

## THOMAS HAWKSLEY LECTURE.\*

THE WORLD'S SUPPLIES OF FUEL  
AND MOTIVE POWER.

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DR. W. CAWTHORNE UNWIN, F.R.S., *President,* IN THE CHAIR.*Friday, 29th October 1915.*

In the first Thomas Hawksley Lecture, the late Mr. Ellington dealt very ably with Water as a Mechanical Agent, a subject to which he had devoted a highly successful life's work.

In the second Lecture, the late Mr. Bryan also dealt with an important hydraulic branch—Pumping and Waterworks Machinery, a field in which he had established an unrivalled supremacy. It is not open to me to deal authoritatively, as my distinguished predecessors have done, with hydraulic engineering. My main study for over thirty years has been the internal-combustion engine in all its various forms, and my experience in design and construction has been mainly acquired in that field. I cannot, therefore, aspire to follow the early Thomas Hawksley Lecturers by confining myself exclusively to hydraulic engineering.

*Thomas Hawksley's Definition of Hydraulic Engineering.*—Thomas Hawksley, however, was a hydraulic engineer in the very widest sense, and he defined hydraulic engineering very neatly in his Presidential Address to the Institution of Civil Engineers in 1872.

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\* First Thomas Hawksley Lecture, by E. B. Ellington, *Proceedings, I.Mech.E.*, 1913, page 1215. Second Lecture, by W. B. Bryan, 1914, page 811.  
[THE I.MECH.E.]

He there stated: "This branch of engineering embraces, and for the most part restricts itself to, the practical application of those of the physical sciences which relate to the properties, conduct, and treatment of fluids, whether inelastic or gaseous." Hawksley was not only a water engineer, but a very distinguished gas engineer; and in hydraulic engineering he included work dealing with gases as well as liquids. Indeed, his idea of hydraulic engineering was much wider than that adopted by professional men of to-day. Following the broad definition given, he said: "It therefore comprehends within its scope the provision and distribution of water and gas for the supply of towns; the collection, conveyance and utilization of sewage; the employment of atmospheric air as a means of impulsion in tubes and for the ventilation of mines; the improvement of rivers and estuaries; the reclamation and defence of land from the sea; the drainage of fens, and the collection and application of water for use in irrigation; and it even renders its assistance to the determination of the suitable form, and the amount of mechanical power, to be given to a ship to enable it to fulfil the conditions imposed by the requirements of commerce and the necessities of war."

Comprehensive, however, as this definition was, Thomas Hawksley's life showed that for him it was all too narrow. Thus, in 1845 we find him at The Institution of Civil Engineers discussing the conditions of working of the Atmospheric Railway, and using his mathematical ability with good effect, he came to the conclusion, shown by late experience to be correct, "that the atmospheric principle was inapplicable to long sections of tube, and therefore was generally inapplicable to the traffic of a long line."

In 1864 we find him appointed the first President of the British Association of Gas Managers, and keenly interesting himself in the Papers then read, including one on "The Application of Gas as a Motive Power," by Mr. Goddard, of Ipswich. This Paper described the explosive gas-engine of Lenoir, as built by the engineering firm of Barrett, Excell and Andrews, of Reading and the discussion showed that even then the gas managers were alive to the desirability of developing a day consumption.

*Hawksley's Advice to Plan in Advance for Peace and War.*—In 1872 he became President of The Institution of Civil Engineers, and in addition to the notable definition of Hydraulic Engineering just given, he urged in the same Address the necessity of preparing for war in times of peace, by designing and building suitable ships, weapons, and munitions. He favoured small high-speed war vessels for commerce protection, and advised members of the Institution to devote themselves to the subject. He would have been delighted with the fast cruisers and torpedo-boat destroyers of to-day, with their speed of 30 to 36 knots, only made possible by steam-turbines developed by Sir Charles Parsons.

Referring to the Franco-Prussian War, he said, "and we have learnt that, in the case of otherwise equally matched antagonists, the victory has been realized by the combatant that was the best provided with the weapons and munitions which, notwithstanding the existence of Government arsenals, had been devised in, and had been largely drawn from, the offices and workshops of the non-military engineer."

Fortunately for us, the great British fleet of to-day has proved itself to be overwhelmingly superior to that of the enemy, and it has been developed by the joint efforts of men like the late Sir William White, Sir Philip Watts, Mr. Tennyson D'Eyncourt, and Admiral Sir Henry Oram on the official side, with non-military engineers like the Hon. Sir Charles Parsons, Sir John Thornycroft, Mr. Yarrow, and many others. Our fleet has also given us time to prepare a large army and supply it with the best weapons and munitions.

In 1876 Hawksley became President of the Health Department of the National Association for the Promotion of Social Science, and in that year he delivered a remarkable Presidential Address at Liverpool, in which he discussed the growing population of England and Wales, and proved that at the then rate of increase, allowing for emigration, 24,000,000 in 1876 would become 42,000,000 in 1918, and at the end of the fifth generation, at the termination of the twenty-first century, 400,000,000, an obviously impossible population for so small a country. Even in 1876 he feels concern for our position, England and Wales having one

person to one and a quarter acres of its 30,000,000 acres of cultivable land, while the other kingdoms of Europe had about five acres of land to each person.

He pointed out that 40 per cent. of the most important articles of food of the people was imported from abroad, and in view of this he said: "Now I ask you, as earnest sociologists, whether a nation can in the proper sense of the word truly say of itself, 'I am great,' so long as it is unable, if need be, to maintain itself? I look, indeed, with alarm to the signs of the times, the general restlessness of European nations, and the possibility of our being entangled in a war . . . for, without in the least doubting the powers of England, and her ultimate ability to come with glory from the fray, I cannot avoid expressing the apprehension that our supplies of food from abroad may be for a time very seriously interfered with, if not wholly interrupted . . . let every patriotic sociologist beseech our Government to look well to its Navy, with the object of maintaining our old command of the sea, and for ensuring the protection of that mercantile marine without which there can be neither health nor happiness for the multiplying millions of this country."

Hawksley's fears for the immediate future of his country proved unfounded, prosperity continued to increase, although he thought "we have thus damaged, I think, irretrievably, our manufacture and commerce . . ." and our country was never more prosperous than in the middle of 1914, when the Great War burst upon us. Hawksley, nevertheless, saw clearly the essentials of success, an overwhelmingly strong navy, a powerful and well-equipped army, and a brave and willing people, willing and eager to fight for liberty, and ultimately to overflow to our ever-increasing over-sea dominions, in answer to the cry, "Space, more space."

Thomas Hawksley had interests not only in hydraulic engineering, however widely defined, but in the welfare of his country, and an intense desire to see it prosperous and happy in the future also. I am, accordingly, encouraged to deal with the vital question of fuel and motive power in the wide manner which would have been adopted by Hawksley.

*Industrial Civilization requires Coal, Oil, and Motive Power.\*—*

The present civilization of the world rests upon a basis of coal and oil fuel, and water, steam, and internal-combustion motive power. At the middle of the eighteenth century the United Kingdom had but the small population of ten and a half millions. It was only entering into the stage of transformation from a purely agricultural country to the first great industrial community of the world. Previous to that time motive power had only been available to a small extent, as provided by water and wind. True, the Newcomen steam-engine then existed, but its use was strictly limited. In the third quarter of that century the work of James Watt raised steam-power from a wasteful process to a relatively economical one; and in the first instance the early Watt engines were entirely used for pumping out mines. The development of the steam-engine by Boulton and Watt was thus continued, and necessitated by the needs of the hydraulic engineer.

The coal consumption of Newcomen's engine was about 20 lb. per i.h.p., while that of Boulton and Watt was from 5 to 7 lb., about one-fourth to one-third of the pioneer engine.

Engineers' later efforts greatly improved upon these figures; thus triple-expansion engines require 2 lb., large steam-turbines  $1\frac{1}{2}$  lb., and suction-gas engines 1 lb. per i.h.p.

