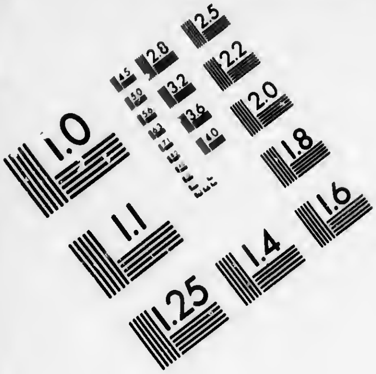

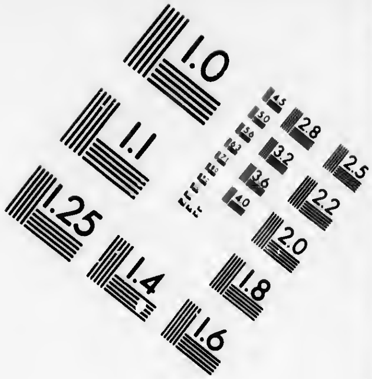

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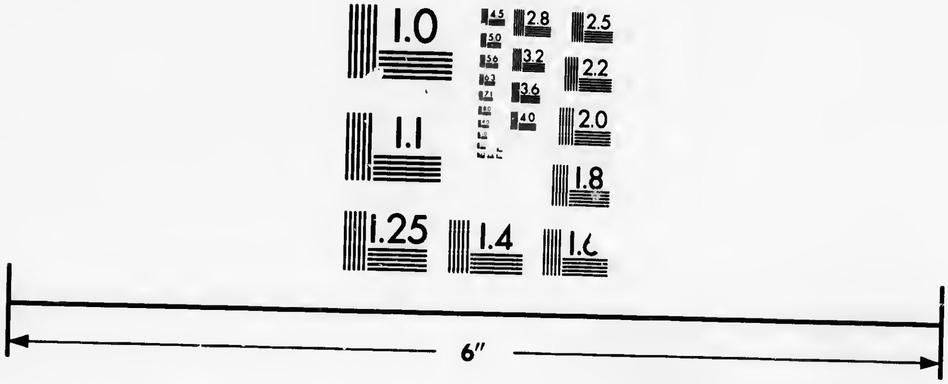

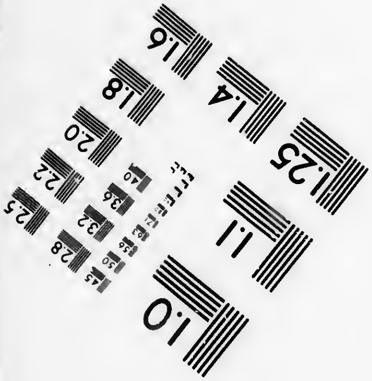

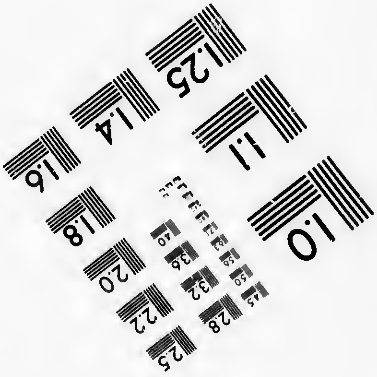

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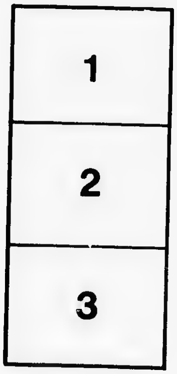

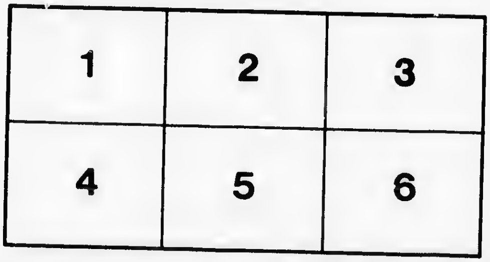

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ENERGY AND LABOR.

By G. C. CUNNINGHAM, M. Can. Soc. C. E.

To be read Thursday 5th November.

