PRESIDENTIAL ADDRESS

By SIR ALEXANDER GIBB, G.B.E., C.B.

The Economics of Power as Applied to Chemical Engineering.

I WOULD like to preface the few remarks I am going to make to you to-day by sincerely thanking you for the mark of confidence you have shown by placing me in the Presidential chair of this Institution. Having accepted office it is my duty, in accordance with ancient custom, to deliver an address of some kind, and you will probably be surprised at my temerity when you read the title. The truth is that when I was asked to name a subject, while I had a very clear idea of the general lines on which I was desirous of framing my remarks, I had still not in any way worked out their detailed application. But a title was immediately required, and so I chose one that would give ample scope for the development of my thoughts in whatever direction they might turn.

Now, generally, the purpose I had in mind was the consideration of some corner of the great field of engineering where the boundaries of chemical and civil engineering march. The demarcation of chemical engineering is not yet, perhaps, as clear on every side as we might wish, for it is of the nature of those succession States born out of the dissolution of wide empires and over whose potential riches envious looks are still sometimes cast. But to-day I will try to choose a point on the boundary where there is no dispute, and where, on the contrary, there is and must be the closest, and equal, co-operation between the two bordering states of the Chemical Engineer and of the Civil Engineer.

It is, indeed, by the contemplation of such points of inter-dependence that one is inspired to press forward towards that ideal which has always been at the back of my interest in the Institution of Chemical Engineers—I mean the co-operation, or alliance—whatever form it may take—of all the great engineering societies and institutions into one comprehensive engineering league or group. It would be difficult to devise a better definition of the nature and objects of all such engineering institutions than that enunciated by Thomas Tredgold and adopted by the Institution of Civil Engineers, the oldest of the engineering institutions, one hundred years ago in their Royal Charter, *i.e.*, "The directing of the Great Sources of Power in Nature for the use and convenience of man."

But that is the vision, and I must leave its pursuit to another time.

To-day, denying myself all such dreams, I shall turn to the more material and practical considerations that arise from a close examination of this "boundary question," and I hope that I may be able to assist in removing certain misconceptions on each side of the boundary and perhaps in marking out certain lines along which the two branches of the profession may advance together and to their mutual advantage.

I propose then to enquire into the position of cheap power in chemical engineering; that is to say as an essential part of electro-chemical and electro-metallurgical processes.

I use the phrase "cheap power" not because it has become a sort of slogan, but because it is a short and handy expression for one of the most important components in modern civilisation. Undeniably this is an age of cheap power. If you consider the progressive decrease in the cost of power over many years, and the lavish, almost prodigal, increase of its provision, you will not impeach the claim—and yet, with appetite only whetted, less satisfied than ever, the unceasing cry goes up from industry, "Cheap power; more cheap power; and still more cheap power."

I must not be taken as in any way minimising the very important position in modern civilisation of the gas industry, or the efforts of a succession of great gas engineers, of whom our first President is one of the most distinguished, if I say that cheap power means cheap electricity. I will go further and say that from the electro-chemical and electro-metallurgical points of view at least, cheap power at present implies hydro-electricity. And, of course, there you will find yourselves within the sphere of the civil engineer.

Now with this development of cheap power there has been a phenomenal development of certain industries making use of electrical power in large quantities. The two have naturally run together. The electro-chemical load is the basis of the economical production of electricity, and economically-produced power is a *sine qua non* of the electro-chemical industry. To the interaction of these interests has been due more than to anything else the great development of cheap power.

It is these new large-scale industries, based, expanded and maintained on cheap electricity, often roughly classed as "cheap power industries" that I shall now proceed to consider.

The consumption of electricity in electro-chemical processes naturally varies enormously, ranging from a few kilowatt hours per ton of one particular commodity produced to several kilowatt years for another. With the former the cost of the power is a bagatelle, with the latter it is a vital factor. The latter only I would include in the term cheap power industries.

I have prepared a list of some of the more important cheap power industries in the order of their demands on electricity, excluding the requirements for heat, light, transport, communication and other such services, which are common to all industries. My estimates do not, of course, portray the position in any one particular factory, but they are sufficiently near to the truth to afford an accurate measure of the present dependence of some of the branches of electro-chemical engineering on cheap power. I shall just give you the name of the product with the approximate amount of electricity consumed per ton against it :—

Pulp and Paper	1,800-2,000	Kilowatt Hours per ton produced.

