NORTH-WESTERN CENTRE : CHAIRMAN'S ADDRESS

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It is usual for chairmen in their addresses to review the progress of some branch of the art to which we all belong, and I should like to crave your indulgence to-night whilst I review the present state of the art of manufacturing electrical energy.

To obtain a perfectly detached and unbiased view of the situation, let us suppose for a moment that the fabled visitors from Mars had expressed a desire to inquire into the methods in use of supplying power to our industries. They would naturally be brought to the Institution of Electrical Engineers as, beyond doubt, upon us is fallen the rôle of purveyors of power to our fellows, and we should blush with honest pride and proceed to conduct our visitors to the nearest super-power station.

But the Martians would naturally want to begin at the beginning and to inquire in what, so to speak, our raw material consists, i.e. what are the available sources of energy which we can tap for the end in view. This inquiry would perhaps put us a bit out, but with a sigh at their ignorance we should sit down and—think!

After a little of this unwonted exercise, we might come to them again with a more or less ordered summary of the situation in some such form as the following, in which we should attempt to put the thing stripped of preconceived notions and in simple phraseology.

POWER OR ENERGY.*

1. *The sun.*—(a) Using the direct heat of the sun concentrated by mirrors or lenses to work heat engines.

(b) Water power, i.e. using the sun as a vast circulating pump to lift water from the sea and put it on the tops of mountains, we making it run back over waterwheels or turbines.

2. *The moon.*—Using its attraction on the waters of the sea—"Harnessing the tides."

3. *Winds.*

4. *Electro-chemical effects.*—Using the difference of electrical potential taken up by two dissimilar conductors when placed in a fluid which chemically combines with one of them when electricity is allowed to flow under this difference of potential.

5. *Molecular activity.*—Or the energy which is given off when some of our larger and more complex molecules disintegrate or explode.

6. *Combustion.*—That is, combining things with the oxygen of our atmosphere to produce heat.

Taking these possibilities in the order in which they are given above, we should explain that the radiation which the earth receives from the sun, although not itself heat, is absorbed and converted to heat on striking against a more or less opaque body. Sufficient of this

* Never mind the confusion in dimensions for the present.

energy can be concentrated on, say, a boiler, and so made to work a steam engine and produce power. On being strictly questioned on the practicability of this device, we should have to admit that it was but feeble and not suitable to be used in our centres of industry.

On the second application of the sun's activity, we can better congratulate ourselves as, Nature and civil engineering helping, we can extract and put to useful work some 90 per cent of the potential energy of the water, that is, in places which are blessed with a climate; in the British Isles, where there is only weather, water power is not so reliable.

On our visitors expressing a doubt as to the possibility of the moon being a source of energy, we are driven to admit that the problem is not so simple as it looks, and that the energy which is really tapped in harnessing the tides is due to the difference between the time of revolution of the earth and that of the moon round the earth, and that making use of the tides would tend towards keeping the moon always opposite one fixed point of the earth's surface.

Winds are at best uncertain, though they have been extensively used for grinding corn, pumping water, and driving small electric generators.

The electro-chemical effect is the most promising of those investigated so far: the conductor which suffers disintegration only does so in proportion to the electricity set in motion, there are no moving parts, and the efficiency is very high. It has to be confessed that the destroyed conductor has in the past been made of some very costly material, and that there is no ready market for the chemical combination produced; but, after all, these are minor points which can no doubt be remedied when we have time to give to them.

No. 5, Molecular Activity, we have to confess is at the moment a little new and puzzling, but it is very promising. In energy given out per pound of material, it exceeds anything else by several millions per cent. It is, certainly, a little difficult to stop and start, and seems a trifle like using up the bricks of which the universe is built, but we shall no doubt be able to report further to a future meeting.

Last on the list comes Combustion. It is known that certain things, notably hydrogen and carbon, will combine with the oxygen of our atmosphere, and in so doing give off heat. But heat is, unfortunately, very low down in the social scale of energy, that is to say, we cannot convert the whole of the energy of heat to other and more useful forms without expending work; we can put only part of the heat energy of combustion where we would wish it to be, and have to reject part as useless. That is to say, up to now we have laboured under this drawback, but there is nothing

inherently impossible in Maxwell's supposition of demons who would let swiftly-moving particles through a door which was closed to slower ones.

