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