusion has been already made, I remarked that having in view the progress made of late years in the electrical transmission of power, it was by no means certain that it would not be possible in the immediate future to utilize the power of the Periyar water for the lighting of Madura, Trichinopoly, or even Madras itself.

The information supplied to the Committee by Professor Forbes shows that this anticipation was in rear of the facts rather than in advance of them.

No. 3.

Preliminary Memorandum by Professor Unwin, F.R.S., dated 20th June 1893, on the Periyar Project.

The data given me are that there is a supply of 600 cubic feet of water per second all the year round with an available fall of 1,200 feet. This would yield 60,000 effective horse-power. The only drawback mentioned is the stoppage of the flow for a fortnight annually for examination and repair of the tunnel and head-works. This difficulty might, perhaps, be met by a service reservoir. For many applications the stoppage would not be a serious difficulty.

The first question is whether the fall should be utilized as a whole or in parts. With twelve hundred feet fall the pipes would be heavy. If the fall is divided the cost of machinery is increased. On the whole, I should suppose it best to divide the fall into two parts of six hundred feet each. I understand the slope of the ground to be about 1 in 4. Then for a fall of 600 feet the pipes would have a length of 2,400 feet.

The probability is that it will prove economical to make the pipes as large as possible. In America, steel pipes of four and five feet diameter have been used under large heads. I think a four-foot steel pipe, double riveted for the lower part, and with transverse joints riveted up from end to end, would be suitable. With a larger pipe the flexibility gives trouble by causing leakage at the joints. I think the pipe should be laid in a trench and covered with earth to diminish the effect of changes of temperature which is liable to rack the joints and cause leaks.

Such a pipe would have an average thickness of about half an inch and a maximum thickness of five-eighths of an inch. It would carry 3,600 effective horse-power on 600 feet fall, and it would weigh about 280 tons. None of these quantities seem impracticable.

The pipe might supply two turbines of 1,800 horse-power each. Under the conditions any type of turbine might be adopted.

Generally for such a large quantity of water a pressure turbine is cheaper than an impulse turbine for equal workmanship and similar adjuncts. But probably conditions of speed imposed by the driven machinery may make it desirable to adopt some form of partial admission turbine. Girard turbines, like those at Terni, would be suitable, or, perhaps, tangent wheels could be more cheaply constructed, for a large power in the conditions at Periyar. Either form permits good speed regulation by a governor.

The Pelton wheel is suggested in the Public Works Department memorandum. But there is no experience in the use of Pelton wheels for so large a quantity of water. I have no reason for thinking that they would cost less than other forms of turbine in the conditions at Periyar. The Pelton wheel is most suitable when used with a single nozzle of small size. If a Pelton wheel of 1,800 horse-power had a single nozzle it would need to be 17 inches in diameter. If it had two nozzles they would have to be 12 inches in diameter each. It is true that Pelton wheels with multiple nozzles were proposed for Niagara, but the regulating arrangements were very crude and I am not aware that they have been tried. They do not seem to me to be so suitable or likely to be so efficient as other turbines.

The efficiency may not be important at Periyar with regard to saving water, but it is important in diminishing the cost of the turbine supply pipes.

Without more knowledge of the country, and the way in which the power is to be applied, it is impossible to make any but the roughest estimate of the cost of the hydraulic power. Further, the cost of transporting the machinery up country and the probable cost of the excavation is not known to me. But I should think very possibly the cost might be between 5*l* and 10*l* per horse-power utilized (capital cost), or, I suppose, between 80 and 160 rupees per horse-power. That is for canals, pipes, turbines, and necessary buildings.

In any case, it appears that power can be obtained cheaply as to capital cost if any application can be found for it. I am disposed to think that the cost of the power would be a small fraction of the cost of electric machinery and transmission for applying it. Hence the problem at the Periyar is essentially a problem of finding an application for a very large quantity of power. The hydraulic part of the problem is the least doubtful and the least difficult. The distance of the site of generating the power from places where it can be easily applied is the most serious obstacle to be met.

Report (Revised) of Professor George Forbes, F.R.S., on the cost of developing the water-power obtained from the Periyar Irrigation Works in the Madras Presidency, dated 7th June 1893.

Having been asked by the Committee to lay before our next meeting a report on the cost of the electrical part of these works, including the generation of electric current, and its transmission to certain points as yet undecided upon, and its utilisation at these points, I have considered the matter very carefully, and, on attempting to make estimates, I have been met by the difficulty that there are many data about which I have no information. It is natural to suppose that the machinery will be made in this country, and will be shipped out to Madras, from which point it will be carried probably by railway. If a railway be constructed over the distance from Madura to the Irrigation Works, this cost of transport need not be great; but if a preliminary plant has to be put down for a limited utilisation of power, the cost may be considerable. I have no data as to the cost at which a pole line can be established for long distances to carry the large conductors necessary. If time had permitted I might have been able to confer with the telegraph department and get out accurate estimates in accordance with the requirements of the case. As it is, my estimates on these heads may be considered as purely approximate. It will be seen, however, that if we work on the lines I suggest, the cost of copper in the line is the principal expense and other matters are of comparatively small importance.