(I must admit that the use of electricity in pulp and paper mills is not strictly an electro-chemical process, being entirely for mechanical purposes. The industry, however, is definitely a cheap power industry.)

Hydrogen Gas	1,600 Killowatt Hours per 1,000 c. ft. produced.	
Pig Iron	2,000 to 3,000	Kilowatt Hours
Refined Iron (from pig iron)	1,500 to 2,500	per ton produced.
Electrolytic Zinc	3,800 to 4,000	,, ,,
Calcium carbide	4,000 to 4,500	,, ,,
Caustic soda	4,500	,, ,,
Nitrogen (direct synthetic process)	5,000	,, ,,
Various ferro-alloys and even more (the highest being for a high percentage Ferro-Silicon)	5,000 to 15,000	,, ,,
Potassium and Sodium chlorates	6,000 to 8,000	,, ,,

(For sodium perchlorate we may add a further 3,000 kilowatt hours)

Phosphorus	11,000 to 13,000	,, ,,
Sodium	14,000 to 15,000	,, ,,
Magnesium	18,000 to 20,000	,, ,,
Nitrogen (cyanamide process)	20,000	,, ,,
Aluminium	25,000	,, ,,
Nitrogen (arc process) at least	80,000	,, ,, per ton of nitrogen fixed.

Consider now further the proportion that the cost of these amounts of electrical power bears to the total production costs in each case. It would take too long to go through the whole list. It will suffice, perhaps, to take four or five instances, say, aluminium, nitrogen, iron, phosphorus and calcium carbide, as fairly representing different aspects of the question.

Aluminium.—The total world production of commercial (that is to say electrolytic) aluminium is fairly evenly divided between America and Europe, between the Aluminum Company in America and the European Cartel here, the latter covering all the factories in Germany, France, Norway, Switzerland and Great Britain, and at present effectually controlling the whole European output. The total present production is over 200,000 tons a year, and the capacity about 300,000 tons, involving the use of $1\frac{1}{2}$ million h.p. of electricity. The world capacity, however, according to present plans, will soon be between 400,000 and 500,000 tons, involving up to $2\frac{1}{2}$ million h.p. of electricity in the one industry. At a cost of ·1d. per unit at the factory, power is responsible for at least 20 per cent. of the total production cost of aluminium, which to-day is about £63 per ton. At ·25d. per unit the cost of the finished product would be raised by £20 a ton.

Nitrogen Fixation.—Changes have been taking place in the industry of artificial fertilisers that indicate an important trend of chemical engineering, and therefore deserve more than passing notice. Taking the three proved processes, the *arc process* now obtains almost solely in Norway. The efficiency of this method is extraordinarily low, 90 per cent. of the electrical energy being represented by the heat of the furnace gases, some of which of course can be turned to account. At ·1d. per unit the amount of electricity required is so great that it would be quite impossible to compete with other processes. The economic price for electricity for the arc process would appear to be certainly below ·075d. per unit.

The *cyanamide process* requires approximately one-quarter the electrical energy of the arc process, but is still definitely a cheap power industry dependent almost wholly on water power.

The *direct synthetic process* requires something like a sixteenth of that used in the arc process, and for this reason and owing to the fact that auxiliary use can be made of the exhaust steam, the synthetic process is entirely independent of water power.

In the light of these remarks I would have you compare the present and pre-war positions of the three processes.

THE WORLD PRODUCTION OF FIXED NITROGEN OTHER THAN IN CHILEAN NITRATE AND BY-PRODUCT AMMONIA.

Arc process				
1913	7 plants producing	19,800 tons being	31.7%	of total synthetic nitrogen
1926*	7 ,, ,,	40,500 ,, ,,	5.5%	,,
Cyanamide process.				
1913	15 plants producing	36,000 ,, ,,	57.4%	,,
1926	28 ,, ,,	174,000 ,, ,,	23.7%	,,
Direct Synthetic process.				
1913	1 plant producing	6,800 ,, ,,	10.9%	,,
1926	49 plants ,,	519,000 ,, ,,	70.8%	,,

* The latest year for which figures are available.

Even with the cheapest power in the world the arc process is practically dead and the cyanamide process is possibly already obsolescent.