The success of the Watt steam-engine enabled coal-mining to be firmly established and coal output increased; and this increase of output was accompanied by the rapid invention and application of numerous mechanisms and processes leading to the plentiful production of iron, steel, textile fabrics, chemical manufactures—soap, alkali—the whole mechanism, in fact, required for the existence and comfortable subsistence of the rapidly increasing population of

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\* Just before delivering this Lecture, my attention was called to an able work entitled "Natural Sources of Energy," by Professor A. H. Gibson, D.Sc., Member, of the University College, Dundee. This interesting work was published in 1913, and in it is discussed the problem of the fuel and motive power of the world in a careful and comprehensive manner. The results given here agree generally with Professor Gibson's conclusions, although arrived at independently from somewhat different data.

these islands, which in 1801 had risen to over fifteen and a half millions.

The steam-engine was rapidly applied to stationary purposes, driving mills and works of various kinds, then to marine engines, and last of all to land locomotives, and by the middle of the nineteenth century in its reciprocating form it had firmly established itself as the greatest source of motive power for man's use. The low cost of coal and the large amount of power obtained from steam for small capital and running expenditures at first made it unnecessary to think of economizing too closely. As time went on, however, the amount of power required rapidly increased. For example, at the beginning of the nineteenth century the steam-power developed in stationary engines in the whole kingdom did not amount to more than 4,000 h.p., and even in 1836 an engine developing 40 h.p. was considered a very important undertaking. In 1836 this power had risen to about 30,000 h.p.

The Committee of Managers of the Birmingham Philosophical Institution published a report on 3rd October 1836 which gave, among other things, a statement of the steam-power employed in Birmingham in 1835; it amounted in all to 2,700 h.p. divided among ten industries, and employed 4,000 men and 1,300 women.

*Total Power of Industrial Engines in Great Britain in 1907.*—In the first census of production for the year 1907, the total power of industrial engines in use in Great Britain and Ireland is given as 10,578,475 h.p., and the steam-engine power of road rollers and road locomotives owned by public authorities amounted to 167,192 h.p. Of the industrial engines, steam reciprocating engines were rated at 9,118,818 h.p.; steam turbines, 530,892; internal-combustion engines, gas, oil, etc., 680,177; and water power, 177,907 h.p. The persons employed in the factories using this large power numbered nearly  $10\frac{1}{2}$  millions; so that, roughly, the power available for the industries of Britain was nearly 1 h.p. per person employed. To support the 46 millions of people now living in the United Kingdom thus requires a continuous enormous expenditure of power, and a very large consumption of fuel.

The total coal known to be in existence in the world is given by Mr. D. B. Dowling as 7,397,553 million tons, and the total output of the whole coal of the world in 1913 was 1,363,878,110 tons. Assuming that rate of consumption to continue, obviously we have over 5,400 years' supply.

The Report of the Royal Commission on Coal Supplies, issued in 1905, as the result of an elaborate investigation, gives the contents of the proved coal-fields of the United Kingdom as 100,000 million tons, and estimates coal in still unproved fields as 40,000 million tons. If one can assume them to realize 25,000 million tons, then at the present yearly consumption of 250 million tons we have still 500 years' supply.

In the year 1903 the output of coal from Britain was, in round numbers, 230 million tons. Of this, about 168 million tons were consumed in the country and 62 million tons exported. Much of this exported coal, however, was used for coaling purposes for British steamers abroad. Under these circumstances it becomes highly important to the country at large, and very interesting to the engineer, to consider what can be done, first, to reduce the rate of use of our coal to a minimum, and second, to study how motive power is to be procured and industry carried on in a coal-less Britain.

In evidence given before the Royal Commission, Dr. G. T. Beilby, F.R.S., makes the interesting calculation that out of an annual consumption of from 143 to 168 million tons of coal, there is a possible saving of from 40 to 60 million tons. I have taken Dr. Beilby's figures for the higher consumptions mentioned, and calculated from his division the percentage used for each separate purpose in the Table on page 598.

Dr. Beilby's estimated saving is thus 60 out of 168 million tons annually, 35·7 per cent. of the portion used for home consumption, or 26·1 per cent. of the total, including the exported coal, and it increases the coal life of our country to 676 years. Dr. Beilby pointed out in a note published eight years later by the British Science Guild, that the large gas-engine had not developed so rapidly, and the steam-turbine had advanced more rapidly than expected, so that the savings he anticipated had not yet been

—	Consumption in Millions of Tons.	Percentage.	Possible Saving.	How Saved.
Railways . .	14	8.4	7	Electric Traction.
Steamers . .	8	4.7	—	—
Factories . .	45	26.8	30	{ Gas Generators and Engines.
Mines . . .	12	7.2	7	{ Gas-Engines and Recovery Ovens.
Blast-Furnaces .	18	10.7	3	{ Gas Generators and Coke.
Iron and Steel .	12	7.1	3	{ Gas Generators and Coke.
Other Metals .	2	1.2	—	—
Brickworks, Pot- teries, Glass and Chemical Works .	6	3.6	2	Gas Generators.
Gas Works . .	15	8.9	—	—
Domestic Purposes	36	21.4	8	{ Gas Cooking, Heating, Bri- quettes and Coke.
	168	100.0	60	

realized. Even without the superior thermal efficiency of the internal-combustion engine, large steam-turbines generating power at central stations are capable of reducing the 45 million tons of coal required for power in factories to nearly Dr. Beilby's figure.

Under pressure of necessity, however, it will prove possible to make other economies, which, however, involve greater changes. Thus, exhaust heat from steam- and gas-engines is utilized at present to a certain extent in heating buildings and carrying on various manufacturing processes, but no comprehensive attempt has been made to supply motive power, light and heat from the combustion of the same fuel. Large central stations with gas-generators and high efficiency gas-engines would give all the motive power required for factories on 15 million instead of 45 million tons of coal, as shown in the Table; but even then the waste heat from water-jacket, exhaust gases, and gas-producers, equals that produced by burning 10 million tons. This distributed through a city as steam at 30 lb. or so pressure above atmosphere could readily supply heat for the household to warm the rooms and perform cooking operations. The high efficiency of steam-heating and cooking



would enable the heat of 10 million tons to do the domestic work at present performed by 36 millions. The open fire would be missed, with its pleasing radiation, but under pressure of circumstances we should be forced to dispense with it. But even if we allow 12 million tons of the 36 to be still used for radiation, the total coal bill would be reduced to one-half, and the industrial life of the country increased to 1,000 years. From this it appears that our present fuel-needs might be met by the use of half our coal consumption. Further economy may be effected by the extended adoption of water-power.

In order to reason with any approach to accuracy, it is necessary to arrive at some probable estimate of the total power available in the world, and to extend the inquiry not only to a coal-less England, but to a coal-less and oil-less world. The total energy available to us is due to solar radiation, past and present, tidal energy, and the earth's internal heat. The great source of all our energy is, of course, solar radiation. Taking Sir J. J. Thomson's estimate of 7,000 h.p.\* per acre as the total radiation of the sun absorbed on the earth's surface with a clear sky, this is sufficient to produce 4,480 h.p. per square mile, assuming an absolute efficiency of conversion of one-tenth per cent. Such a result, however, can only be hoped for in desert districts, where the sun's rays are not obstructed by clouds or vapour. If this enormous energy were easily available, then engineering problems would chiefly deal with the generation of motive power in great deserts such as those existing in Africa, and the transmission of the power so generated to districts where man could live and pursue his manufactures.

*Sun Power.*—Though many engineers, including Ericsson, have experimented with sun engines,† so far no method of using the direct solar energy of radiation has been invented which is capable of

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\* Professor A. H. Gibson gives the value as 8,000 ft.-lb. per minute per square foot in areas between the Equator and 45° North and South Latitudes.