Conditions to be fulfilled.

The fall which will be utilised is sufficient to develop about 50,000 horse-power on the shafts of the turbines. The first proposition is that this water-power should be developed by means of separate turbines, each of 5,000 horse-power. If smaller units be taken the cost per horse-power will be greater. The most successful working will be obtained from turbines with a vertical shaft, driving dynamos on the same shaft, each dynamo being of 5,000 horse-power. The points to which the electricity has to be carried by conductors vary from 80 to 350 miles. The purposes for which the electricity can be used are various. First, it can be used for the electric lighting of Madura, Trichinopoly, and Madras, and possibly other places. This refers both to arc and incandescent lighting—are lighting being suitable for open spaces, incandescent lighting being suitable for interiors, but being more costly. The electricity conveyed to a distance may also be converted into motive power for driving factories. It is possible that such factories might be attracted by cheap power to sites about 100 miles north of the irrigation works, and the same distance to the south-east, and perhaps in other places. The cheap power might attract cotton mills, and might start new industries, such as the refining of metals and extracting them from their ores.

Among these the production of aluminium by electrolytic processes immediately suggests itself, such processes having been successfully worked both in Europe and America. The uses to which aluminium is put are, at present, limited; but there is now a great effort being made to introduce it into several manufactures, and it is not impossible that the demand may increase considerably. It is worth pointing out the fact that the electrical conductivity of aluminium is very high, being twice as great as copper for equal weights of metal. Thus, if aluminium could be produced at a cost of 1s. per pound it would be possible to compete with copper for electrical purposes. I have not the data to permit me to say with certainty whether this is possible or not, but information will doubtless be forthcoming, on the authority of Professor Roberts Austen. A good deal has also been done in the production of

other chemical substances by electrical action not in the domain of metallurgy alone.

In all these cases a continuous current of low electric pressure is required, whereas the current which is transmitted to a distance must necessarily be at high pressure. The transformation can be cheaply effected by using high-pressure current to drive a motor, and having on the same shaft a low-tension generator of electricity, but there are several other methods concerning which I will report more fully at the proper time.

A field for the utilisation of motive power developed by electricity which promises to be very considerable is that of electric traction. Nearly every city in the United States has its street cars or tramways worked by electricity, and several of the principal steam railroads have put down electric locomotives especially for dealing with the local work in their shunting operations with heavy freight trains, and for this purpose very powerful locomotives have been constructed. It is worth considering whether the demand for tramways in Madras is sufficiently great to make it likely that a development in this direction would be important.

The question is also well worth consideration whether the railways in the Presidency south of the town of Madras might not be advantageously worked by means of electric locomotives.

These being the general conditions that require to be fulfilled, I will now state the character of the machinery which seems to me best suited for carrying out these objects.

Character of Machinery.

The first point to be considered is the electric pressure at which the current is to be carried to the distant points. The higher the pressure the cheaper are the conductors required for transmitting the current; and since, in these cases of lighting and power transmission the cost of conductors is one of the largest items of expense, it becomes a matter of the utmost importance to reduce this cost as far as possible, and this can be done by increasing the electric pressure to the highest limits which we can safely recommend.

The experiments of 1891, between Lauffen and Frankfort, showed that it was perfectly feasible to use 20,000 to 30,000 volts by means of overhead conductors. There were certain difficulties met with which we now know and appreciate, and which will always be avoided in the future. The Oerlikon Company, who were engaged in that experiment, are now putting down a line 43 kilometres in length for an electric pressure of 40,000 volts. At Niagara Falls the electric pressure which we propose to adopt is 20,000 volts in the first place, with a possible increase as the work proceeds. I should say that, in the case of India, where the atmospheric conditions are favourable rather than otherwise, it would be safe to contemplate the employment of 30,000 volts, or perhaps even 40,000, in the first instance, with overhead conductors. Such a system seems possible when we consider that the chief trouble in the higher latitudes with which I have hitherto had to deal arises from the effects of sleet and snow, and also that in the regions where these overhead poles will be set up, disastrous cyclones are not to be seriously feared. This is the cheapest way in which the line could possibly be laid.