Iron and Steel.—The whole use of electricity in the manufacture of iron and steel is too complex a subject for even cursory consideration. It will be sufficient for my purpose to state that pig-iron is now produced electro-thermally (i.) from iron ore, and (ii.) (the so-called synthetic iron) from scrap.

With both, the cost of power bears particularly heavily, in view of the low-selling price of pig-iron. At ·1d. per unit the cost would be in the region of

22s., or over 30% of the present-day price. The electrical smelting of iron-ore is, therefore, confined to those countries where deposits of ore are contiguous to very cheap water power and where fuel is unduly expensive—that is to say, Sweden, Norway and Italy. Synthetic iron, also a water-power industry, is practically restricted to France and Canada. It has certain definite advantages of purity and flexibility which in certain conditions justify the cost of the power where this is low. Electric furnaces for refining steel are now, of course, an essential part of all modern steel works, and electrolytic iron and steel, too, have valuable qualities that foreshadow possible developments in this direction, but their comparatively low consumption of power and independence of a high process factor exclude these processes from the category of cheap-power industries.

Phosphorus is produced electro-thermally, the principal raw material being calcium phosphate, the present cost of which I take to be about £2 per ton. At ·1d. per unit I calculate that the electricity consumed in the process would be approximately 20% of the total cost. But the actual cost of the principal raw material to the manufacturers cannot be definitely ascertained, and is a variable quantity. I am inclined to think that the proportion of electricity to total cost may often be rather higher.

Calcium Carbide.—Much of the calcium carbide produced is, of course, used in the fixation of nitrogen by the cyanamide process. The raw materials are simply coke (or anthracite) and limestone, and their total cost is about £3 per ton of calcium carbide produced. The cost of energy at about 35s. is, therefore, the heaviest item in the process.

These figures should give us, I think, some idea as to what is really implied by the phrase "cheap power industries." The cost of power has, in fact, been the predominating, sometimes almost the sole, consideration in the location of these industries. Their grouping at Niagara was originally due to the supply of what was then the cheapest power in America. Niagara now offers every facility to the manufacturer except really cheap power; and isolated and almost inaccessible Canadian sites are in consequence being exploited in preference by those who can afford to do so. Similarly, Norway, in spite of conditions otherwise on the whole rather unfavourable, and Switzerland have, because of their favourable water-power resources, always been an obvious field for certain branches of electro-chemistry.

These are all cheap-power countries, but the point that is of prime interest to us is what really constitutes cheap power from the point of view of the location of electro-chemical and electro-metallurgical industries. What is the upper limit of the cost of power above which it will become too heavy a burden for these industries, and do conditions here in this country fall within this limit? To answer these questions it is necessary to consider in some detail the present position of the generation of electricity.

As we are dealing solely with large-scale electro-chemical and electro-metallurgical industries, I shall, in computing electrical costs, assume a 100% load factor. Such a load factor, while by no means unknown in electro-chemistry over busy periods, would be exceptional for a full year. On the other hand, annual figures which have been obtained in many electro-chemical processes do not fall far short of it, for a high process factor is generally vital for economic production. Ignoring the periodical effects of market conditions, a load factor of at least 90% is attainable and attained in the majority of electro-chemical manufactures, and in particular industries such as aluminium reduction and nitrogen fixation it is safe to assume (with the same reservation) a load factor of 95%. In taking 100%, therefore, I do not think that any considerable margin of error is involved.

The cheapest electricity in the world is, or certainly was, to be had from some of the pre-war Norwegian hydro-electric installations. Their total capital cost was in one or two instances at the amazing figure of approximately £4 10s. to £5 per h.p., and the average for Norwegian developments before the War was not very much above £10 per h.p.

At the then prevailing rates of interest on money, and with working and other costs as they then were, this meant that the pre-war cost of electricity in Norway as supplied to large-scale electro-chemistry was of the nature of ·035d. per unit at the switch-board, or say, 30 units to the penny. But although the Norwegian figures were nowhere else equalled, there have been exceptionally cheap hydro-electric installations also in Sweden, France, Switzerland, Canada and the United States, in which capital costs as low as £12 per h.p. were reached, and £16 to £18 were not unusual. Thus there was available in certain places before the War for electro-chemistry and electro-metallurgy a constant supply of water power at a cost at the factory of from about ·04d. to about ·08d. or ·09d. per unit.