† Professor Gibson gives an account of recent solar motor experiments,

supplying any large amount of power. The world, however, may be considered as a huge solar engine, in which the waters of the seas are evaporated by the heat absorbed, and much of the vapour carried to high levels, at which it is deposited as water, and flows down to the sea. By this process we get a complete cycle of operations, including evaporation of water into steam, condensation of the steam into water, evaporation again, and so on. In falling from the high level to the low level of the sea, power can be obtained from this water. Hydraulic power, in fact, is a form of sun power, and will continue in existence long after all the coal and oil in the world has been exhausted. Coal and oil have also been produced by the action of the great solar engine, and they contain a portion of the energy of radiation of past ages, stored up in the growing wood and leaves of plants; accumulations which are now being rapidly drawn upon by mankind. Coal and oil are thus the result of past radiant energy, while wind and water-power are due to present radiant energy. In one case the store in the earth is being used up and cannot be replaced; in the other case, so long as the solar system lasts, power exists also. Mr. Ellington very clearly took this view in the first Hawksley Lecture, when he said: "On a review of the whole subject, it appears that water-power is likely to become increasingly important. It is perennial in its source. As a mechanical agent it has numerous ramifications, which are constantly extending, and its direct application to industry offers a large field for the exercise of the talents of the inventor and the engineer."

*Increasing Importance of Hydraulic Power.*—Although I have devoted myself to the rival power obtained by internal combustion, I thoroughly agree with what Mr. Ellington has said. Undoubtedly as time goes on, hydraulic power must become of increasing importance. Mr. Ellington estimated the average rainfall in the United Kingdom as 25 inches per annum, and he calculated that, assuming a fall of 500 feet, this gave 100 h.p. per square mile continuing throughout the year. But a small part of the area of the United Kingdom is at so high a level as 500 feet. The total

area of the United Kingdom is roughly 121,000 square miles. Taking suitable ground of 500 feet level at 5 per cent. of the total area, and assuming it possible to construct artificial lakes by means of dams, from this area nearly two million h.p. could be obtained, available for eight hours per day every day of the year. In some areas of England the rainfall is more than 60 inches per annum, and on these areas the altitude is about 1,000 feet.

Mr. Alexander Newlands, Chief Engineer of the Highland Railway, read a most interesting Paper before the British Association in 1912, on Scottish Water-Power, in which he adopts the view of Professor G. Forbes, F.R.S., that the available hydraulic power in Scotland exceeds one million h.p. Mr. Newlands has investigated many convenient power stations, and gives a list of forty-five localities, from which he considers a total of 205,000 h.p. could be obtained. He states that the Kinlochleven Works of the British Aluminium Co. on the west of Argyllshire cost £600,000, and develop 30,000 h.p., at a capital expenditure of £20 per h.p. The total cost of current used is one-sixteenth of a penny per unit, after allowing for interest on capital and depreciation.

The average investment cost of all American water-powers he gives as £40 per h.p. developed. Mr. Newlands comes to the conclusion that installations costing up to £20 per h.p. could deliver power at a cost with which no steam plant could hope to compete. In Norway and Sweden, where Pelton wheels are used, with high heads, installations exist which cost £10 per h.p., and in these countries power has been advertised for sale as low as thirty shillings per h.p. per annum. Mr. Newlands quotes the *Electrical Review's* comparison of the minimum costs of an electrical horse-power per annum from

	£	s.	d.
Water in Switzerland . . . . .	1	19	0
Steam in England . . . . .	4	11	8
Blast-Furnace Gas in Germany . . . . .	4	1	7
Producer-Gas in England . . . . .	5	0	0

From these figures it is evident that in Scotland, even at the present time, hydraulic power presents economic advantages when

compared with power obtained from the cheap coal of to-day by steam- and gas-engines. With increasing scarcity of coal, undoubtedly hydraulic power will in the future show greater advantages, and even in England and Ireland it might be possible to earn interest on capital expenditure greater than £40 per h.p. By great engineering works, it might be just possible to obtain perhaps three million h.p. from areas which could be given up for the purpose. This power obviously is insufficient for British needs.

To increase production, other sources may be drawn upon. In the conditions assumed, the only other source of energy at all comparable to water is the yearly fuel growth of trees and undergrowth. It is difficult to arrive at any probable value of wood growth in the United Kingdom. The whole area under forests is 3,081,754 acres, and I can find no published figures dealing with annual yield. The total area of German forests is given as 34,569,800 acres, and the yearly yield as 26,183,410 cubic yards of timber, and 23,348,640 cubic yards of fire-wood. Taking a cubic yard of fire-wood as weighing 0.6 ton gives 14 million tons as the annual growth of fire-wood in Germany. This equals 6,200,000 tons of coal in heating value. The forest area of the United Kingdom is about one-eleventh of that of Germany, so that on this scale we could only produce heat equal to 563,000 tons of coal. Obviously fire-wood growth with us cannot be expected to give more than about 350,000 h.p. No doubt larger areas will be devoted to forests in the future, and greater power obtained, but I fear even then the yield could not make up for the loss of coal. There only remains wind and tidal power for consideration. Wind power may be neglected. Tidal power, however, would add materially to the total, but at the cost of great, inconvenient, and expensive works.

Oil does not materially affect our problem. The total oil produced from wells and distilled from shale in the world is about 5 per cent. of the weight of coal raised, and according to Sir Boverton Redwood, even if the whole of the crude petroleum were employed as fuel, in steam raising, it would not replace, allowing for its high thermal value, much more than 5 per cent. of the world's output of coal; while if used in internal-combustion engines,

it would be equivalent as a source of power to about 15 per cent. of coal. Only a small proportion, however, of the crude petroleum can be regarded as available for use as a source of power, for by far the larger part is in demand as an illuminating agent, and as a lubricant for machinery.

Sir Boverton Redwood states also: "Some of the older oil-fields of the United States are becoming exhausted, and Dr. David T. Day, of the United States Geological Survey, considers that at the present rate of increase of the output of petroleum, the known oil-fields of that country will, on the basis of the minimum quantity of oil obtainable, be exhausted by the year 1935, whilst even if the present output were only maintained, the supply would, on the same basis, not last for more than 90 years." The oil supply of the world, accordingly, does not greatly help us to extend the duration of industrial civilization. The earth's heat—the only other source of power—is unavailable, and could not be drawn upon in our present state of knowledge. In the absence of coal, then, it appears that all the energy available for power in the United Kingdom would not exceed 4 million h.p., or 6·5 million h.p. less than is at present used in our factories alone.

But we also require fuel to produce power for railways and ships. In the Table (page 598) railways use 8·4 per cent. and factories 26·8 per cent. of our total coal consumption. Assume that locomotives require the same weights of coal as factories for each horse-power developed, then the locomotive power of our country is about 3·3 million h.p. Our mercantile marine requires another 5 million h.p., and the Royal Navy in time of war also requires 5 million.

Altogether, to carry on the industrial civilization of these islands in time of peace, on the scale of to-day, absorbs a power of about 19 million h.p., and without coal we could only obtain 4 million. Obviously, a change of condition such as this necessarily involves great modifications in our social life and a large reduction in the population which we can support in comfort.

Taking 1,100 million tons as the world's output of coal for 1907, on the assumption that the proportion used for factories and railways is the same as in our country, then the world's factories

require 295 million tons, and railways 93 million tons. Assuming the same consumption per h.p., the world's factories require 60 million h.p., and the world's railways 19 million. I have estimated the power of the world's shipping as—mercantile marine, 10 million h.p.; warships, 13 million h.p. The total power used in the world generated by the combustion of coal is thus of the order of 100 million h.p.\* :—

	Million h.p.
World's Factories . . . . .	60
World's Railways . . . . .	19
World's Ships . . . . .	23
	<hr/>
	102

This estimate does not include existing hydraulic power. Assume it to be 13 million h.p. Then the total power required in a coal-less world would be 115 million h.p. There is little doubt that the hydraulic supply of the world † is capable of producing more than this, so that even when our world's coal is exhausted all the power required will be forthcoming. In this case, however, storage batteries must be greatly improved to enable ships to be propelled electrically. But as about 40 per cent. of the world's coal is consumed in producing motive power, 60 per cent. of the heat value of the total coal must be replaced from some other source. The only further source of heat would then be growing wood; a large quantity would be grown in tropical countries and transported as charcoal, but fuel so obtained would be expensive, and heat and chemical action in domestic and metallurgic use would be economized to the utmost.

It is very evident, therefore, from this short discussion, that the line of the engineer's duty is to be found in economizing all the energy remaining in these islands in the form of coal, and thus postponing the period of industrial change in England. Engineers have long felt the pressure of this duty, and have strenuously

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\* Professor Gibson gives the same figure, 100 million h.p., but arrives at it in a different way.