Coming now to the generation of the current, the first thing which has to be decided is whether we shall adopt the continuous or the alternating current. The disadvantage of the former is that it has hitherto been impossible to construct a continuous current dynamo of high electric pressure successfully. This arises chiefly from the fact that a commutator is necessary in this class of machine. A second disadvantage of the continuous current is that there are no means of

transforming the pressure without the use of moving machinery. It has sometimes been proposed to obtain a high pressure by connecting, in series, a large number of continuous current dynamos. For example, it has been proposed that each 5,000 horse-power unit should consist of 20 dynamos in series, each of 250 horse-power, giving 1,000 volts, making a total of 20,000 volts. No sound engineering scheme on these lines has been worked out. The expense is enormous, and the danger of handling such machinery would be very great indeed. With the alternating current, on the other hand, it is possible to generate the current directly at the extremely high pressures which make transmission to great distances possible and economical; it is also possible to generate the current at low pressure, and then, by means of a transformer, to convert it into a current of high pressure for transmission over the line, and at the far end the pressure can be again reduced by a stationary transformer, and led into workshops, or elsewhere, or used for lighting purposes, at the moderate pressures which experience suggests. An alternating current dynamo is also about 40 per cent. cheaper than a continuous current machine of the same capacity, when dealing with large amounts of power.

Whether we consider the matter from the point of economy, safety, or certainty of uninterrupted supply, the alternating current has immeasurably the advantage. I could speak at much greater length on this point if thought desirable, but the point has been so universally conceded by the most experienced engineers, that it hardly admits of argument.

Assuming now that the alternating current is to be used, we must settle whether it is to generate current in a single phase, in two phases, or in three phases. The single phase alternating current is admirably adapted for all lighting purposes. Synchronising motors also work with a very high efficiency, but they require to be started mechanically so as to attain the synchronising speed before being put into circuit. Numerous alternating motors have been made with a single phase which start automatically, but hitherto they have not been largely developed, chiefly because there has been so little demand. Two-phase and three-phase motors start perfectly well on full load, and are quite as satisfactory as continuous current motors for ordinary workshop practice, and will serve for driving tramways or locomotives. They can be stopped, started, and reversed with the utmost ease. They have no commutator, nor collecting rings, on the revolving part, which is completely detached from the rest of the machine except at the bearings. The disadvantage of these multi-phase motors is that they require more than two wires. This is certainly a defect in distribution through a town, or in application to electric traction.

When alternating currents are being used for transmission, it is probable that the best way of using the power for traction purposes is to convert the alternating current into a continuous current at the place where it is used, by means of an alternating current motor driving a continuous current generator. Special machines have been constructed for this purpose which combine the motor and generator parts into one armature, an ordinary continuous current machine being used with insulated rings fixed round the commutator, four or three of them according as we are using a two-phase or a three-phase current, brushes being fixed to rub on these rings as they revolve, the rings being attached electrically to commutator bars at equal distances round the periphery of the commutator. The two or three-phase currents being passed through these rings to the armature cause it to rotate, and the ordinary brushes of the continuous current machines take off continuous current, which serves to excite the field and which may be used for any purpose. Such machines have been constructed largely by Schuckert of Nurnberg, and to a certain extent by the two great American competing manufacturers of electrical machinery.

It appears, then, that the alternating current, either of one, two, or three phases, can be transmitted so as to develop power for motive power and for electro-chemical operations. Certain advantages have been claimed for the three phases. It has been said that the cost of copper in the conductors is less than with two phases. It has also been said that the turning power given to a motor is more uniform with three phases than with two. These claims are untenable.

It has also been said that the three-phase system requires only three wires and that the two-phase system requires four wires. This is not true. The two circuits of the two-phase system may be worked with a common return wire, and when this is done the copper required is less even than with three phases.

The three-phase system has the great objection that the three circuits must be inter-connected. This gives rise to a great deal of trouble in regulating the current, and also in testing the system for faults, and correcting these. The three circuits can never be at the same pressure, unless they are all loaded equally, and this makes the use of the system impossible for lighting purposes. I have made a number of tests on this point which I can lay before the Committee if desired. The single-phase and two-phase systems are free from these objections, and therefore I give them the preference.

The only question now is whether the single phase or the two phase is the best. For many reasons, I should be inclined to say that a single phase was the best, but the two-phase machinery develops two totally distinct currents, passing through different circuits, each of which can be regulated independently. It can also work multi-phase motors, the advantage of which has already been stated. The two-phase machine gives a larger out-put for the same weight of machinery than the single phase. For these reasons, I would, for general purposes, prefer the two-phase system; but this must depend largely on the character of the uses to which it is to be applied. If the circumstances are such as to yield readily to the adoption of a single-phase current for all purposes, I would be inclined to give it the preference. In the meantime, I propose to deal with the question as if we found it advisable to use two-phase machines, as this is more likely to prove to be the case.