In presenting the following paper to the Canadian Society of Civil Engineers some apology should, perhaps, be offered for having taken up a subject that is different in style from those usually brought forward. Instead of describing some particular work, a general investigation of labour in its application to work is undertaken. Engineers have constantly to deal with questions of cost of construction, and these questions immediately involve the question of the cost of that labour, from which all construction results. Therefore an investigation into the cost of labour—an enquiry as to what constitutes labour—cannot, perhaps, be without interest to engineers, and may prove of some value. It is impossible, however, to make this investigation or enquiry without crossing, at some points, the well beaten paths of the political economist. Indeed, we do not proceed far before we find our track running parallel to his, and in a comprehensive survey of the question it is necessary to include much that has been mapped out by previous explorers. When the country is particularly difficult and rugged—to pursue the metaphor—we will often find it best to follow the established trail, but at other points, again, with true engineering instinct, we may bridge some deep chasm rather than make a long and labourous detour to avoid it.

What is labour? An answer to this question that will be sufficiently wide to embrace all kinds of labour is that, "Labour is the expenditure of energy," and so far as the work of producing or constructing is concerned, "Labour is the expenditure of energy to the doing of useful work that commands remuneration."

Man, in his dealing with nature, can create nothing. All that he can do is to arrange matter in different forms from those in which it previously existed. The whole phenomenon of production consists only in the collection, separation, combination, arrangement and distribution of matter. There is nothing made, in the sense of something being brought into existence that previously was non-existent. The only means by which this treatment of matter can be effected is by the application to it of energy, the energy of force or motion. By the application of force and motion to matter it is brought into new combinations, and is made subservient to human uses. The object of labour is to bring matter into such conditions that it may be immediately useful, or that, when acted upon by natural forces, such as solar heat, it may produce commodities that are of use.* Broadly speaking, manufactured articles come under the first division, agricultural commodities under the second. But whatever the commodity may be, the expenditure of energy is required, *i.e.*, labour, to obtain or produce it. Even the fruit growing wild on the tree requires the labour of gathering it before it can be used.

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* Compare "Principles of Political Economy," J. S. Mill, book i, chap. i, sect. 2.

Before going further it may be well to devote a little time to the consideration of energy, in the special sense in which the term is now used, and to the source from which energy, as we know it upon the earth, is derived. A full discussion of the subject would occupy more space than can be afforded here, but a most complete and beautiful elucidation of the question will be found in the eighth chapter of Herbert Spencer's "First Principles"—on the Transformation and Equivalence of Forces.

The doctrine of the conservation of energy shows that energy or force, like matter, can be neither created nor destroyed. All that can be done is merely to transform energy, that is, to change it from one form of being into another. Joule and others have investigated the energy of heat and have determined its mechanical equivalent; this they have found to be 772 foot pounds for one degree fahrenheit. That is to say there is as much energy contained in one degree fahrenheit of heat as would raise 772 pounds weight a foot high, or conversely 772 pounds weight when raised a foot high would, if let fall under the action of gravity, give forth one degree of heat by the force of the fall. The weight, when raised up, possesses energy in the potential form. So long as it remains raised it is capable of doing work by letting it fall. When it has fallen it no longer retains potential energy, but its energy appears in the heat caused by the fall, or it may be in the work it has done in falling. Thus this weight in falling might be made to raise another similar weight to a similar height (friction disregarded), when the potential energy would be transferred to No. 2; or it might be used to raise half its weight to twice the height, or a quarter of its weight to four times the height, or so on, in all of which cases the potential energy would simply be transferred from one weight to the other.