† Professor Gibson's estimates of the total available water-power of the world is 200 million h.p.; United States of America water-power from 35 to 55 million h.p., of which 5.3 million were utilized in 1908.

endeavoured to find means of obtaining power at less and less fuel cost; so that even while Watt and Boulton were still struggling to make the condensing steam-engine a commercial success, others were experimenting with various schemes which did not require the use of steam. In these days it was felt that part of the loss of energy experienced in obtaining motive power by steam was due to the latent heat of the steam in passing from the liquid to the gaseous state. This was true in a limited sense, but the science of thermodynamics had no existence until about 1840, and accordingly engineers had nothing to guide them in determining the laws by which heat produces mechanical work. The idea, however, that latent heat absorbed heat energy undoubtedly had its effect in provoking attempts to use atmospheric air as a source of motive power.

*Stirling and Ericsson's Hot-Air Engines.*—The earliest hot-air engine which was reasonably successful was the invention of a clergyman, Dr. Stirling. In this engine air was heated at constant volume with increase in pressure, and the power was obtained by subsequent expansion. In another engine of what is now known as the constant-pressure type, Ericsson, the well-known American engineer, compressed air, heated it at constant pressure, and expanded it in a larger cylinder than the compression cylinder. In both the Stirling and the Ericsson engines a contrivance known as the regenerator was used, which was the subject of much controversy and misunderstanding. The early Stirling engine was produced in 1815, but thirty years after a Paper was read by Mr. James Stirling at the Institution of Civil Engineers upon "Stirling's Improved Air Engine." The main improvement consisted in working with air at a greater original density than that of the atmosphere, and the engine had so far succeeded that two had been used at the Dundee Foundry Co.'s works, one giving 21 and the other 45 h.p. Mr. Stirling claimed that the 21 h.p. engine required only  $2\frac{1}{2}$  lb. of coal per h.p. hour. This is an extraordinarily good result, and could only have been obtained by the action of the regenerator. It is clear, however, from the Paper and from the discussion, that many engineers then imagined that,

with a perfect regenerator, no heat would disappear in performing work. The speakers in this discussion included Robert Stephenson, and, curiously enough, he plainly misunderstood the whole process of action of Stirling's engine. His remark on the regenerator was illuminating: "He understood the process to consist of heating the air in a vessel, whence it ascended to the cylinder between numerous thin laminae, by which the caloric was absorbed, to be again given out to the descending air. Now, it appeared to him that, though the ascending process was natural and easy, the reverse action would require a certain expenditure of power, in the depression of the plunger." A Mr. Cottom said: "It was evident that if it was practicable to arrive at the theoretical condition of the absorption of all the caloric by the thin laminae during the upward passage of the air and the giving it out again during the downward passage, there would not be any loss of heat."

Other Papers were read on the same subject at the Institution of Civil Engineers in 1853, and the discussion interests us particularly, because Mr. Thomas Hawksley joined in it. Mr. Hawksley considered that the machine involved a mechanical fallacy, and that the regenerator produced no mechanical effect whatever. Here Hawksley was clearly in error, but he erred in good company, because at the same time the famous Dr. Faraday said: "Twenty years ago he had directed his attention to this question, and from theoretical views he had been induced to hope for the successful employment of heated air as a motive power; but even then he saw enough to discourage his sanguine expectation, and he had, with some diffidence, ventured to express his conviction of the almost unconquerable practical difficulties surrounding the case, and of the fallacy of the presumed advantages of the regenerator." Brunel also considered the use of the regenerator to be an entire fallacy. Sir George Cayley, about the same time, described another hot-air engine, which may be considered as the first of the internal-combustion type acting with solid fuel under constant pressure. In his engine he pumped air into a furnace, and led the heated products of combustion through valves into the interior of a cylinder. He also was unsuccessful.



The Stirling and Ericsson engine worked, but both engines were extremely bulky and heavy. Ericsson built a hot-air engine for operating the hot-air ship "Ericsson" in America, and the cylinders were no less than 14 feet in diameter. From these he got only about 300 h.p. Both types of engine failed, because of the rapid burning out of the cylinder bottoms with the direct action of the fire, as it was found impossible to heat the air rapidly enough to the required temperature without maintaining the temperature of the metal surfaces much higher than the maximum temperature to be attained by the air. Some inventors, as has been stated, proposed to heat the air by combustion, and Cayley's was the first attempt to do this with solid fuel. Cayley, however, introduced difficulties as grave as external heating, hot gases had to pass through pipes and valves to the motor cylinder, and this made it impossible to maintain a high temperature without damage to the machine.

Inventors dealing with internal combustion introduced into a cool cylinder a mixture of gas or inflammable vapour and air at atmospheric pressure, ignited this mixture at constant volume, and drove a piston by the increase in pressure. Professor Farish of Cambridge, at his philosophical lectures at the University, exhibited a model engine so operated as early as 1817. Other inventors attempted to operate their engines by atmospheric pressure, producing the necessary vacuum or reduction of pressure by the combustion of an inflammable gas in air.

*The Cecil Engine.*—The Rev. W. Cecil, M.A., of Cambridge, read a Paper in the year 1820 before the Cambridge Philosophical Society, on the application of hydrogen gas to produce a moving power in machinery, with a description of an engine which is moved by the pressure of the atmosphere upon a vacuum caused by explosions of hydrogen gas and atmospheric air. He described an engine which he had constructed to operate on the explosion vacuum method. He thus explains the principle of his engine: "The general principle of this engine is founded upon the property which hydrogen gas mixed with atmospheric air possesses of exploding upon ignition so as to produce a large imperfect vacuum.

If two and a half measures by bulk of atmospheric air be mixed with one measure of hydrogen and a flame be applied, the mixed gas will expand into a space rather greater than three times its original bulk. The products of explosion are, a globule of water formed by the union of the hydrogen and the oxygen and the atmospheric air and a quantity of azote, which, in its natural state (or density, 1) constituted 0.556 of the bulk of the mixed gas. The same quantity of azote is now expanded into a space somewhat greater than three times the original bulk of the mixed gas—that is, into about six times the space which it occupied before; its density is therefore about one-sixth, that of the atmosphere being unity. If the external air be prevented by a proper apparatus from returning into this imperfect vacuum, the pressure of the atmosphere may be employed as a moving force nearly in the same manner as in the common steam-engine; the difference consists chiefly in the manner of forming the vacuum.”

Fig. 1, Plate 7, shows in perspective the drawing accompanying Mr. Cecil's Paper in 1820. The operation of the engine consisted in drawing into the cylinder a proportion of atmospheric air and hydrogen, igniting this mixture at the end of the stroke, allowing the hot gases to be discharged from the cylinder by the pressure of combustion, then cooling the gases in the cylinder and producing a vacuum to operate the piston.

The Figure also shows different views of the engine, and a diagram showing the power obtained by the vacuum. Mr. Cecil stated that the engine rotated at 60 revolutions per minute; in practice it was found to work at considerable power and perfect regularity. In the model constructed, the engine used 17.6 cubic feet of hydrogen gas per hour. Evidently, however, the engine was rather noisy, because the inventor stated: “To remedy the noise which was occasioned by the explosion, the lower end of the cylinder A, B, C, D, may be buried in a well, or it may be enclosed in a large air-tight vessel.” This engine is very crude, but extremely ingenious. It is also interesting to note that Cecil made experiments by which he determined approximately the maximum pressure produced by means of a mixture of hydrogen and

atmospheric air. He gives this maximum pressure as 180 lb. per square inch absolute.