Having now decided that alternating current, with 30,000 or perhaps 40,000 volts, and two phases, would be generated, it becomes necessary to consider what should be the frequency of alternations. This is a matter to which I have given great attention in the past year. I find that, for motive-power purposes, the lower the frequency, the better is the result down to about 10 periods per second; but when the current has to be used for electric lighting, whether arc or incandescent lamps, these low frequencies are not available. It appears, then, that by using a frequency of 50 we can work both arc and incandescent lamps, but the efficiency of our motors is sensibly reduced. I content myself at present with stating this result generally, instead of devoting, as I might, considerable space to showing the data on which I have arrived at this very definite conclusion. With any frequency under 50 periods per second arc lamps are found to flicker; with any frequency under 30 periods per second incandescent lamps are found to flicker disagreeably. If the chief use were for power purposes, it would clearly be desirable to have the motors working at the greatest efficiency; and in this case I would recommend the adoption of a low frequency, somewhere about 10 or 15 periods per second, and the lighting would then be done, either by means of motors driving electric generators, or by means of some commutating machine, possibly like the one to which I have already referred. It seems to me probable, in the present case, that a very large amount of electricity might be used for the electric lighting of Madras, and if this is the case it might be best to put down the generators of such a character that they would do the lighting at

the cheapest rate, and therefore have a suitable frequency. Motive power could still be efficiently supplied from these generators, although the efficiency of the motors would not be so high, and might only amount to perhaps 85 per cent.

On the whole, then, it might be assumed, for the present purposes, that we shall employ a current with a frequency of about 50 periods per second.

Since the pressure which we shall employ on the line is at least 30,000 volts, it becomes a question whether this ought to be generated directly in the dynamos, or whether the dynamos should give us a current of lower pressure, transformers being added for raising the pressure before the current goes into the line. This last method has been generally considered to be essential for very high pressures, but the additional expense of providing transformers is very great, the cost of transformers amounting in a number of estimates which have been before me to as much as the cost of the generators. If the dynamo be revolved about a vertical axis, and if the armature be fixed and the field magnets be made the rotating part, it becomes as easy to insulate the dynamo as it is to insulate a transformer, and the reduction in cost is very great. We thereby attain, also, an increased efficiency of the whole plant, and we avoid all trouble of introducing the extra self-induction which is involved by the employment of a step-up transformer. This design also enables us to put very considerable momentum into the revolving part, which serves to take up the irregularities due to the varying consumption of power in the moments while the turbine governor is adjusting itself to the varying load.

So far as it is possible to form a judgment without having fuller details of the purposes to which the transmission plant is to be applied, I would say that the above type of machine is what is required, having the following characteristics:—5,000 horse-power, vertical shaft generating 30,000 or 40,000 volts direct, frequency 50 per second, two phases. Such a machine can be got out at a remarkably moderate figure, and I can speak with confidence on this point from having had tenders for dynamos of this power from a number of different firms in Europe and America.

The cost of this dynamo may be taken at not over 6,000£, but I find it impossible, at present, to estimate the cost of transport and fixing; nor can I estimate the cost of buildings until the designs of the turbines are submitted. These are all points which must be considered in detail when it is resolved to take further steps in the matter. The cost of transformers of 1,000 horse-power or over may be taken as certainly not over 1£ per horse-power, and I am of opinion that they ought to be constructed at half this price. The principal cost of the whole of this plant would lie in the line, owing to the great distances to which the current has to be carried, and to this point I shall now give some consideration.

The Line.

It is quite hopeless to deal with this project except by means of an overhead construction of the line. In many cases, depending on the climate, where heavy snow falls, sleet, and violent cyclones are encountered, an overhead construction is certain to lead to discontinuity in the service, but from what I have been able to learn of the climate in which it is suggested to put down this plant, there will be no serious trouble from this cause. I would therefore propose to put down a line of poles. These may be either of iron or of wood; in the latter case they should be made A shape for strength. It may be well, in considering the cost, to suppose that the line is laid out in units of 5,000 horse-power, but in some directions a much larger amount of power can be taken, and the actual cost in the poles will, in these cases, be less.

In the meantime I assume a set of poles for each 5,000 horse-power unit. The poles will be provided with special insulators, of which I can give details when required, embodying everything that has been learnt by past experience as to the troubles that have to be got over in this form of construction, and about the successful action of which there cannot be the slightest doubt. By this method of construction, in fact, I would have no hesitation in going up to an electric pressure of 40,000 volts, and this it would be most desirable to use in case it is proposed to go so far as Madras, whose distance from the irrigation works is 350 miles. It will be well to consider the cost of 40,000 volts carried to a distance of 350 miles.