For the moment, therefore, we make heat by combustion and are still at a loss for a means of converting this to mechanical energy. We need some connecting link between the fire and the generator shaft. Let us consider the theoretical requirements of this connecting medium. It must take up energy from the fire, and in so doing alter its physical state or condition; in which altered state it is introduced into the engine and reverts to its former state, parting with the energy it received from the fire.

Imagine a giant kept at work in the cellar compressing helical springs which are brought up and put into a machine. The catch released, they expand and do work and are dropped back into the cellar to be re-compressed.

Now we find ourselves in the painful position of having to tell our visitors that we make a practice of rejecting the springs when they are only about one-fifth expanded, shooting them out into the atmosphere to complete uselessly the remaining four-fifths of their work there. A total energy of 1 019 British thermal units is, we explain, required to convert a pound of water at 212° F. into steam at 388° F. and a pressure of 200 lb. per square inch above atmosphere. If we expand this down to atmospheric pressure and 212° F. and allow it to escape, it will carry away at least 825 B.Th.U., and the best that the engine can possibly do is to use the difference, namely 194 B.Th.U. or, say, 19 per cent, for the production of mechanical energy. We might at some trouble and expense provide a place of much lower pressure than the atmosphere for the engine to exhaust into, say at 1 lb. per square inch pressure and 102° F. The one pound of water stuff would then take 1 129 B.Th.U. from the fire and depart from the engine with at least 788, leaving with the engine a maximum of 341 or 30 per cent. As a matter of fact the actual efficiency of the engine is, of course, much less than these figures. These large amounts of energy received from the fire and rejected by the engine are usually not only wasted but become a source of annoyance to our neighbours. We are accustomed to refer with pride to this as "the age of steam," but the above figures do not seem to justify much pride. Steam, like Jacob, has usurped the place of the first-born not by historic right, nor by any particular aptitude for the rôle, but mainly through the influence of its godfathers Watt and Stephenson. Several other fluids have, from time to time, been proposed, such as carbon bi-sulphide or ammonia, but up to now engineers have turned up their noses at all such and, truth to tell, their noses would be the chief sufferers!

There are, however, some other promising avenues of attack on the problem. One is to make the condenser itself a source of heat for a second thermal-cycle engine, and this idea has not received the attention it deserves from practical engineers, though it has been carried some little way on the theoretical and experimental side and has shown some promise.

Another line to follow would be not to condense the exhaust at all but to pump it straight back into

the boiler or heater, there to receive another supply of energy; but this is, apparently, contrary to the laws of thermo-dynamics as we at present understand them. For, if we come to think of it, the steam is condensed to water and the 1 000 B.Th.U. per pound wasted and sent to make things hideous on the cooling towers, not from sheer vice but mainly because, as water, it occupies less bulk than as steam and is, therefore, more easily pushed back into the boiler to be re-vivified. If we could only find some way of putting the exhaust steam back into the boiler as it is released from the engine, instead of making it return to water to be again re-evaporated by our precious fuel just the other side of the boiler plates, the possible efficiency of a steam engine might be almost indefinitely increased.

Thermo-dynamics as expounded by Carnot expresses the efficiency of this conversion of heat to mechanical energy in terms of temperature, and lays down that the maximum possible efficiency is dependent on the temperature range employed in the engine, i.e. is equal to the drop in the temperature of the working fluid whilst passing through the engine, divided by the absolute temperature on entering. The temperature on leaving is dependent on what methods we have available for cooling, for which water, either from a river or cooling tower, generally has to be used, producing a lower temperature of about 100° F.

On the other hand the combustion of most of our fuels with the oxygen of the air will produce temperatures in the region of 2 000° F., thus giving us a possible efficiency of

$$\frac{2\,000 - 100}{460 + 2\,000} \text{ or } 77 \text{ per cent.}$$

Our present practice, however, is to employ our 2 000° F. in raising steam and superheating it to, say, 600° F., giving a possible efficiency of only

$$\frac{600 - 100}{460 + 600} \text{ or } 47 \text{ per cent.}$$

This shows up our wrong-headed way of stating boiler efficiency by expressing it as heat delivered over heat received, ignoring the temperature and, therefore, the *availability* of the heat. One might almost as well calculate the efficiency of a water turbine as water emitted over water supplied.