*The Brown Engine.*—Mr. Cecil did not carry his invention further, but another inventor, Mr. Samuel Brown, took out patents in 1823 and 1826 in which he operated by filling a vessel with flame to expel its contained air and throwing in a jet of water to condense the flame. This produced a partial vacuum, and the atmospheric pressure was made available for utilizing the power by means of an ordinary piston. Samuel Brown was very persevering, and according to the *Mechanics' Magazine* published in London in August 1824, he had then made a model which raised 300 gallons of water 15 feet high on one cubic foot of gas. In 1832 it appears that four of his engines were in use for pumping:—(1) One at Croydon at the canal, raising water from a lower to a higher level; (2) one at Soham in Cambridgeshire, for draining part of the middle fen district; (3) one at Eagle Lodge, Old Brompton; and (4) one at Eagle Lodge, Old Brompton, of the beam type. It was stated that the cylinder of the Croydon engine was 3 feet 6 inches in diameter by 22 feet high. Engine No. 3 was inspected by the editor of the *Mechanics' Magazine*. Its cylinder was 3 feet  $8\frac{3}{4}$  inches diameter by 22 feet high; and it discharged 750 gallons per stroke, four strokes per minute, 12 feet high. Brown claimed in a circular published in 1832 that the coke and tar obtained in making coal gas for the Croydon engine were sold for such sums as produced a profit in addition to giving motive power for nothing. He stated that the whole annual expense of the Croydon gas vacuum engine, including coal, wages, repairs, depreciation, rent, amounted to £666 14s. 0d., while the receipts from the sale of coke and tar were £769 12s. 0d., so that the annual profit was £102 18s. 0d., without counting the value of the pumping work done, which previously cost the Canal Co. £275 per annum to effect by steam-engine. This state of affairs, however, could not have been permanent, as after some years of work the engines were displaced. Brown also applied his vacuum gas-engine to driving a carriage in 1825 and to propelling a boat on the

Thames in 1827. These early attempts were obviously inspired by the low-pressure steam-engine with its vacuum obtained by steam, but no real success was attained, the gas consumption—that is, the consumption of heat for producing a given power—being very high.

*Lenoir Gas-Engine.*—Meanwhile the work of Joule, determining the mechanical equivalent of heat, taken together with that of Macquorn Rankine, Thomson and Clausius, based partly on the earlier investigations of Carnot, had developed a definite theory of the relationship between heat and mechanical work. Accordingly, we find the advocates of internal combustion increasingly active, and in 1860 Messrs. Marinoni introduced in Paris the famous Lenoir gas-engine. In it the principle is exceedingly simple and evident. The piston moved forward a part of its stroke by the energy stored in the fly-wheel, and took into the cylinder a charge of gas and air at the ordinary atmospheric pressure. The valves cut off communication, and the explosion was occasioned by electric spark. The piston was thus propelled to the end of the stroke. Exhausting was performed exactly as in the steam-engine. This engine was practicable but very uneconomical. It was largely used, however, for pumping. One such engine was inspected by the Author at Petworth House, Petworth, in 1882, and it had then been working, pumping water, for about twenty years. This engine was replaced some years ago by an engine of the National Gas Engine Co.'s manufacture, which was used both for pumping and electric lighting. Fig. 2, Plate 8, is from a photograph showing a Lenoir engine of  $\frac{1}{2}$  h.p. built by the Reading Iron Works, Ltd., about 1866.

*The Engines of Otto and Clerk.*—It was very soon found that, to obtain economy in an internal-combustion engine, compression was necessary, and the history of the modern internal-combustion engine dates from Beau de Rochas' famous pamphlet in 1860, in which the alternate use of a cylinder as pump and motor and the use of considerable compression was fully described. To the late Dr. Otto, however, belongs the honour of bringing this type of engine into practical use. This he did in 1876. Otto's was the first compression gas-engine to succeed in practice. I produced my

first compression engine in 1878, and exhibited it at work at the Kilburn Royal Agricultural Show in 1879. In this engine compression was also used, but an impulse was obtained at every forward stroke of the motor piston. The engine best known, however, as of the Clerk type was not produced till 1881, in which year it was exhibited at an Electrical Exhibition in London and later in Paris. This engine was the first in which the piston overran ports by which the exhaust was discharged, and where the charge was admitted to the cylinder from a separate pump in such a way as to discharge the exhaust products before it. Practically all the internal-combustion engines of the world now operate either on the Otto four-stroke or on the Clerk two-stroke system. In these engines the explosion takes place at constant volume, so that the pressure rises.

*Constant-Pressure Engine.*—As far back as 1873 a constant-pressure engine was introduced by an American inventor, Brayton. This engine resembled a hot-air engine in which air was compressed into a reservoir at a constant pressure, then expanded into a working cylinder at the same pressure, and the volume increased by the formation of flame. An American engine of this type is shown in Fig. 3, Plate 8. Brayton's engine used light petroleum, and it had a certain success. It had considerable application for stationary work, and it was intended to apply also to the propulsion of boats and vehicles. The modern constant-pressure engine, however, does not work in the Brayton manner. The Diesel type depends upon the compression of air to about one-twelfth of its original bulk in a cylinder, the raising of the temperature of the air to a sufficient extent to ignite heavy oil when injected into it in fine spray. The injection occurs from the beginning of the stroke during a very small advance of the piston on its forward stroke. A diagram is thus produced which is substantially a constant-pressure diagram. This engine is extensively used for many purposes, including pumping. It sometimes operates on the Otto and sometimes on the Clerk cycle. The smaller engines use the Otto method and the larger the Clerk method.

*Comparison of Steam and Internal-Combustion Engines.*—During many years, compression was continuously increased in constant-volume types of engine, and with increased compression came increased economy of fuel. At the same time coal-gas was supplemented by other gaseous fuels; first, Dowson pressure-gas made from anthracite, then suction-gas from anthracite, coke and other fuels, and later waste gases from the blast-furnace. Many substances also were utilized to produce gas for engines, many of them waste products, sawdust, dried peat and wood chips of different kinds. Bituminous fuel was also used, at first only in conjunction with ammonia-recovery processes; later, on a smaller scale, for gas only.

Many obstacles were found to increasing engine dimensions indefinitely. In the early days of the internal-combustion engine, enthusiastic pioneers like myself considered that ultimately the internal-combustion engine would entirely displace steam. In a Paper read at the Institution of Civil Engineers in 1882, I stated: "The gas-engine is as yet in its infancy, and many long years of work are necessary before it can rank with the steam-engine in capacity for all manner of uses; but it can quite well be made as manageable as the steam-engine in by no means a remote future. The time will come when factories, railways, and ships will be driven by gas-engines as efficient as any steam-engine, and much more safe and economical of fuel. Gas-generators will replace steam-boilers, and power will not be stored up in enormous reservoirs but generated by coal direct as required by the engine.

"The steam-engine converts so small an amount of the heat used by it into work that, although it was the glory and honour of the first half of the century, it should be a standing reproach to engineers and scientists at the present time having constantly before them the researches of Mayer and Joule."

Other engineers like Sir Frederick Bramwell shared in this feeling. Sir Frederick even went so far as to predict that, by 1931, steam-engines would only be found in museums. A gallant attempt was made by those interested in the gas-engine to fulfil Sir Frederick's prophecy, and very great progress has been made.

The internal-combustion engine has acquired a definite position in the engineering world, and shares largely with the steam-engine in the power production of the world. Progress, however, has revealed conditions of unlooked-for advantage in the steam-engine which so far has not been attained in internal-combustion engines. The advent of the steam-turbine, developed by the genius and indefatigably hard work of the Hon. Sir Charles Parsons, has proved clearly that, for large powers, reciprocating pistons operating in cylinders must become a thing of the past.