In order to find out how much copper must be put into the conductors to give the most economical results, it is necessary to tabulate the results with different densities of current, and to compare the money loss in power wasted as heat in the conductors with the interest on the capital sunk in copper. It is necessary to select such a current density that, by a slight increase or decrease in this density, the additional gains and losses owing to difference in power wasted and in interest on capital sunk shall be equal.

If, however, there is no great prospect of so large a demand arising as to utilize all the available power it may be worth while to deliberately waste a considerable amount of horse-power, at a cost only of putting in turbines and dynamos, and wasting this power on the line by using much lighter conductors. In this way we shall arrive at a greater economy on the limited output, and I will work out the figures for the line to Madras.

The difference between these two ways of looking at the problem is this,—In the one case we take the value of a horse-power as the selling value at the point where it is delivered, in the other case as the cost of production at the hydraulic works. It is extremely unlikely that the cost of this production of power would amount to more than 15£ per horse-power, which, at 10 per cent. per annum, would mean 30s. a year for the cost of producing a horse-power.

Having reference to what has now been stated, it will be best to examine what will be accurately the actual cost of the line at different densities of current on the long distance of 350 miles to Madras, assuming an electrical pressure of 40,000 volts. Accordingly, I have computed the following table, in which the first column indicates the mean density of current reckoned in amperes per square inch. In the second column is given the cost of the copper per horse-power generated, the price being taken at 50£ a ton. The third column gives the horse-power that is lost on the line, and the fourth the remaining fraction of a horse-power that is available. The fifth column gives the cost of copper per horse-power delivered; and the sixth and last column gives the amount of horse-power that has to be generated at hydraulic works in order to deliver one horse-power at Madras.

D.	Copper per Horse-Power generated.	Horse-Power lost.	Horse-Power left.	Copper per Horse-Power delivered.	Horse-Power to be generated per Horse-Power delivered.
	£			£	
100	70	·08	·92	76	1·1
200	35	·16	·84	42	1·2
300	23	·24	·76	30	1·3
400	17	·32	·68	25	1·46
500	14	·40	·60	23	1·66
600	12	·48	·52	23	1·9
700	10	·56	·44	22·7	2·3
800	9	·64	·36	25	2·8
900	8	·72	·28	28	3·5
1,000	7	·80	·20	35	5·0

This table will be useful for general reference when we have obtained accurate data as to the cost of hydraulic works. The cost of the line, as indicated above, includes by far the greater portion of the total cost of the electrical plant. The electrical item of next importance is the cost of poles and insulators, which, for each unit of 5,000 horse-power, I have taken at 90*l.* a mile, being 1*l.* per pole and 2*s.* 6*d.* per insulator with its attachments, and I have taken 60 poles to the mile. It is probable that in dealing with larger amounts of power the cost will come out somewhat less. It is impossible to fix upon the best density of current to employ until we know the cost of the hydraulic part of the works, because, as will be seen in the last column, when we reduce expenditure on the line we are increasing the amount of hydraulic power that requires to be developed. I will take a single case to illustrate the manner in which this table can be applied. Let us assume that a density of 400 amperes per square inch should be the most economical value. In that case we can include the main features of expense in the electrical part of the design. As I have stated above, the cost of a dynamo of the type which I have recommended would come to 6,000*l.* for a 5,000 horse-power unit, and the cost of a transformer I will take at 1*l.* per horse-power, although I am quite confident that this is considerably in excess of what we shall find in practice. I do not know how much to allow for cost of transport and erection, and that will be dealt with when the question of more detailed estimates arises. At that time also the small additional electrical appliances, such as switch boards and measuring instruments, may be considered.

The total cost of the principal parts of the electrical plant come out, on the assumption of a density of 400 amperes per square inch, as follows:—

	£
Copper on the line	25.0
Poles and insulators	6.3
Dynamos for 1.46 horse-power	1.75
Transformer for 1 horse-power	1.0
Per horse-power delivered, total	34.05

This is the cost for one horse-power continuously delivered at Madras. If we were dealing with the *lighting* of a city, only, the cost of line would refer to a *mean* (or more exactly the *root of mean square*) output of one horse-power, which would probably involve a maximum four times as much. The cost of dynamos and transformers would then have to be multiplied by four and the total capital would be 42.3*l.* for a *mean* output of one horse-power. This way of looking at it makes the electrical cost much more favourable when compared with steam, as the irregularity of lighting hours makes a steam plant very expensive to run.

