## III.

### FINAL DEDUCTIONS.*

27. **Our Progress,** whether in the direction of industrial improvement or of intellectual growth, depend, the first mainly, the second largely, upon the extent and the success of man's utilization of the four great natural forces, or "energies," as the man of science calls them: heat, light, electricity, mechanical or dynamic power. Civilization is based upon their application to the purposes of humanity in the world of matter; intellectual and even moral progress is advanced by that steady march of improvement which, in modern times especially, has so constantly promoted the material welfare of the world, and has thus given leisure for that employment of the mind in higher work which is the essential prerequisite to either intellectual or moral elevation.

The greatest of all our problems to-day is thus that of making this utilization of the forces of nature more general, more efficient, and more fruitful. Could the engineer, to whom all this work is intrusted, find a way of producing steam-power at a fraction its present cost; could he transform heat energy directly and without waste into dynamic; could he find a method of evolution of light without that enormous loss now

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* From *The Forum*, Sept. 1892: "The Great Problems of Science," by R. H. Thurston.

inevitable in the form of accompanying heat; could he directly produce electricity, without other and lost energy, from the combustion of fuel—could he do these things to-day, the growth of all that is desirable to mankind and the advancement of all the interests and powers of the race would be inconceivably accelerated. Moral sentiments, logical power, inventive genius, capacity for accomplishing all the grander tasks of civilization, develop together. All gain and retain existence through the mysterious power, possessed by all, of transforming and utilizing those original natural energies coming to us all alike from the central sun, and to the central sun from initial chaos and a diffused universe. Every motion and every power of each and all is due to conversion of these primary energies for a specific purpose and in a specific manner.

The engineer, to whom is confided this duty of utilizing all the forces of nature for the benefit of his fellows, has, however, now apparently reached a point beyond which he can see but little opportunity for further improvement, except by slow and toilsome and continually limited progress. He seems to have come very nearly to the limit of his advance in the directions which have, up to the moment, been so fruitful of result. His steam-engine is doing nearly the best that can be done, so far as he can see, in the conversion of heat into power; light is produced through the steam-engine and the dynamo-electric machine about as efficiently as he can hope to obtain it by known methods; heat is obtainable for his thousand purposes, economically at least, only by the combustion of his rapidly disappearing stores of fuel laid by in the past millenniums for his use during a brief life on the globe, and without visible substitute when they shall have been exhausted; and civilization, the life of the race, dependent upon our coal-beds, is only assured of ultimate and, on the geologist's scale of time, early extinction; unless, indeed, again consulting nature and studying the lessons of life, as we have so often profitably done before, we can learn of new ways of availing ourselves of existing forms of energy in nature, or of enormously improving our methods and reducing those wastes which are now so frightful, as judged from the standpoint of both the engineer and the man of science. Whether we can expect or even hope to accomplish the first of these tasks is extremely doubtful, not to say absolutely improbable; that we may possibly succeed in the second may be less unlikely. In any case, our only recourse is the same method which has brought us all that we now possess: scientific research and the study of nature's own methods.

28. **What we are to Seek** is, first, a method of producing, directly or by modification of other ether-vibrations, just that sort of ether-wave which we require, in the form of heat, light, or electricity, of exactly defined rate and amplitude of vibration; secondly, the complete transformation of either or all forms into mechanical power, into "dynamic" energy. It is easy to say and usually is safe to assert that what has been done may be again done; what is accomplished to-day in nature may be, in a similar manner or by parallel methods, performed by man. Nature accomplishes many of the tasks that man is about attempting, and has been holding up to him the solution of his problems throughout the ages. It is

for him to solve her riddles and thus to obtain power at a fraction of its present cost; prolong the life of the race indefinitely; secure light, isolated from heat, and in many times the quantity for a given amount of labor now expended; and produce electricity without loss and directly, instead of, as at present, through the intervention of heat-engines with their now enormous wastes. Human progress depends upon the ability of mankind to do more work, and to accomplish greater tasks, to supply the necessaries of life with less expenditure of time and strength, thus to secure leisure for the production of the comforts and the luxuries that give modern society its characteristics, and to insure that leisure for thought, invention, intellectual development of every kind, which still more strikingly characterize the highest civilization. In all this, only the application of the forces of nature without waste and the complete subjection of all its energies can give maximum result.