In the early days of the compression internal-combustion engine (about 1880) the average efficiency of the steam-engines in use was very low. In Britain an average steam-engine of medium size would usually be found to convert only 5 per cent. of the total heat of the coal burned under the boiler into indicated work in the engine-cylinder. The best result obtained, even with large reciprocating steam-engines, about that time did not exceed 10 per cent., calculated in the same way. The early Otto cycle gas-engines of the same date converted 16 per cent. of the total heat of the coal-gas used into indicated power within the cylinder. As years went on this efficiency was greatly improved upon, and about 1910, internal-combustion engines of 15 inches diameter cylinder, when carefully made, could be relied upon to give an indicated thermal efficiency of 35 per cent., and in some experimental tests even so high as 40 per cent. has been obtained. At one time it was believed that as gas-engine cylinders increased in diameter, efficiencies would also increase, because of the diminished proportional surface causing less heat loss from the hot flame to the enclosing walls. It was found, however, that increase beyond 15-inch cylinder diameter produced but little practical change in actual indicated thermal efficiency. Careful investigation into the phenomena of the gas-engine cylinder by many investigators, including the present Author, proved conclusively that little gain could be expected from further increase of cylinder dimensions. Much scientific work had been done by the British Association Committee on Gaseous Explosions and by Committees of the Institution of Civil Engineers and of the Institution of Mechanical

Engineers. These investigations clearly proved that definite properties of the working fluid limited the thermal possible efficiencies, so that if even the whole heat-flow through the sides of the cylinder be put an end to, only a moderate increase in indicated thermal efficiency would result. Distinct limits to increased thermal efficiency were shown to exist. The conditions, however, of heat-flow within the cylinder were more and more clearly understood, and were found to be greatly affected by cylinder dimensions; increased cylinders prejudicially affected the power of the cylinder-jacket and piston to dissipate the heat of the explosion and so tended to undue rise in wall temperature. In other words, it was found that the larger the cylinder became, the greater became the difficulty of preventing heat fractures in breech-ends, cylinders, liners, and pistons. It was speedily found that in the ordinary four-stroke or Otto cycle-engine, 22 inches to 24 inches was the safe limit of cylinder diameter for engines having unwatered pistons. Immediately these dimensions were exceeded, it became necessary to pump water through a hollow piston and also through the exhaust-valve, in order to keep down wall temperature and avoid fracture and pre-ignitions. Although watering a piston does not appear to be a formidable operation, yet it inevitably increases the weight of the piston and reciprocating parts of an engine, and so diminishes the possible piston-speed by increasing the stresses due to the acceleration and retardation. Engines as large as 51-inch diameter cylinder have been made, but the weight required per horse-power was very greatly increased. The law of similar structures shows clearly that for entirely similar engines of increasing cylinder dimensions, the weight per indicated horse-power increases directly with the cylinder diameter. This is true of steam- as well as of gas-engines, but the gas-engine is at a disadvantage because the ratio between maximum and mean available steam-pressure is much more favourable than that between maximum explosion and mean pressure; and, further, the double-acting steam-engine for a single piston produces two impulses per revolution, while a double-acting four-stroke engine requires two revolutions within which to produce two impulses. Accordingly,



the weight of a gas-engine for a given power is greater than that of a steam-engine of equal cylinder diameter. A gas-engine is thus necessarily heavier than a steam-engine of the same power and cylinder dimensions. The law applies even with greater force to engines of the Diesel type, where pressures of compression of 500 lb. per square inch must be provided for, and a sufficient margin must be left to allow for even 1,000 lb. per square inch, due to explosive instead of constant-pressure ignition, which sometimes occurs, especially when starting. All these difficulties tended to restrict the commercially saleable internal-combustion engine to moderate powers. On the Continent engine-builders favour large cylinder slow-running engines of great weight; but in England such engines never became really popular, and the great gas-engine trade of Britain has been built up on the basis of a cylinder not exceeding 24-inch diameter usually running with an unwatered piston and exhaust-valve. In England the multiple cylinder high-speed internal-combustion engine has had considerable success, and is now made by well-known engineering companies in sizes up to about 3,000 h.p. for one engine.

In reciprocating steam-engines for fast battleships and passenger steamers, the limit of weight for power was approached about 1895, and it became evident that, if higher speeds were required, some other method of obtaining motive power must be adopted. Sir Charles Parsons began his work on the land steam-turbine in 1884, and began experiments on the marine steam-turbine in 1894, and in a marvellously short time he passed from the engines of the "Turbinia," giving 2,000 shaft h.p., to the engines of the "Mauretania," giving 70,000 shaft h.p. It was speedily proved that the steam-turbine in various forms gave large powers within limitations of weight impossible by any other method. Powers of 100,000 h.p., for example, now frequently found in battle cruisers, such as the "Lion" and "Tiger," could not have been obtained from reciprocating steam-engines at all; still less could such powers have been obtained from internal-combustion engines of any type, whether gas or Diesel oil. Further improvements in gearing the steam-turbine to its propeller enabled the weight of the turbine to

be greatly reduced, and its speed of rotation arranged for maximum efficiency, while allowing the speed of rotation of the propeller also to be arranged for maximum efficiency. Consequently the turbine became more and more economical.

In the early days of the small steam-turbine the steam consumption was large, but now Sir Charles Parsons is able to offer a large power turbine with a steam consumption as low as 9 lb. per shaft horse-power. In such an engine 20 per cent. of all the heat of the steam is converted into shaft horse-power, and with a boiler of ordinary efficiency this may be taken as giving a return of at least 15 per cent. of the whole heat of the fuel in useful work transmitted by the shaft. It was speedily found that these large turbine engines gave but little trouble in the engine-room compared with their reciprocating predecessors, and as a result the Parsons steam-turbine has become in a few years supreme in all battle fleets; indeed, if the total horse-power upon the seas of the world be taken as about 24,000,000 h.p., 8,000,000 h.p. is accounted for by the Parsons turbine.

The difficulties found to accompany increasing cylinder dimensions have thus limited the internal-combustion engine to comparatively small units; a 5,000-h.p. engine is considered very large for any form of gas-engine; a 5,000-h.p. steam-turbine forms an ordinary unit for an electric light station engine. Obviously the internal-combustion engine must be considerably modified before it can equal the steam-turbine as a mechanism for producing large powers. As a machine for converting heat into work, the internal-combustion engine is still supreme; but engineers must now devote themselves to overcoming the mechanical difficulties of very large powers. It is possible to increase the thermal efficiency still further, but gain in that direction will not help us in our competition with the steam-turbine. So far as I can see there is no hope of an indefinite increase in power using reciprocating pistons. Something must be done to introduce the rotary principle. Many attempts have been made to produce a gas-turbine, the most important recent attempt being that of Mr. Holzwarth, whose gas-turbine has been built by Messrs. Brown,

Boveri and Co.; but, so far as I know, no success has yet been attained. The theory of the Holzwarth turbine in its form last known to me necessarily gives a somewhat low thermal efficiency; I have calculated it to be 15 per cent. of the heat of the working fluid, and in 1912 the extreme value claimed by Mr. Holzwarth was 23 per cent. Such results do not practically improve upon those of the largest steam-turbines.

Other methods, however, of dispensing with the reciprocating piston and cylinder are quite practicable. The large Humphrey pump described in the second Thomas Hawksley Lecture dispenses with pistons, and utilizes an explosion-chamber in which gases are compressed and ignited, and operate by throwing a heavy column of water into motion. This method has advantages, but it is necessarily heavy for a given power. It appears possible to use water in another manner by filling a chamber, exploding a compressed mixture above the water, and forcing the water through a jet to operate a turbine of the Pelton type. Arrangements would be made to allow for the varying velocity of the water due to fall of pressure by expansion, and it would be quite possible to obtain an efficiency between explosion-chamber and Pelton wheel of about 80 per cent. Such a turbine could be made to work using the same water repeatedly, and high efficiency combined with light weight is possible. A brake efficiency of 30 per cent. is possible. Experiments in this direction are worthy of consideration. Before such engines could compete for the highest powers reached by the steam-turbine, gas-producers must be considerably modified and improved. The Mond type producer using bituminous fuel has been fairly successful, but it depends largely for success on the recovery of ammonia, and this involves a bulky and heavy plant. This is allowable in stationary installations, but for marine purposes much lighter and smaller producers would require to be designed capable of consuming bituminous fuel as completely as is done in a steam-boiler furnace, so that but little tar ever exists in the gas. If tar once gets into gas, an enormous scrubbing plant becomes necessary. Producers will require to be designed and experimented with, which avoid the huge scrubbing plant required at present in

all bituminous producers. With such producers and such engines a brake efficiency of 25 per cent. between fuel and Pelton wheel would not be difficult to obtain, and a 30 per cent. efficiency is quite possible.

With such mechanisms built in large power units, the power of Britain could be obtained for nearly one-third the present fuel consumption, and the work of the gas-engineer would thus materially aid in prolonging the coal life of Britain.