In a quite analogous manner fuel possesses potential energy. The fuel, before combustion, is a store of energy. During the process of combustion heat is given out which can be applied to the doing of work. Whence comes the energy of the fuel? Modern science shows that it comes from the sun's rays. The energy of the sun has been absorbed in the production of the fuel and is held stored up there until combustion again sets it free. And each unit of heat set free by combustion has, as before explained, its mechanical equivalent. If each unit could be captured and made to do work all could be transformed into work done. Unfortunately, our appliances and engines for converting heat into work are as yet so imperfect that by far the greater part of the heat evolved in combustion escapes and spreads through the surrounding media, and only a very small portion of it is converted into useful work. From calculations which the writer made in regard to the energy of fuel in locomotives *, it was found that on the Canada Southern Railway, a line having very flat gradients, running through the southern part of the Province of Ontario, so small a quantity as 2·3 ounces of coal produced in combustion sufficient energy to move a ton weight (American) one mile. Though the fact that a little piece of coal such as this—that can easily lie in the palm of one's hand—possesses within itself the dormant force that is capable of moving a mass more than thirteen thousand times its weight a distance of a mile is sufficiently astonishing, yet what must be our wonder at the power of fuel, when we find that to do this great work only 3 per cent. of the total energy contained in this little piece of coal is used, and 96½ per cent. is lost and wasted. If all the energy contained in the 2·3 ounces of coal could be harnessed and made to do work, it would, on the Canada Southern Railway, be capable of moving a ton weight 28½ miles! While we have this fact before us, let us compare it with similar work done by human energy alone, unaided by mechanical appliances. To convey a ton (2,000 lbs.), a distance of a mile by "bearers" would require the full energy of two men for a whole day. If

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* Cunningham on "The Energy of Fuel in Locomotives:" minutes of proceedings Inst. Civil Engineers, vol. lxxxiii, p. 311.

they took 100 lb. loads, each would require to make ten "trips," and thus walk 20 miles to do the work. The energy of two men being expended for a day, would therefore, only accomplish what the energy of 2·3 ounces of coal does on the Canada Southern Railway in three minutes,—taking the speed of a freight train at 20 miles per hour. We see from this how much better adapted fuel energy is to the doing of such work than human energy.

The energy of the human body that is expended in doing work, or carrying on the vital processes, is obtained in a similar manner to the energy of the locomotive. The food that we eat is the fuel that supplies us with energy, and the assimilation of this food is analogous to the combustion of fuel that takes place in an engine furnace. The energy of the food is also derived from the same source as the energy of the fuel, namely: the sun's rays. This will be made clearer by a quotation from an article on this subject written by Prof. Balfour Stewart, that appeared in the *Contemporary Review* for July, 1882, "On the Conservation and Dissipation of Energy."

"A healthy man possesses energy, for he has the power of doing work: there must, therefore, be in his body a store of energy, and this must be energy of position, or potential energy, as it is called. This is clearly derived from the food which he eats, taken in conjunction with the air which he breathes. Something analogous to combustion must be taking place in his animal frame, and just as in an engine the energy of the fuel is converted into heat and work, so in his body the energy of food is converted into heat and work. Food, therefore, has a kind of energy analogous to that which fuel possesses. Now, whence does food derive its energy? It is either animal or vegetable; if the former, no doubt the animal which furnished it had fed on vegetables, so that we may limit our enquiry to the latter. Whence then do vegetables derive their energy? We reply, from the sun's rays."

A complete investigation of this subject in all its aspects, such as is undertaken by Spencer in the chapter before mentioned, shows that the prime source of all energy on the earth is the sun's rays. In order to lay the foundations on which to build the succeeding argument in regard to labour, it is necessary to make some quotations from this chapter. At page 206, Spencer says:*

"When we enquire under what forms previously existed the force which works out the geological changes classed as aqueous, the answer is less obvious. The effects of rain, of rivers, of winds, of waves, of marine currents, do not manifestly proceed from one source. Analysis, nevertheless, proves to us that they have a common genesis. If we ask, Whence comes the power of the river current, bearing sediment down to the sea? The reply is, The gravitation of water throughout the tract which this river drains. If we ask, How came this water to be dispersed over this tract? The reply is, It fell in the shape of rain. If we ask, How came the rain to be in that position whence it fell? The reply is, The vapour from which it was condensed was drifted there by the winds. If we ask, How came the vapour to be at that elevation? The reply is, It was raised by evaporation. And if we ask, What force thus raised it? The reply is, The sun's heat. Just that amount of gravitative force which the sun's heat overcame in raising the atoms of water, is given out again in the fall of those atoms to the same level. Hence, the denudations effected by rain and rivers during the descent of this condensed vapour to the level of the sea, are indirectly due to the sun's heat. Similarly with the winds that transport the vapours hither and thither. Consequent as atmospheric currents are on differences of temperature (either general, as between the equatorial and polar regions, or special as between tracts of the earth's surface of unlike physicial characters), all such currents are due to that source from which the varying quantities of heat proceed. And if the

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* "First Principles." Second Edition.