The gas turbine offers a possibility of using these high initial temperatures, but it would probably exhaust at a temperature comparable with that of an ordinary boiler fire. Further use of these hot exhaust gases could then be made for raising steam.

In a recent Government report it was estimated that on the average 5 lb. of coal are burnt for each horsepower-hour produced in industrial power plants. Taking this figure for what it is worth, I have endeavoured to draw up a corresponding balance sheet, showing receipts and expenditure, though it must be confessed this somewhat resembles Angelina's first attempt at domestic account-keeping—on the left-hand side it ran: "Received from Edwin, £5," while on the right appeared "Spent it all."

<i>Received</i>		B.Th.U.	Per cent
5 lb. of coal at, say, 13 000 B.Th.U. per lb.	65 000	100	
<i>Paid out</i>			
Proportion used for banking boilers at nights and week-ends	6 000	9.3	
Lost in ashes	1 000	1.5	
Sent up the stack as hot gases—			
100 lb. at 500° F. excess temperature	12 000	18.5	
as steam in the flue gases	2 000	3.0	
as carbon imperfectly burnt to CO	1 000	1.5	
Radiation from boiler, engine and steam pipes	4 000	6	
Mechanical friction of engine	250	0.4	
Sent to cooling towers in circulating water (7 lb. of steam per lb. of coal, 1 000 B.Th.U. per lb. of steam)	35 000	54	
Used in auxiliaries	1 200	1.8	
As one brake horse-power-hour	2 550	4	
	65 000	100.0	

Four per cent !

Let us take these sources of waste seriatim and see what can be done to lessen or prevent them. The banking loss is obviously that due to bad load factor, and decreases as the latter increases ; the most fruitful way of bringing this about is to make use of the diversity factor of different classes of load and to supply as many of them as possible from the same power plant.

The loss due to hot flue gases up the stack can be reduced by reducing either their quantity or temperature. In the example it has been assumed that 20 lb. of flue gases are made per pound of coal burnt, which corresponds to about 11 per cent CO₂ ; it is difficult consistently to obtain better results than this whilst retaining the barbarous practice of burning solid fuel on the bars ; with liquid or gaseous fuel the quantity of flue gases can easily be reduced to two-thirds of this amount.

The temperature could and should be reduced by, first, steam superheaters and then feed-water heaters in the flue. This process is, however, limited in practice by the next item on the loss account, namely, the steam in the flue gases. This steam arises from the original moisture in the coal, from the water of combustion of the hydrogen content, and also from steam jets, which are sometimes used for carrying in the air for combustion.

The more steam is present, the more the process of extraction of heat from the flue gases is limited on account of the corrosive action of the water formed by condensation on the tubes of the feed-water heater. Surely it is time that manufacturers faced the problem of making a cheap form of economizer with, say, cast-iron tubes, which could be put on the tail end of the feed pump and could extract a good proportion of the 21.5 per cent carried away by the flue gases and steam together.

The radiation losses can in general be much reduced by more attention to the lagging and brickwork than often falls to their lot.

But the efforts of the reformer may well quail before the stupendous loss carried away by the condensing water and made hideous in the cooling towers.

Before leaving this attractive picture it will be well to put on record a balance sheet to compare with the 5 lb. per horse-power-hour, but embodying such of the refinements hinted at in the preceding paragraphs as have been at present achieved in the best steam practice.

Working at a good load factor with any large turbine plant, one brake horse-power-hour may be produced from one pound of coal, thus :—

<i>Received : 1 lb. coal @ 13 000 B.Th.U. = 100 %</i>			
<i>Expended :</i>			
	B.Th.U.	Per cent	
In ashes and incomplete combustion	130	1	
In hot gases up stack (14 % CO ₂) 16 lb. at 400° F. excess	= 1 550		
Less taken up by feed-water heater	800		
	750	5.8	
As steam in flue gases	300	2.3	
As CO	300	2.3	
Radiation	400	3.1	
Friction in turbine bearings	120	1	
In circulating water	7 800	60	
In auxiliaries	650	5	
In 1 b.h.p.-hour	2 550	19.5	
	13 000	100.0	

Very high temperatures and pressures may be used, and great increases of both these may be looked for in the future in the attempt to increase the ratio of available total heat in the working fluid.

Let us now turn to the internal combustion engine and gas producer and see how this combination will stand similar overhauling.