*Progress of Indicated Thermal Efficiency.*—So far the work of the engineer during the nineteenth and twentieth centuries has resulted in improving the indicated thermal efficiency from 3·8 per cent. obtained by the Boulton and Watt condensing low-pressure steam-engine to 35 and 40 per cent. obtained by explosion and constant pressure internal-combustion engines. The following Table shows the progress very clearly :—

*Indicated Thermal Efficiency of Steam and Internal-Combustion Engine.*

<i>Steam.</i>	<i>Indicated Efficiency.</i> Per cent.
Boulton and Watt Condensing Low-Pressure, about 1820 . . . . .	3·8
Cornish Engine, about 1850 . . . . .	9·0
Triple Expansion, about 1910 . . . . .	17·0
Parsons Turbine, about 1914 . . . . .	28·0
<i>Internal-Combustion.</i>	
Lenoir, about 1860 . . . . .	4·0
Compression—Constant Volume, } 1876 . . . . .	16·0
} 1905 . . . . .	35·0
(two or four stroke)	
Compression—Constant Pressure (Diesel), 1910 . . . . .	40·0

The indicated efficiency refers to the proportion of the total heat of the steam or working fluid given to the engine converted into indicated work. The indicated work obtained for 100 heat units in the fuel is, of course, less because of boiler and steam-pipe losses ; and, where a gas-producer is used, because of gas-producer losses. Assuming a very favourable figure for the efficiency between the

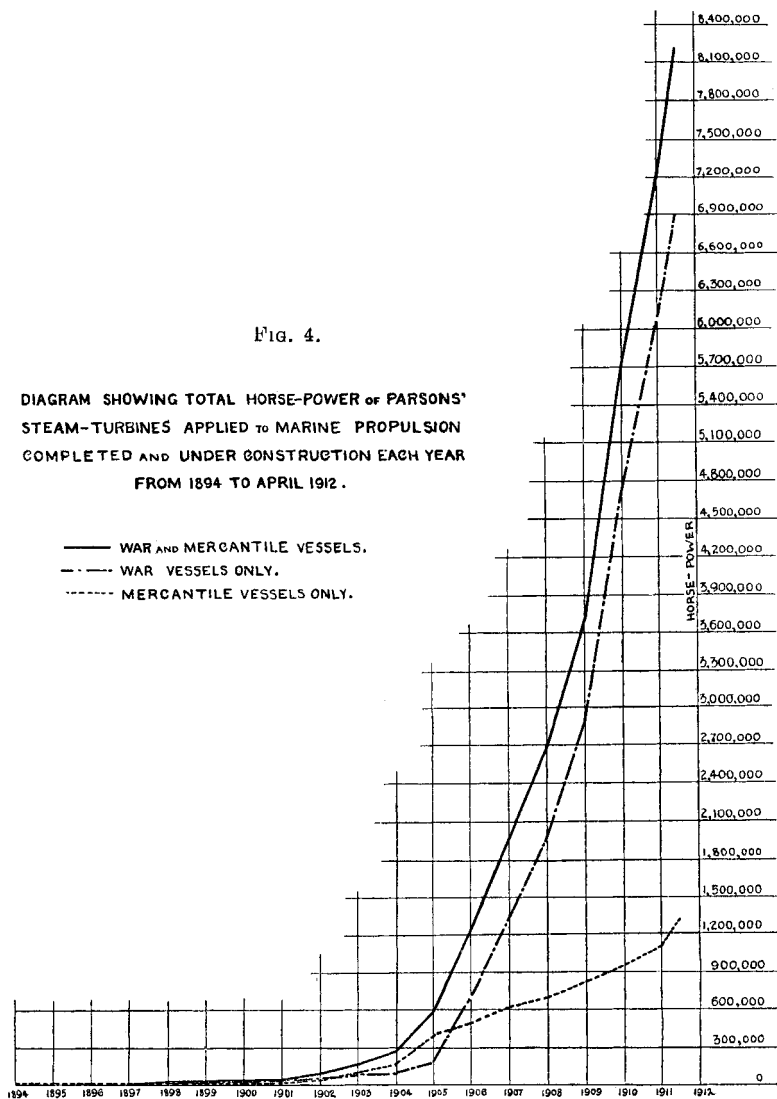
boiler and the steam-cylinder, 0·8, it will be seen that the indicated efficiency from the heat in the fuel in the case of the Boulton and Watt engine is only 3 per cent., and in the case of the explosion internal-combustion engine 28 per cent. Applying the same correction to the Parsons turbine, we get  $18\frac{1}{2}$  per cent. as the best result of heat conversion from fuel to the shaft horse-power of the engine. In comparing modern efficiencies, therefore, the steam-turbine shows  $18\frac{1}{2}$  per cent. heat conversion from the fuel against 28 per cent. heat conversion from fuel by gas-producer in the explosion gas-engines. From this it would appear that, even against the best steam-turbine, a very substantial advantage would be gained if internal-combustion engines were made of similarly high efficiency operating on the continuous rotating principle. This, however, is a matter for future development, and offers an excellent field for the young and ambitious engineer. At present the power in use by steam-turbine, both on sea and on land, is greatly in excess of that produced by stationary internal-combustion engines.

I am indebted to Sir Charles Parsons for two interesting curves shown in Figs. 4 and 5. Fig. 4 (page 620) gives the total horse-power of Parsons' steam-turbine applied to marine propulsion between the years 1894 and 1912. From this it appears that in 1912 over 8 million shaft horse-power of marine steam-turbines were either completed or under construction up to that date, while, as shown in Fig. 5 (page 621), to the end of 1911,  $6\frac{3}{4}$  million horse-power had been completed for land purposes only. The power of stationary and marine internal-combustion engines of all kinds does not approach those figures. Still, the internal-combustion engine has made great progress, and undoubtedly the difficulties at present existing will be ultimately overcome. I fear, however, the solution of these difficulties will not enable Sir Frederick Bramwell's prediction to be accomplished even in 1931. Steam-engines, internal-combustion engines, and water-turbines and engines will even then exist together, each satisfying a separate want.

From what I have already said, it will be seen that engineers' efforts have been continuously directed for about 150 years

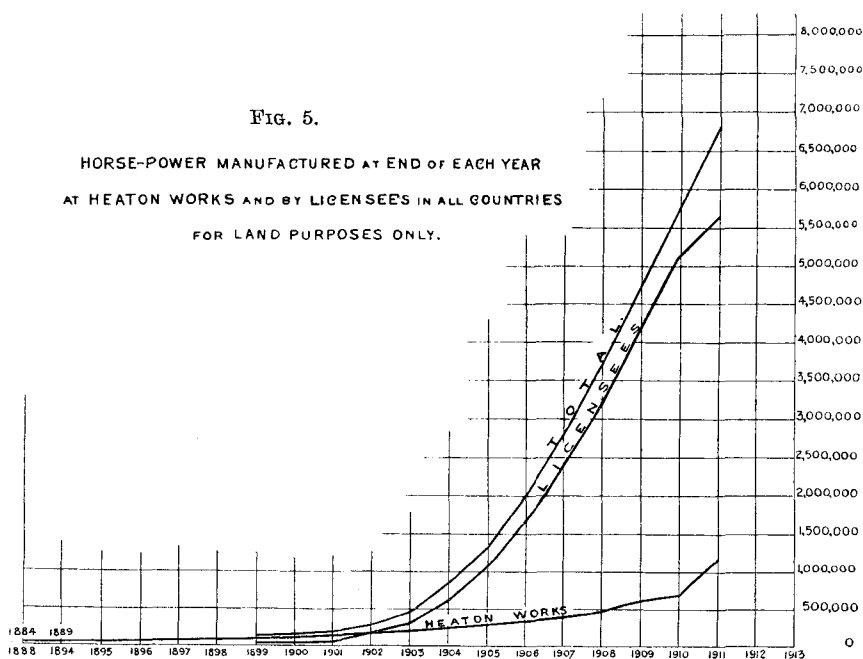
Fig. 4.

DIAGRAM SHOWING TOTAL HORSE-POWER OF PARSONS' STEAM-TURBINES APPLIED TO MARINE PROPULSION COMPLETED AND UNDER CONSTRUCTION EACH YEAR FROM 1894 TO APRIL 1912.



towards increasing the thermal efficiency of their prime movers; and in this quest for greater economy they have adopted a working fluid, flame, much more difficult to deal with than the early working fluid, steam.