" winds thus originate, so too, do the waves raised by them on the sea's surface. Whence it follows that whatever changes waves produce,—the wearing away of shores, the breaking down of rocks into shingle, sand, and mud—are also traceable to the solar rays as their primary cause. The same may be said of ocean currents. Generated as the larger ones are by the excess of heat which the ocean in tropical climates continually acquires from the sun; and generated as the smaller ones are by minor local differences in the quantities of solar heat absorbed; it follows that the distribution of sediment and other geological processes which these marine currents effect, are affiliable upon the force which the sun radiates. The only aqueous agency otherwise originating is that of the tides, an agency which, equally with the others, is traceable to unexpended astronomical motion. But making allowance for the changes which this works, we reach the conclusion that the slow wearing down of continents and gradual filling up of seas, by rain, rivers, winds, waves and ocean streams, are the indirect effects of solar heat."

Again at page 209:

"That animal life is immediately or mediately dependent on vegetal life, is a familiar truth; and that, in the main, the processes of animal life are opposite to those of vegetal life, is a truth long current among men of science. Chemically considered, vegetal life is chiefly a process of de-oxidation, and animal life, chiefly a process of oxidation. Chiefly, we must say, because in so far as plants are expendors of force for the purposes of organization, they are oxidizers (as is shown by the exhalations of carbonic acid during the night), and animals in some of their minor processes are probably de-oxidizers. But with this qualification, the general truth is that the plant, decomposing carbonic acid, and water, and liberating oxygen, builds up the detained carbon and hydrogen (along with a little nitrogen and small quantities of other elements elsewhere obtained), into branches, leaves and seeds, and absorbing oxygen, recomposes carbonic acid and water, together with certain nitrogenous compounds in minor amounts. And while the decomposition effected by the plant, is at the expense of certain forces emanating from the sun, which are employed in overcoming the affinities of carbon and hydrogen for the oxygen united with them; the re-composition effected by the animal, is at the profit of these forces, which are liberated during the combination of such elements. Thus the movements, internal and external, of the animal, are re-appearances in new forms, of a power absorbed by the plant under the shape of light and heat. Just as in the manner above explained, the solar forces expended in raising vapour from the sea's surface, are given out again in the fall of rain and rivers to the same level, and in the accompanying transfer of solid matters; so the solar forces that in the plant raised certain chemical elements to a condition of unstable equilibrium, are given out again in the actions of the animal in the fall of these elements to a condition of stable equilibrium."

And again at page 220:

"Not only is the force expended by the horse harnessed to the plough, and by the laborer guiding it, derived from the same reservoir as is the falling cataract and the roaring hurricane; but to this same reservoir are eventually traceable those subtle and more complex manifestations of force which humanity, as socially embodied evolves * * * * * Currents of air and water which before the use of steam were the only agencies brought in aid of muscular effort for the performance of industrial processes, are, as we have seen, generated by the heat of the sun. And the inanimate power that now, to so vast an extent, supplements human labour, is similarly derived. The late George Stephenson was one of the first to recognize the fact that the force impelling his locomotive, originally

" emanated from the sun. Step by step, we go back from the " motion of the piston to the evaporation of the water; thence " to the heat evolved during the oxidation of coal; thence to the " assimilation of carbon by the plants of whose imbedded remains " coal consists: thence to the cabonic acid from which their car- " bon was obtained: and thence to the rays of light that deoxi- " dized this carbonic acid. Solar forces, millions of years ago " expended on the earth's vegetation, and since locked up beneath " its surface, now smelt the metals required for our machines, " turn the lathes by which the machines are shaped, work them " when put together, and distribute the fabric they produce,"