To find the annual charge, it will be noticed that the copper conductors are permanent value, and it is sufficient to make a charge of 4 per cent. interest on this, while on all the rest of the plant we should make a charge of 10 per cent. for interest and depreciation. This gives the following annual charges:—

	£
Copper conductors	1.0
Poles and insulators	0.63
1.46 horse-power dynamos	0.18
1 horse-power transformers	0.10
Per horse-power delivered	1.91

This is for a continuous service. If the maximum demand were four times the mean, the cost would be 2.75*l.* per mean horse-power per

annum, and during all the daytime most of this power could be diverted to other purposes.

I have taken this case of transmission to Madras as being likely to be a crucial case to determine whether a further consideration of the question is necessary, because it seems possible that in Madras there may be created a large demand for electricity both for the lighting of the houses and streets, and also for working electric tramways. In the previous part of the report where I dealt with a distance of 100 miles, I assumed that we were working with a pressure of only 30,000 volts, but if 40,000 volts can be used for Madras, it can equally well be used to the shorter distances, and a corresponding economy would be thereby introduced.

It will now be asked whether I can undertake that these results can positively be accomplished. With regard to the cost of dynamos I have gone at considerable length into a statement of the type of dynamo which I would recommend, and my principal object has been to so specify it that we shall be able to obtain such a dynamo at a moderate cost, and since the estimate which I have given is founded on estimates that have been given me for somewhat similar dynamos by a number of manufacturing firms, and as a percentage has been added to cover the extra cost of going to an insulation which will stand a pressure of 40,000 volts, I have no doubt that the cost given for the dynamos is well within that which we should be able to accomplish.

As to the cost of transformers, my estimate here is again in excess of certain estimates which have been received by me for another work where the transformers are built for large powers.

Concerning the price of poles and insulators, I have no hesitation in saying that in any country that I have had to consider in this connection, the work could be done at the price which I have named; but I have not the necessary information with regard to India to enable me to say with certainty whether it is the case there also. All the machinery hitherto referred to, dynamos and transformers, can without a question be built so as to generate and utilise directly the electric current generated at the considerable pressure of 40,000 volts.

With regard to the line, I would not have any hesitation in saying that this would also be satisfactorily done if I knew that there were no special climatic conditions which may interfere with it. So far as I am aware, there are none such, and I therefore feel the utmost confidence that the line can be carried at the above pressure with freedom from interruption in the supply and with ordinary precautions there will be no danger. Since, however, as I have already stated, experiments are at this moment being made in Switzerland, where a line is being tried over a distance of 13 kilometres, and using a pressure of 40,000 volts, it will be interesting to follow the progress of this work, and as I have been promised an early account of the results, this information will be available, and will be of considerable utility to us. I ought to mention that in the project for utilising Niagara Falls I am recommending the adoption of a pressure of only 20,000 volts for transmission to Buffalo, and I am well aware that in doing so I am subjecting myself to the accusation of timidity in not wishing to go to a higher pressure. There is no question of timidity in this. I consider that for the 15 miles of distance which have to be traversed, the 20,000 volts giving, say, a loss on the line of only 3½ per cent., is amply sufficient; and it is more with a desire not to lead people to suppose that we are going to unusual pressures than for any other reason that I have not adopted a higher pressure. The manufacturing company which has had most experience in this direction proposed a pressure of 25,000 volts even for this short distance, and another electrician who has proposed using the continuous current in a manner, however, which would be quite unsuitable, has prepared his plans for a pressure of 20,000 volts, though everyone with practical experience must admit that the danger in working a continuous current at this pressure would be very considerable.

It would have been possible for me to have gone considerably more into the details as to the methods which I would propose to adopt to make such a system as I have sketched out successful, but I feel that at the present stage of the enquiry what I have said is amply sufficient if the Committee will take it from me that I have naturally had occasion in the course of my other professional work to consider these details very thoroughly, and that generally the data from which I have worked out the cost above, are such as would be conceded to be trustworthy by the engineering profession generally.

As to the uses to which such a supply of electricity could be devoted, this question will naturally come up for consideration by the Committee later. There is, first, the possibility of attracting large industries to places within 100 miles of the works. Again, there is the electric lighting by both arc and incandescent lamps in Madras, Trichinopoly, Madura, and elsewhere. There is also the field of electric traction, including, partly, tramways in the large towns, and longer tramways connecting outlying villages with towns. I have already alluded to the further possibility of working all the railways in the Presidency south of Madras by means of electricity, these being now worked by steam.

It seems quite clear that up to the distance of 350 miles, that is, up to Madras, it will be possible to supply electricity at any low pressure suitable for electric lighting or for motive power at a cost of not more than 4% per horse-power per annum, including all costs with a margin for contingencies.

No. 5.

Report by Professor Roberts-Austen, C.B., F.R.S.

Water Power at the Periyar Irrigation Works.

Cost of extraction of Aluminium.