When fuel becomes more and more expensive as our coal supply becomes obviously lessened, organized attempts will be made to obtain economies which are not worth while so long as



coal is cheap. Dr. Ferranti, in a Presidential Address to the Institution of Electrical Engineers, some time ago, dealt with the possibility of economizing for both power and heat by the electric conversion and conveyance of all the fuel energy. He showed the advantages of large central stations distributing electric current at a very low price—he mentioned one-eighth of a penny per unit—applying this current for all the purposes of heating, lighting and

motive power. So long as fuel is cheap, no doubt Dr. Ferranti's scheme might be usefully put into operation; but when fuel becomes really dear, too much heat is lost in the process of conversion into electric current. Central stations could be established in which steam-turbines were used for generating electric power, and where the exhaust-steam from the turbine was discharged at a pressure above that of the atmosphere, so as to maintain the temperature above  $100^{\circ}$  C. Such turbines would not give the thermal efficiency now obtained by Parsons, because they would lack the long expansion used by him in his largest and most efficient machines. The exhaust heat, however, could be used for manufacturing purposes and for household heating in a city, and a combined heating and thermal engine could thus be produced whose theoretical efficiency was 100 per cent.; the only loss would be that due to conduction during distribution, but heat supply for a city for heating houses and for doing low temperature manufacturing work could be readily obtained from the waste heat of the steam-turbines at the central stations. A large part of the heat necessary for comfortable life and industry could thus be obtained. Where medium high temperatures were required, a gas of low calorific value could be distributed, and efficient furnace arrangements could be made to obtain the necessary temperatures with a maximum economy. The waste heat from such furnaces could also be used to raise steam to enable general heat distribution to be conducted. Under these conditions many chemical processes, such as smelting, would be conducted electrically, with only such weight of carbon as was necessary for the chemical reaction—the high temperature for the reaction would be given by the electric heating. By combinations of steam-power and internal-combustion engines and exhaust heating, using both engine exhaust and furnace discharge, great economies would be effected and fuel consumption would be very greatly reduced. Dwelling-houses would be heated by circulating steam or hot water up to a certain temperature, and the added radiant heat necessary for comfort would be obtained either electrically or by burning small quantities of coal or gas in suitable fires. Although such conditions favour a low efficiency



use of steam for motive power, yet at a further scarcity price of fuel the high efficiency in the internal-combustion engine would find its field, because, broadly, a greater electrical heat and light could be obtained with a given fuel consumption, and the engine exhaust-gases would be at a higher temperature, and so have heat in a form available for a greater number of manufactures than the low temperature steam.

*Future of Hydraulic Power.*—Long before the final exhaustion of coal-pits, the increased expenditure necessary for heating and motive power would increase the pressure upon the hydraulic engineer, and undoubtedly much greater use would be made of water-power. I have already referred to Mr. Ellington's interesting calculation as to the total water-power of Britain determined by assuming all the rainfall to be available from a level of 500 feet above the sea, except that portion required for the use of the population, and absorbed by vegetation and evaporation. Mr. Ellington calculates on this basis that 35 million horse-power would be available for 2,000 hours in the year. If this could be done, of course, Britain, except for marine purposes, could be independent of coal. This calculation, however, requires two-thirds of the area of England to be arranged at the high level of 500 feet as a huge storage tank for rain-water, but with our present knowledge such an area is an engineering impossibility.

The future interaction of the world's three great prime movers—water, steam, and internal combustion—is very difficult to predict and appreciate. The effect, for example, of importation of coal from outside sources can hardly be predicted.

Whatever happens in the future, however, we may rest assured that hydraulic power will play a most important part, and that what has been called the "White Coal of the Mountains" will assume greater and greater importance with the increasing age of an industrialized world. In an able Paper read at the Zürich Meeting of this Institution in 1911, Mr. L. Zodel concludes with this statement: "Members of the Institution of Mechanical Engineers are indeed the representatives *par excellence* of steam

and steam power. Water power, the 'White Coal of the Mountains, will hardly be of much importance in their own country, compared with that all-powerful 'Black Queen of Energy' of which they have an abundance; but it may, indeed, play a very great part in the development of the resources of the vast colonial possessions composing the British Empire." Undoubtedly Mr. Zodel saw clearly; but as time goes on Britain itself will become more and more dependent on hydraulic power.

Meantime, by the application of high-efficiency engines, the use of all waste heat for domestic and industrial purposes, and the application of all available water-power, all on a large scale, the engineer may extend the industrial period in England to over one thousand years. Long before that period our dominions across the sea will have become huge nations exceeding the 100 million souls as predicted by Professor Seeley, and even a coal-less England will remain great and prosperous, the intellectual and strategic centre of a vast empire.

Altogether the engineers of the future have before them vitally important and interesting problems, and on the success of their work depends the future of our country—whether we can support, five hundred years hence, an industrial population of fifty millions, or an agricultural one of about twenty millions. Of our immediate future I have no fear. We shall assuredly uphold our liberty and independence, notwithstanding all the warlike efforts of the Germanic powers; but our distant future undoubtedly depends more on the efforts of engineers than on the labours of war or politics.

The Lecture is illustrated by Plates 7 and 8 and 2 Figs. in the letterpress.

The attendance was 57 Members and 82 Visitors, including a few Ladies.

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The LECTURE was repeated by Dr. CLERK in Manchester, Glasgow, and Cardiff:—

At MANCHESTER, at The Engineers' Club, Albert Square, on Tuesday, 2nd November. The PRESIDENT was in the Chair, and about 150 were present.

At GLASGOW, at The Rankine Hall, Institution of Engineers and Shipbuilders in Scotland, Elmbank Crescent, on Monday, 8th November. Dr. ARCHIBALD BARR (*Member of Council*) presided, and 52 were present.

At CARDIFF, at the South Wales Institute of Engineers, Park Place, on Thursday, 11th November. Principal E. H. GRIFFITHS presided, and 59 were present.



Fig. 2.  $\frac{1}{2}$  H.P. Lenoir Gas-Engine, 1866.

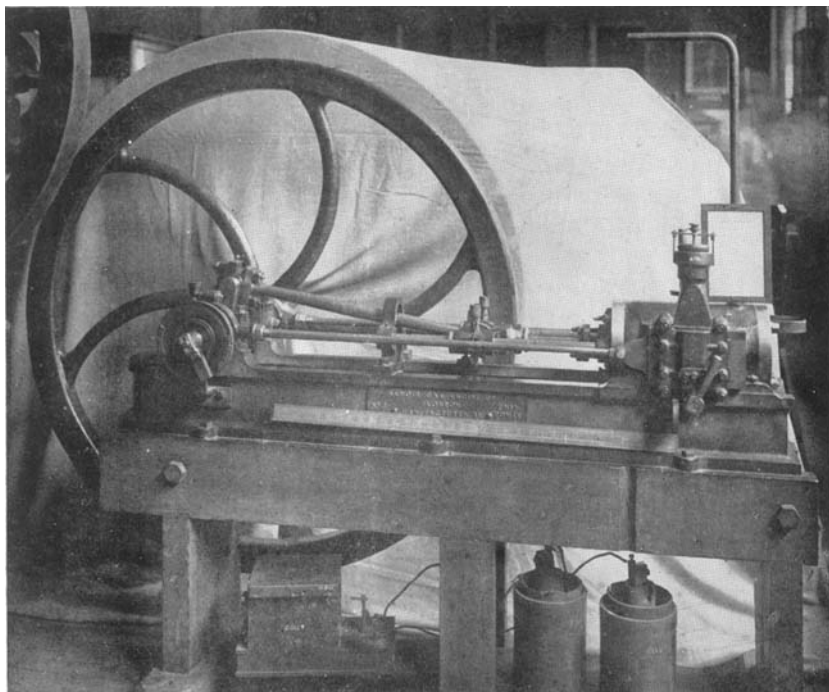


Fig. 3. *Constant-Pressure Engine, Brayton, 1873.*