Average practice in moderately small non-recovery plants yields about one horse-power-hour for each pound of coal, and the balance sheet for such a power plant would look something like this :—

<i>Received : 1 lb. of coal @ 13 000 B.Th.U. = 100 %</i>			
<i>Expended :</i>			
	B.Th.U.	Per cent	
Banking losses	250	2.0	
Lost in ashes	800	6.0	
„ radiation from producer and engine	700	5.5	
„ engine friction	450	3.5	
„ „ cylinder cooling water	3 000	23.0	
Used in auxiliaries, blowers, etc.	250	2.0	
Carried away in engine exhaust	5 000	38.5	
Given out as 1 b.h.p.-hour	2 550	19.5	
	13 000	100.0	

The largest of these losses is that carried away in the exhaust gases. A good deal of this can, however, be used for raising steam in a special form of fire-tube boiler, but here again we are limited in the amount of heat we can extract from these gases by the undesirability of condensing the steam they contain; this is another case for the cheap feed-water heater mentioned before. However, as it is, nearly two-thirds of the heat in the exhaust can be used for raising steam, which may amount to 2 lb. of steam per pound of coal into the producers, of which more anon.

The next serious loss is that in the water used for cooling the gas-engine cylinders. This is more difficult to negotiate, as low-temperature heat is rather a drug on the market. Probably, unless there is a demand for hot water for some other purpose, the best plan is to combine gas and steam plant. This has been carried out in some combined engines in America, using both the gas-engine cylinders and the exhaust to raise steam, which is used in another cylinder driving on to a common crank-shaft.

Another proposal, and one that goes much more to the root of the matter, is known as the "Still" engine which employs a common cylinder, one side of the piston being acted on by the gas and the other by the steam generated by the heat in the exhaust. Each side of the engine has to give away just what the other requires; the gas end of the cylinder and the piston receives its necessary cooling by the steam, and the steam end is warmed by the burning gases, and so condensation on the cylinder walls is obviated. I believe and expect that this "Still" engine will "get a move on" presently.

I cannot leave this part of the question without mentioning recovery of by-products, but I feel that this is too large a matter to be included in this address, and, moreover, I should be poaching on the special preserves of other well-known Manchester engineers. The battle at present largely turns on whether the by-product recovery producer can or cannot be made self-supporting in the matter of the steam it uses. We have shown that the auxiliary boiler on the exhaust of the gas engine can provide the necessary steam for this purpose, but the producer reformers aver that the reformed producers will have none of this and will make their own steam and more. If this proves to be the case, it becomes frequently a question between the relative values of coal and by-products whether it does not pay to gasify the coal used for steam power plants; this will probably be done, however, only by the people whose main business is the supply of power, as the tinker, tailor, and candle-stick maker will not often want to combine manufacturing chemistry and salesmanship of fertilizers with his other activities.

It only waits, however, for the perfecting of the gas turbine to make the gasifying of coal and the recovery of by-products a foregone conclusion.

And then, of course, at the back of all this is the immense possibility of gasifying what would otherwise be waste fuel. Mr. Drummond Paton will no doubt tell us, with his accustomed eloquence, how there is being left in the pits enough potential energy not only

to supply all the industrial power required in Great Britain, but also endless supplies of fertilizers, disinfectants, and fuel oil, as well as smokeless fuel for our domestic hearths.

There is another possible way of utilizing the heat of combustion and converting it into electrical energy, namely, by means of the thermo-pile. If one junction of two dissimilar metals is heated and the other junction cooled, the two free ends take up a difference of potential. If electricity is allowed to flow under this potential difference the hot junction is thereby cooled and the cool junction heated. Heat is also conducted along both metals from the hot to the cool ends and is made all along both metals by the passage of the electric current. If the heat appearing from these three causes at the cool ends is wasted, the thermo-pile as a means of converting heat to electricity is necessarily inefficient; but it need not be wasted. It was pointed out above that there is an unnecessary loss of temperature between the fire and the water in a boiler, say 2000°F. to 400°F. This temperature difference could be used in a battery of thermo-piles having their hot junctions in the fire and their cool junctions in the water. The heat which would otherwise be wasted is then used in raising steam, and the heat that disappears in the Peltier effect is converted into electrical energy at 100 per cent efficiency. For every 1 per cent of the total heat generated which is thus converted, the yield per pound of coal burnt is increased 4 per cent in the best, and 25 per cent in the average case, the heat balance sheets for which are given above.