The position is materially different now and it is almost certain that we shall never again see water power developments on such a cheap scale. For this there are several reasons, chiefly that the more promising sites have already been utilised. The rise in prices, even when off-set by such improvements in engineering design and construction as have been effected, has also certainly raised capital costs by at least 40% to 50% and in addition to this there is a wider demand for industrial power, bringing in competitors able to pay a higher price for power.

I will not say that a large scale hydro-electric development might not now be possible, in exceptional circumstances, in, say, Norway or Canada, at a cost of £20 or so per h.p. The estimated cost of the development of the Slave River project on the Winnipeg River, which is now under construction, is only £21·6 per h.p.; but any water-power station which can be developed for anything under £25 per h.p. must be considered as unusually cheap. Even in favourable circumstances and in the most favoured countries we shall generally have to rest content with a capital cost of £25 to £35 per h.p. Developments are projected, even in America and Canada, at costs as high as £45 per h.p.

Standing charges and working costs will also require some revision upward, and on the whole it may be assumed that the average cost at the switchboard of hydro-electric power in the most favourable conditions in a large scale development and on a 100% load factor will now lie somewhere between ·065d. and ·125d. per unit.

The Aluminum Company's huge development now in hand at Chute à Caron on the Saguenay River, in Quebec Province, and the Duke-Price hydro-electric installation at Isle of Maligne on the same river are generally believed, and certainly from the ideal location one would expect them to be, as cheap as any large scale post-war hydro-electric installation. From the most favourable of various figures I have seen quoted, I estimate the production cost of the power at not less than ·065d. per unit at 100% load factor. In a typical but smaller Norwegian development which recently came to my notice, the Norwegian Government leased power for a large scale electro-chemical works at ·075d. per unit delivered, which was found to be a very favourable figure.

Generally, then, we may take ·07d. to ·145d. as the outside limits of the cost of power delivered to a nearby factory in averagely favourable conditions in typical cheap power countries. The economic golden mean is, of course, for all industries a matter of balancing conflicting advantages and disadvantages. Carriage or location of raw materials, accessibility to markets, and available labour supplies have all to be considered, and where these other circumstances are particularly favourable it would probably be possible for all but the heaviest consumers of electricity to operate successfully with considerably higher power costs than the above. As the proportion of power to the total cost diminishes, so, of course, the limit is automatically raised.

What, then, of this country? Here we have very few hydro-electric installations already developed, the only outstanding one being the combined Kinlochleven and Lochaber developments of the British Aluminium Company, the final stage of which is not yet completed. They will together eventually produce 140,000 h.p., continuously available in all but very dry summers, at a total capital cost of a little under £40 per h.p., taking pre-war and post-war costs together.

Beyond this we have only a large amount of general information concerning the problems of water power in Great Britain. I have devoted much time to considering and exploring the possibilities that hydro-electric development offers in this country, and I am satisfied that our water power resources will eventually be found to exceed the estimates of the Water Power Resources Committee. But it will, I think, be exceedingly difficult to find sites of any importance capable of development at £40 per h.p. The average will be considerably higher, and in many cases transmission costs will be an inevitable extra.

I think we should be over-sanguine to hope for any hydro-electric power plant in this country capable of producing at ·125d. per unit, and I am inclined to think that with a few exceptions we are not likely to be able to get water power in present circumstances at much less than ·16d. per unit. It is possible that labour and material costs may, over a long period, come down to some extent, and improvements in detail will certainly be made so that existing wastage and losses will be further reduced; but it has to be remembered that hydro-electric development started at a high rate of efficiency, and the percentage of the actual h.p. now obtained to the theoretical h.p. is such that a large improvement is, I fear, out of the question.

There is, of course, tidal power, and that is a matter very near to my heart. The technical principles have been worked out, but many necessary improvements for efficiency will only be possible when someone has the courage to try them out. Economically the position is less clear. I am convinced that sooner or later we shall utilise the tides, but the solution will, I believe, be in conjunction with steam power stations and the "Grid."

It appears, in fact, to be inevitable that hydro-electricity in this country will generally cost considerably more than in the most favoured water-power countries.