The metallurgical questions which I have those relating to the possibility of obtaining electrical energy, falling water being the means.

Mr. Chatterton's memorandum, which for entrusted to the Committee, states, page 3, that in India there are numerous deposits of corundum worked as a source of emery. They occur in Coimbatore, Bellary, North Arcot, and Kistna, Mysore, and further off in Rewah and the Narmada.

* "Manual of the Geology of India," Part III, "Economic Geology," by V. Ball, London, Trubner & Co., 1881.

I have analysed a specimen of corundum from the Salem district, obtained from the Geological Museum of Jermyn Street, and find it to be of a high degree of purity, but I have no means of ascertaining whether it is an average sample. It is added that it is not absolutely certain that these deposits would be capable of yielding the 40,000 tons per annum which it is estimated will be required. It is also stated that 10% per ton would probably be the maximum price to be paid for it.

I have as yet been unable to obtain either from Sir George Birdwood, or from the Imperial Institute, specimens of the particular deposit

mainly to consider are metallic aluminium by electrolysis.

On the basis of the inquiry into the southern part of the country, which have long been the districts of Salem, Coimbatore, Bellary, North Arcot, and Kistna, in the Native State of Mysore, and the Narmada Hills in Assam. I have cited the authority.

by Mr. Chatterton as describing the Indian deposits of corundum, but cannot find any analyses of the materials.

which would probably afford the source of aluminium, I am therefore in doubt as to the purity of the deposits generally, or as to the readiness with which the corundum could be reduced by electrical agency. I do not propose at present to give details as to the exact nature of the plant which is to be adopted, but it will probably closely resemble that adopted at the Patrierott works near Manchester, of which elaborate descriptions are available. Attention will therefore be mainly directed to the considerations of such details of cost of production as can be obtained.

First as regards the energy required for the electrical reduction of aluminium.

Mr. Chatterton's Memorandum states that in 1890 at Pittsburgh, about 500 horse-power is continuously employed in the production of 375 lbs. of aluminium per day. He also quotes from a paper published by Mr. J. H. J. Dagger* in which it is stated that an electrical furnace absorbing 500 horse-power, working Cowles process, yielded 410 lbs. of aluminium in the form of alloy.

I am of opinion that the adoption of Cowles original process, which only yields alloys of aluminium with copper or iron, should not be contemplated, and that it will be preferable to direct attention on the production of pure aluminium, and for this, the prominent processes are those of Heroult, of Hall, and of Minet. The best known works for the production of aluminium itself is the "Aluminium-Industrie-Actien-Gesellschaft, Neuhausen, at Schaffhausen on the Rhine." The dynamos are furnished by the firm of Escher, Wyss, & Co., of Oerlikon, near Zurich.

Three dynamos are employed, two of 600 horse-power, and one of 300 horse-power. This is probably equivalent to 482 English horse-power, and 241 English horse-power respectively. The axes of rotation are vertical.

Great care seems to be directed to the control of the speed of the turbines and dynamos which is known to be an important point in connection with all electrical installations devoted to metallurgical purposes. Each dynamo is of multipolar type, and gives a working current of about 6,000 to 7,000 amperes. The potential is about 30 volts with a speed of about 150 to 200 revolutions per minute.

At Froges, in the Department of Isere, France, the installation is similar in character, and the bath submitted to the action of the electric current consists of alumina diffused, or melted in fused cryolite, the native double fluoride of aluminium and sodium. Without going into precise details it may be well to add that in both the Heroult and Hall processes, the bath is either bauxite or preferably pure alumina suspended in fused cryolite, a layer of copper or of iron being sometimes placed at the bottom of the bath when it is desired to form alloys with the liberated aluminium. In the Minet process, on the other hand, the bath which is submitted to the influence of the current contains 30 to 40 per cent. of an artificial fluoride of aluminium and sodium and 60 to 70 per cent. of common salt the bath being regenerated with pure alumina. The composition of the bath, however, varies, one proportion being,—

- 1 part cryolite.
- 2 " artificial fluoride.
- 4 " alumina.

The cost of horse-power at the Periyar Works is estimated by Colonel Pennycuik at 20 rupees per annum for 24 hours daily. At Pittsburgh it is found that 22 electrical horse-power hours (or 16,412 Watts) are required for the production of a pound of aluminium. Assuming that a loss of 15 per cent. occurs, and that 25.9 horse-power is required at the turbine to produce the 22 E horse-power at the bath, this on

Colonel Pennycuik's estimate would cost 1.07 pence (valuing the rupee at $\frac{1}{4}$ th of a sovereign).