It is now well known that the heat-engines, whether steam, gas, hot air, or ether, only utilize a fraction of the power latent in their fuel, and that this fraction, as a maximum, in even an ideally perfect engine, is measured by the division of the range of temperature through which they expand their "working fluids" by the "absolute" temperature of the fluid as supplied to the engine; that is, a temperature measured from a point about 460°, on the Fahrenheit scale, below the Fahrenheit zero. This fraction, we have learned, is, in the case of the modern steam-engine, usually between one fourth and one half; while the actual performance of our engines falls to one fourth or one half this ideal maximum, in the ordinary and best engines, respectively.* The engine fully utilizing, ideally, but two and one half pounds of steam and one fourth of a pound of coal per horse-power per hour practically demands six to eight times this amount, even when of the best construction; while the average engine probably utilizes but one pound in ten, and often but one in twenty, wasting from ninety to ninety-five per cent of all the heat from its furnaces. The gas-engine gives higher thermodynamic performance than the steam-engine; but it compensates this advantage by loss, through a "water-jacket," of one-half of all the heat that it should completely transform into useful work.† No method is yet discovered of imitating nature in direct conversion of heat into other forms of energy without waste; and our production of light, in our most recent and most wonderful inventions, involves the same waste by the intermediate use of the heat-engine for primary transformation of heat into mechanical energy, in turn to be converted, with great efficiency, into electricity, thence to be once more transformed, with great waste again, into light. The direct evolution of light, purely, or of electricity alone and without loss, from fuel oxidation, though it is constantly performed by nature, is as yet beyond the power of man. Could these problems of life be solved, power and light would cost us but a small fraction of their cost to-day; and the exhaustion of our coal-beds would be deferred

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* "Steam and its Rivals," R. H. Thurston: *Forum*, May 1888, p. 341. Also "Manual of the Steam-engine," vol. i. (New York, J. Wiley & Sons, 1890).

† "Last Days of the Steam-engine," R. H. Thurston: *North American Review*, July 1889.

thousands of years. Were grander problems ever presented or nobler prizes ever offered the man of science than these? Nature solved them in the earliest days of the earth's history; it begins to seem probable that man may find a way to penetrate the secrets and solve the problems of life and vitality. All that he seeks may be evolved from the mysteries and lessons of life.

29. **The Living Body** is a machine in which the "law of Carnot," which asserts the necessity of waste in all thermodynamic processes and in every heat-engine, and which shows that waste to be the greater as the range of temperature worked through by the machine is the more restricted, is evaded; it produces electricity without intermediate conversions and losses; it obtains heat without high-temperature combustion, and even, in some cases, light without any sensible heat. In other words, in the vital system of man and of the lower animals nature shows us the practicability of directly converting any one form of energy into any other, without those losses and unavoidable wastes characteristic of the methods the invention of which has been the pride and the boast of man. Every living creature, man and worm alike, shows him that his great task is but half accomplished; that his grandest inventions are but crudest and remote imitations; that his best work is wasteful and awkward. Every animate creature is a machine of enormously higher efficiency as a dynamic engine than his most elaborate construction as illustrated in the 30,000 horse-power engines of the "Campania" or the "Lucania," or in the most powerful locomotive. Every gymnotus living in the mud of a tropical stream puts to shame man's best effort in the

production of electricity; and the minute insect that flashes across his lawn on a summer evening, or the worm that lights his path in the garden, exhibits a system of illumination incomparably superior to his most perfect electric lights.

Nature in each of these cases converts the energy of chemical union, probably of low-temperature oxidation, into just that form of energy, whether mechanical or of a certain exactly defined and required rate of ether-vibration, that is best suited to the intended purpose, and without waste in other force, utilizing even the used-up tissue of muscle and nerve for the production of the warmth required to retain the marvellous machine at the temperature of best efficiency, whatever the environment, and exhaling the rejected resultant carbonic-acid gas at the same low temperature. Here is nature's challenge to man! Man wastes one fourth of all the heat of his fuel as utilized in his steam-boiler, and often ninety per cent as used in his open fire-places; nature, in the animal system, utilizes substantially all. He produces light by candle, oil-lamp, or electricity, but submits to a loss of from one fifth to more than nine tenths of all his stock of available energy as heat; she, in the glowworm and firefly, produces a lovelier light without waste measurable by our most delicate instruments. He throws aside as loss nine tenths of his potential energy when attempting to develop mechanical power; she is vastly more economical. But in all cases her methods are radically different from his, though they are as yet obscure. Nature converts available forms of energy into precisely those other forms which are needed for her purposes, in exactly the right quantity, and never wastes, as does invariably the engineer, a large part of the initial stock by the production of energies that she does not want and cannot utilize. She goes directly to her goal. Why should not man? He has but to imitate her processes.