These few extracts will indicate, with sufficient clearness, the sense in which the term "Energy" is used, and give in as condensed a form as possible, the conclusions arrived at by the application of the modern doctrine of the Conservation of Energy. From this we see that all force with which we are acquainted on the earth (except the force of gravity) is primarily due to the sun's rays. All human energy and all animal energy, the force of rivers and winds, the energy of heat and light in whatever manner manifested · all are ultimately due to the solar rays. And thus a strong healthy man, and a heap of coal are each of them sources from which can be obtained energy that may be applied to the doing of work; and both derive their energy from the same source—the Sun.

Reverting now to the definition given, that "Labour is the expenditure of Energy," we can understand how wide that definition is. Both energy and matter are alike uncreatable and indestructible. All that man can do is to move matter, and to guide and control energy. The energy that he can make use of appears under various forms; but under all these forms it can be used by man to certain extents and degrees, and can be directed by him to the doing of work. And in so far as energy is used to do work that commands renumeration, it is Labour in the sense in which that word is used by the *Political Economist*. With this fundamental notion of what Labour is, we will be in a position the better to investigate all the phenomena of Labour.

In his primitive condition man has control over no other energy than that stored up in his own body, and produced by the consumption or cumbustion of the food he eats. If he wishes to move from one place to another, he can do so only by his own muscular exertion: *i. e.* by the expenditure of his own energy. If he wishes to convey anything from one place to another, he can do so only by carrying it himself: *i. e.* by a further expenditure of his own energy. The first step in advance of this primitive condition is taken when he rears and trains animals,—horses and cattle—to do this work for him; thus substituting the less costly animal energy for his own: or when he makes boats, "dugouts," or canoes, by which he can convey himself and his goods on the water with a less expenditure of his own energy than he would have to make to do the same work on land. A further advance is made when he constructs vehicles for his horses to draw, and prepares ways on which the vehicles may travel, thus economising the energy of his horse, and enabling it to convey more goods in this manner than it could when loaded in the primitive fashion on its back: and when he improves the build of his boats, so that, by offering less resistance to the water, his energy in propelling may be able to convey a larger weight of goods than formerly, and thus rendered more efficient. A still more decided advance is made when he applies sails to his boat, and employs the energy of the wind—which he can obtain without any cost of production—to propel the boat and its load, while his energy is expended merely in directing and guiding the vessel. Every improvement in shipbuilding has been made with constantly the same effect: to obtain the largest and fastest carrying capacity with the least expenditure of human energy: to build vessels, and to construct and arrange sails for them, that will enable them to be moved with the slightest breeze, and at as many angles to the direction of the wind as possible: that is, to make the largest possible use of the energy of the wind, without the direct propelling force of human energy.

The application of animal energy to the doing of work has proceeded on lines similar to those above indicated. Horses have been carefully bred and reared so as to produce animals that were capable of exerting great strength, or putting forth great speed; that is, animals in whose bodies the energy of the food consumed would be transformed into the largest possible amount of active energy, and whose bodies should be best adapted to retransform this energy into work. Vehicles have been constructed as light as possible, and of the best form that could be devised for easy movement, and roads have been built offering as little resistance as possible to the movement of vehicles, so that a minimum of the energy of the animal might be wasted in overcoming mere resistances of the vehicles or road, while a maximum should be devoted to the performance of useful work. Every one knows that with a heavy, lumbering vehicle on a hilly broken road, a horse could take a much smaller load than with a light well constructed vehicle on a smooth, evenly-built road; the reason being that in the first instance a large part of the horse's energy is absorbed in overcoming the resistances of vehicle and road, and a small part only left to be applied to the conveyance of the load, whereas in the second case a small part of the energy is absorbed by the resistances of vehicle and road, and the larger part applicable to the conveyance of the load.