With reference to this estimate it may be well to point out that Professor Coleman Sillers stated in 1891, with reference to the production of aluminium, that he did not consider it "safe to predicate the value of metal, produced upon anything short of £15 per horse-power per annum, for 24 hours daily, while perhaps \$20 per horse-power "would cover all contingencies." This would give for 22 electrical horse-power (allowing (as he did only) 10 per cent. loss in conversion), six cents, or 3 pence, as against Colonel Pennycuik's 1.42 pence.

A still more recent estimate by Herr Diehl, puts the probable cost of energy in the Heroult and Minet processes respectively at a much higher figure as will be seen by the annexed table, yet his estimate for the total cost of a pound of aluminium by the Heroult process is under 2s., and for that produced by the Minet process a little over 1s.

It will thus be seen that the cost of energy as estimated by Colonel Pennycuik compares very favourably, even if the output of the proposed works should be forced to such an extent as to require a higher voltage.

If the voltage were raised to 20 at the bath, then 35 horse-power hours would be theoretically required to produce a pound of aluminium, and the cost of energy would be raised to 2.23 pence, but the establishment charges might in this way be somewhat reduced. It may be assumed that in a large works the cheapness of the Native labour would counter-balance the increased cost of superintendence, and the two items of cost, labour and superintendence, might be taken at 1s. d. per lb. of aluminium produced. In consideration of the fact that all appliances would need to be brought from a great distance, it would be well to allow 2d. per pound to meet the charges of interest on capital and for repairs. Chemical stores would be also expensive, and 1d. per lb. had better be allowed for this item; and as carbons suitable for electrolytic work at high temperatures have to be exceedingly dense, ordinary charcoal is quite unsuitable. As a safe approximation, based on such imperfect data as I have been able to collect, I should say that suitable electrodes could not be produced under a cost of 2d. pound at the spot.

The estimate therefore will be,—

	d.
Energy	1.10
Alumina, 2 lbs.	6.0
Labour and superintendence	1.5
Interest, repairs, and maintenance	2.0
Chemical stores	1.0
Carbon electrode	2.0

	s.	d.
Cost of 1 lb.	1	1.6

Captain Hunt's estimate of the cost of making 1 lb. of aluminium,—

	d.
2 lbs. alumina (52.9 Al.)	3
1 lb. carbon electrode	1
Chemicals, carbon dust, pots	0.5
22 electrical h.-p. hours (water)	2.5
Labour and superintendence	1.5
General expense, interest, and	1.5
Total cost	10.0

Very grave considerations are presented by the nature of the material it is proposed to employ.

Mr. Chatterton allows 1.1d. a lb. for the cost of the corundum, or if alumina were imported from Germany he places the cost at 20s. per ton, or say, 2.2d. a pound, and such alumina would not contain more than 50 per cent. aluminium. I believe that this is considerably under estimated; on the other hand an authority already quoted places the cost of prepared alumina (containing 52.9 per cent. of aluminium) at 1.5d. per pound. If the corundum is associated with either much iron or silica, its reduction will present great difficulties. It is not easy to purify aluminium from silicon and iron, and moreover the presence of much silica in the bath would lead to great loss, as it would decompose the cryolite giving rise to the evolution of fluorine. Much will, therefore, depend on the purity of the corundum, and on the readiness with which it can be reduced. In the absence of direct experiment upon these points I incline to the opinion that it will be preferable to employ artificially prepared alumina rather than the Native mineral.

Appendix to No. 5.

Zeitschrift des Vereines Deutscher Ingenieure Sieger District Meeting, 7th June 1892, 27th May 1893, p. 600.

Manufacture of Aluminium, Hr. Diehl.

Method and Raw Material	Cost of 100 lbs. Alum.	Per Cent. of Alum.	Cost of 1 lb. A. I. in Raw Material	Rates for 1 lb. of Aluminium yielded.		Horse-power Hours for each 1 lb. Aluminium.		Value of Horse-power Hours in Shillings at 0.001 per Horse-power Hour.		By-products with 1 lb. Aluminium.		Amount of		Value in Shillings	Total Cost of Product from.
				60 per Cent.	90 per Cent.	60 per Cent.	90 per Cent.	60 per Cent.	90 per Cent.	Co.	Cl.	Carbon Electrode.	Coke.		
1. Ferrous Amalgam	27.7	30.0	35.4	—	—	—	—	—	—	1.52	—	—	—	—	—
2. Manganese chloride with chlorine	4.336	84.0	566	13.636	9.090	18.4	12.2	1.116	7.11	—	—	50	—	0.68	1.811
3. Manganese chloride with chlorine	4.336	84.0	566	13.636	9.090	18.4	12.2	1.116	7.11	—	—	—	90	1.184	1.901 for 60 per cent. 1.649 for 90 per cent.

2. Co. kept in the place
9/15 out 19th 90

2593W 7/13-10-93