Mysterious as seem these processes and methods, however, and wonderful as seem their results when compared with the crude ways of the engineer and the man of science, we at least know something of them, and are even familiar with many facts relating to them. The facts are these: Every living creature throughout the animal kingdom is a machine which takes into its internal furnace, or whatever it may prove to be, its fuel, its "food," composed of vegetable matter or, like the body receiving it, itself directly derived from vegetation; and by a chemical process in what the chemist calls the "wet way" it consumes this food, the resulting products of this chemical action being such as, dissolved in the blood, may be converted into brain, nerve, muscle, and fat; and by later combustion and transformations at low temperature it may produce heat certainly, electricity probably, often light, and always mechanical power. The composition of this fuel is known to be principally familiar chemical elements mingled with the rarer in minute proportions. The hydrocarbons, water, and a little lime, phosphorus, sulphur, and other minerals, such as iron, constitute the food of all living creatures.

Every process involved is carried on at "blood-heat" in the higher animals, and at much lower temperatures in the "cold-blooded" creatures; and all parts of the system are retained at substantially the same temperature at all times. All heat is thus the result of low-temperature combustion; all light and electricity are evolved at a constant low point on the scale, and these energies are converted into new forms, or into dynamic energy, and applied to the performance of work without variation of that temperature. That heat *is* produced is a matter of constant experience and observation, and we throw off more as we work harder, whether with mind or body, and as we move more rapidly. That this heat, so far as converted into other energies by the body, must be so converted at a sensibly constant temperature is obvious from the fact that the change goes on in a mass of circulating fluids; that this proves that the conversion is not thermodynamic, but is due to some entirely different and unknown method, is equally evident to the engineer, who understands that only so could the "law of Carnot" be evaded. That this action is possibly electrodynamic is indicated by the fact that electric currents traverse the system, and that we may at any moment compel the muscles to do work by the application of a current from an external source.

30. **Of the Methods of Production of Energies** in the body, we know as yet absolutely nothing; but we do know that electricity may be produced in large quantity, and at "high pressure," as the electrician says, as illustrated by the torpedo and the gymnotus or electric eel; and the anatomist knows the mechanical structure of the organs from which it is evolved, though he is ignorant of the processes therein conducted. We also know that the best currents for electrodynamic operations are those of low intensity, such as are easiest of control and insulation in the body. By analogy with the other methods of transformation, we may presume that the source of this

vital fluid in the animal is low-temperature combustion or other chemical action, and that a system of direct conversion is there in operation.

Scientific men are somewhat more familiar with the case of the firefly, curiously enough; that is to say, the production of light without heat, as well as the transformation of energies resulting in the economical production of heat and power in the animal system. It has long been known that certain chemical compounds, notably fats containing sulphur and phosphorus, may be burned at exceedingly low temperatures, with an evolution of a mild light almost or quite entirely free from heat. Some such compounds are found in nature, and the chemist has artificially produced others. He finds that he may at will produce, in some cases, slow and cold light-production or rapid and heat-producing oxidation. Numerous experiments upon the firefly and the glowworm indicate that theirs is a light thus obtained. This so-called "phosphorescence" is seen in many insects, worms, fishes, and mollusks, and even in vegetable and mineral matter. For a century this investigation has been in progress, and it is well established that the low-temperature combustion of a peculiar substance, given form in the body of the firefly, for instance, by peculiar organs specially constituted for that purpose, results in the production of light without heat. This has been most recently and most conclusively proved by Messrs. Langley and Very, who show by actual measurement with the Langley "bolometer," an instrument capable of measuring even the heat received from the moon, that "insect light" is accompanied by approximately one four-hundredth part of the heat which is ordinarily associated with the radiation of flame of the luminous quality of those familiar to all of us. Thus "nature produces this cheapest light at about one four-hundredth part of the cost of the energy which is expended in the candle-flame and at but an insignificant fraction of the electric light or the most economic light which has yet been devised." Many deep-sea fishes and nnmberless animalcules exhibit a solution of this problem.