To every thoughtful mind who has devoted much attention to this question of power supply, there must have been forced the conviction that, when all our national resources are used as they ought to be used, ample power would result as a by-product, when with a stroke of the pen all fuel charges would be struck out of the bill for power. It would then remain for engineers to reduce the capital charges, which can be done slowly by reducing the cost of plant, but much more quickly by increasing the load factor and diminishing the transmission losses of our big power stations. Manchester has given a lead in this direction by the cultivation of large power consumers situated near to the station and willing to accommodate their demands to the exigencies of the other loads.

There is a possibility that the use of steam might be justified if the latent heat in it could be extracted and used for some useful purpose such as process work in the factory or a commercial supply of hot water for domestic washing and heating. The latter most attractive possibility is well known and some amount of work has been put into it,* but all the literature on the subject which I have been able to find has been too partial and has stopped short of actually proving or disproving the commercial possibility of the scheme. It may be perfectly true—

- (1) That what the industrial household is most in need of is a supply of hot water for washing the person, the clothes, and the culinary apparatus; and
- (2) That the power station without much interfering

* Mr. Pearce has had examples of this at work in Manchester for years. See also W. M. Selvey on "A System of Combined Electric Power and Commercial Heating Generating Stations" (Sheffield, 1918).

with its function as a power station could supply hot water. But it does not in the least follow—

(3) That the ratio of the demand for power to the demand for hot water is of the same order of magnitude as the ratio of their production in a joint station ; or

(4) That even if 1, 2, and 3, are all true the supply could be given at a price which the industrial householder could and would pay.

I propose, therefore, taking for granted items (1) and (2) to prove the truth of (3) and (4). For this purpose I have thought it best to take an actual example, giving my assumptions and figures so that any alteration in the conditions can easily be allowed for.

Take an industrial community of, say, 10 000 inhabitants grouped into 1 670 households of 6 members each, 3 of whom are working. Their houses, arranged on garden-city lines, 8 or 9 to the acre, and allowing for wide roads and ample open spaces, would occupy about three-quarters of a square mile. The demands for electrical energy per household would be about 6 400 units per annum for those employed in the factories (1 h.p. per individual), 500 units for lighting and cooking in their homes, and 100 units for carrying the household about in trams and for public lighting ; total, 7 000 units per annum per household. As there are 1 670 households the town would require a power station turning out about 12 million units per annum, which at 25 per cent load factor would have a maximum load of a little over 5 000 kW.

Suppose the station to work with a vacuum of about 20 inches, it would take about 20 lb. of steam per unit. These 20 lb. of steam could, on condensing, yield 20 gallons of hot water at about 160° F., so that we have an average of 400 gallons of hot water per household per day. Allowing 50 gallons per day for baths and washing, 350 gallons are left for warming

the house. If we allow the water to cool from 160° to 100° F., about 200 000 B.Th.U. are liberated per 24 hours, which is sufficient to keep a 5-room house comfortably warm. (For those who are more familiar with electrical units this corresponds in heating effect to about 2½ kW for 24 hours.)

In a town of this size there are about 15 miles of roads. To carry the hot water from the central station four 5-inch mains will suffice ; from these would radiate 2-inch mains ; and from these a ¾-inch service would supply each house.

Flow and return pipes would be provided, the flow pipes being lightly lagged.

The loss from these pipes would amount to less than 15 per cent of the heat delivered to the houses if the lagging of the flow pipes allowed half of one B.Th.U. to escape per square foot per hour per degree Fahrenheit, which would not be considered a very good steam-pipe covering.

The total cost of the pipes, including lagging, excavating, laying and filling in would be about £45 000. The extra plant required at the central station might add another £5 000. 6 per cent interest and 2½ per cent depreciation (21 years' life) = £4 250 per annum = 1s. per week per house, which surely would gladly be paid for this service.

Due to working at a lower vacuum the coal burnt in the central station would be increased from, say, 14 000 to 15 000 tons per annum. On the other hand, the service of hot water supply to the 1 670 houses would save each householder at least 6 tons of coal a year, so that the community would, by adopting the hot water scheme, burn 1 000 tons more coal in its central station and 10 000 tons less in its domestic grates, a net saving of 9 000 tons per annum to the community, with a corresponding reduction in smoke and all its attendant evils.