But if we must reconcile ourselves to being not amongst the most favourably situated hydro-electric countries, we can equally comfort ourselves, in view of our coal resources, both as regards quality and quantity, that the margin between steam power and water power the world over, and all the more in Great Britain, is much less now than it was. Before the War a figure of ·2d. per unit for the total cost of production including all capital charges had been reached in steam power stations; in the case of one large steam station with a particularly high load factor a supply of power for electro-chemical purposes was, I know, able to be provided at .16d. per unit. But these were admittedly exceptional cases. Since then, however, the improvement in efficiency has been remarkable, and the consumption of British Thermal Units in one large power station on a favourable load factor has actually been reduced below 14,000 per kilowatt year. This may be compared with 22,000 British Thermal Units per kilowatt year which was the best reached fifteen years ago. With a 50% load factor, electricity is now being generated on a large scale at a switchboard cost of about ·275d. per unit, and I am confident that a modern 100,000 kilowatt steam power station in the most favourable circumstances could in these days be built to produce electricity on the basis of a 100% load factor at .185d. per unit at the switchboard. In a year or two the figure will be ·175d.

Moreover, the efficiency of the generation of electricity by steam is still comparatively low, and there is a corresponding opportunity for improvement, chiefly in the direction of higher pressures and higher temperatures. A modern steam power station, then, is already able to compete, on a 100% load factor basis, with a hydro-electric installation costing anything more than £65 per kilowatt capacity.

As the load factor falls so the advantage of the steam power station becomes greater. At about 50% only really cheap water power can compete. I would emphasise the point. Up to the present the best steam results are not so favourable as hydro-electric figures, but whereas—speaking generally—the most economical water-power sites have already been developed and whereas the efficiency of water-power plant has already reached nearly to its possible limit, the trend of development in steam stations is more promising, and they will in many cases in the future be able to compete with new water-power development.

When the best, however, has been made of our position—and I have gone as far as I dare—it might appear that this country at the present time (apart from our colonies and overseas possessions) falls short of the requirements of the cheap power industries. If the matter ended there, the outlook for us in many of these electro-chemical industries which play such an important part in modern life and the pioneering work of which in so many cases was carried out in this country, would not be encouraging.

But fortunately for us there are other considerations. The more one considers the history of these cheap power industries, the more one will, I believe, come to the conclusion that cheap power has been allowed to play a somewhat disproportionate part in their development. I speak here with some temerity. But it is a fact that in some of the most important electrc-chemical industries processes are almost exactly the same as they were thirty years ago, and entail an uneconomic use of electricity.

The profusion of cheap electricity has, indeed, to some extent been a disadvantage in that it has tended to remove the incentive to research and invention which otherwise economic factors would have forced. Here in this country we can hardly hope ever to have ultra-cheap hydro-electric power, but that should really be an encouragement to us. *Res angusta domi* is a useful spur to effort, and there are countervailing advantages here, and ways by which apparent disadvantages can be turned to profit by ingenuity—and I need not point out that ingenuity should be of the essence of the engineer, chemical, civil or other.

At any rate, if electro-chemistry fails to advance, pure chemical methods will have increasing successes at its expense. I do not think there could be a better example of this tendency than the history of nitrogen fixation to which I have already referred.

The business of a chemical engineer is to take the best that exists and to improve on it, and only by doing so shall we justify our existence. Civil and chemical engineering will always be dependent on each other to a certain extent, and each can and ought mutually to benefit by supplying in the truest sense the needs of the other. I can only hope that the foregoing remarks may be of some use to those responsible for the manufacture of chemicals and chemical material in large bulk, and while on the one hand giving some indication of the possibilities and limitations of cheap power, may on the other hand afford an incentive to the inventive genius and powers of application of chemical engineers.

May I, in conclusion, thank you for again allowing me to be your President, and assure you that with the help of the Council and Officers I will do everything in my power to serve this Institution and to promote its interests during the time given me in which to work.

Sir Frederic Nathan, proposing a hearty vote of thanks to the President for his Address, said he had given them a most interesting collection of facts and had drawn deductions from them which they would all wish to consider seriously. He looked forward to the second year of Sir Alexander Gibb's Presidency as one which would be as fruitful in the interests of the Institution as the preceding one had been.

Mr. J. Arthur Reavell, seconding the vote of thanks, said the Presidential Address pointed a great ideal to those engaged in chemical engineering and chemical science. It made the members proud to belong to the Institution and proud of their President for giving such an Address.

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