31. **The Advantage** to be hoped for from the substitution of the economical ways of nature for the wasteful ways of man may be imagined from the following facts: Experiments by Mr. Merritt, in the Cornell University laboratories, have shown the wastes of the incandescent electric lamp to be from 93½ to 99½ per cent, according to intensity of current; while Mr. Nakano's tests, in the same place, of the arc lamp give a waste of 95 to 84 per cent. The insect wastes almost nothing. But even now the electric light has ten or fifteen times the efficiency of the oil-lamp, and is still better as compared with the candle. Professor Langley found the common gas-burner to waste 99 per cent of the developed energy of combustion. His fireflies were more efficient in the proportion of one to thousands. The six millions of tons of coal supposed to be concealed in the earth, at our present rate of consumption, if employed for power-production, would supply about fifteen thousand millions of horse-power for twelve thousand years; but could we discover and employ nature's methods and gain in such proportion as is indicated above, we might feel sure that all the wants of the race would be supplied as long as the earth should continue the possible abode of man. Years ago it was remarked in an inaugural address as presi-

dent of the "American Society of Mechanical Engineersé'*:

"I have sometimes said that the world is waiting for the appearance of three great inventors, yet unknown, for whom it has in store honors and emoluments far exceeding all ever yet accorded to any one of their predecessors. The first is the man who is to show how, by the consumption of coal, we may directly produce electricity, and thus, perhaps, evade that now inevitable and enormous loss that comes of the utilization of energy in all heat-engines driven by substances of variable volume. Our electrical engineers have this great step still to take, and are apparently not likely soon to gain the prize that will reward some genius yet to be born. The second of these greatest of inventors is he who will teach us the source of the beautiful soft-beaming light of the firefly and the glowworm, and will show us how to produce this singular illuminant and to apply it with success practically and commercially. This wonderful light, free from heat and from consequent loss of energy, is nature's substitute for the crude and extravagantly wasteful lights of which we have, through so many years, been foolishly boasting. The dynamo-electrical engineer has nearly solved this problem.e Let us hope that it may be soon fully solved, and by one of those among our own colleagues who are now so earnestly working in this field, and that we may all live to see him steal the glowworm's light and to see the approaching days of Vril predicted so long ago by Lord Lytton. The third great genius is the man who is to fulfil Erasmus Darwin's prophecy closing the stanzae

* Transactions "A. S. M. E.," November 1881, R. H. T.

"'Soon shall thy arm, unconquered steam, afar
Drag the slow barge or drive the rapid car,
Or on wide-waving wings expanded bear
The flying chariot through the fields of air'"

And even this latest of the mechanic's triumphs, already known to present far less difficulty than was formerly supposed, will attain highest success only when nature's methods of energy-transformation are discovered and adopted.

Should the day ever come when transformations of energy shall be made in nature's order, and when thermo-electric changes shall be a primary step toward electrodynamic application to purposes now universally attained only by the unsatisfactory processes of thermodynamics as illustrated in our wasteful heat-engines, the engineer, following in his work the practice of nature, which has been so successful throughout the life of the animal kingdom, will find it easy to drive his ship across the ocean in three days; will readily concentrate in the space now occupied by the engines of the "Majestic" a quarter of a million horse-power; will transfer the 3,000,000 horse-power of Niagara to New York, Boston, Philadelphia, to be distributed to the mills, shops, houses, for every possible use, furnishing heat, light, and power wherever needed; and may possibly do quite as much for the benefit of mankind by breaking up the modern factory system and distributing labor in comfortable quarters as by this reduction of costs of products to the consumer. One of the many difficulties in the way of successful navigation of the air is known to be that of securing some propelling instrument that shall not weigh more than about ten pounds to the horse-power. Could we evade Carnot's law by complete energy-transformation, we could to-day build engines of over 400 horse-power to the ton weight, and that obstacle would be out of our way. Could we completely transform heat or mechanical power into light, a resulting advantage would also be the reduction of the whole system of light-producing machinery in weight and bulk in corresponding degree. These gains would be observed in innumerable directions.

**32. Costs.**—On the other hand, nature in all her transformations makes use of chemical processes and organic and complex compounds that may prove to be too costly as substitutes for the fuels, though the latter are subject to present wastes; and thus the question of dollars and cents, always controlling, comes in to confuse the wisest of scientific men. However that may be, these problems must always afford instructive lessons to the student of the mysteries of nature; and the bare possibility that by following her methods he may find ways of so enormously benefiting his fellow-man and of adding so greatly to the comfort, the pleasure, the safety, and the opportunities of the race, must be quite sufficient to stimulate every young aspirant for fame and every lover of research to strive to achieve some one or all of these solutions of the grandest scientific problems that remain unsolved. It seems more than probable that it is to the mysteries and lessons of life that the chemist, the physicist, the engineer, must turn in seeking the key that shall un lock the still unrevealed treasures of coming centuries. These constitute nature's challenge to the engineer.