Similar, too, has been the application of the energy of flowing or falling water to the doing of work. Man built dams, and constructed mill races with sluices, wheels and other appliances, so that he might make use of the energy of water falling from a higher to a lower level, and apply part of it to the doing of work. In order to secure this supply of energy from the water, it was necessary first to expend energy in the construction of dams, mill races, etc., just as, in order to get the full benefit of animal energy it is necessary previously to expend energy in the construction of vehicles and roads, and in the rearing of animals. But this first expenditure of energy is more than recouped by the subsequent saving effected in the energy expended in the doing of work. The true reason for the use of energy other than human, is that other kinds of energy can do certain kinds of work quite as well as human energy, and that other kinds of energy in the doing of this work are much less costly than human energy. The amount of work done—using work in the scientific sense of "foot pounds"—in raising a ton one hundred feet, is the same whether it be done by men, horses, or wind or water-driven machinery. The quantum of energy expended or absorbed is the same in one case as in the others; but the cost of the energy is much greater for men than for horses, and much greater for horses than for wind or water-driven machinery.

A further and great advance in obtaining cheap energy was made when man discovered how to apply the energy of heat developed in the combustion of fuel, to the doing of work. This energy of fuel is precisely analogous to the energy of men or horses, and is derived ultimately from the same source. It is also much less costly than the energy of men or animals, and though in direct comparison, not less costly than the energy of wind or falling water, yet in its application to the doing of work has so great an advantage over these energies, in continuity and portability, that ultimately in practice it is found to be less costly than either in the vast majority of cases. Wind-driven machinery is subject to the fitful changes of the wind, and to the complete loss of the energy when the wind dies away. Water-driven machinery is liable to similar drawbacks through changes in the weather, causing the water to be frozen in cold or dried up in great heat. When these contingencies arise the machinery stops, production of commodities is suspended, while the maintenance of the men and animals engaged about the machine must be continued during the enforced idleness, just the same as while work is going on. This cost of maintenance has, therefore, to be borne with no concomitant production to support it. But no such drawbacks exist in regard to the use of energy derived from fuel. So long as we have fuel we have our store of energy, and the application of it to the doing of work can go on whether the wind blows or not; alike in cold or in hot weather. That fuel energy is less costly that the energy of men or animals, when coal can be obtained without extraordinary difficulty, the following example will show:

The amount of effective energy that can be obtained from 30 pounds of food consumed by a strong work horse in a day, is about 13,200,000 foot pounds. On a good road, with a wheeled vehicle, this energy would be capable of transporting a ton weight (including the weight of the vehicle) 30 miles.* But on a well constructed railway, with flat gradients, there is sufficient effective energy in 5 pounds of coal to transport a ton weight 30 miles. Now disregarding the energy that must be previously expended in either case for the construction of the road or railway, we can at once see that in order to procure horse food, by the ordinary methods of farming followed in a settled and cultivated country, those must be a much greater amount of energy expended in raising 30 pounds of such food, than in obtaining 5 pounds of coal where the coal mines are at all reasonably convenient or accessible; in other words that the horse food would cost a great deal more than the coal. Reducing the comparison to a common money basis, such as would hold for Ontario, we would find that the horse food cost 30 cents, while the coal cost one cent, that the source whence the horse energy is derived cost thirty times more than the source of the railway locomotive energy; and besides this, to the cost of the horse energy must be added the cost of a man's energy expended in driving and tending the animal while to the cost of the fuel energy must be added only a very small fraction of a man's energy; for two men together could quite well direct and control the energy developed in the combustion of 20 tons of coal. Thus a day's energy of a horse is only equal to the energy derived from 5 pounds of coal, in a locomotive engine running on a good line of railway; and the work which occupies a horse the whole day in the doing can be done by 5 pounds of coal in about an hour and a half.

Similar reasoning may be applied to make the comparison with human energy. A strong, able-bodied, well-nourished man can develope in a day's work about 2,200,000 foot pounds of energy, equal to one-sixth of the energy of a horse. To produce this energy the combustion of from 3 to 4 pounds of food is required. The cost of this, reduced to similar money basis to that above given, is 30 cents per diem. To accomplish the same amount of work, of a similar kind to that done by a horse (such as hauling a vehicle on a good road), six men would have to be used; and the cost of the food from which their energy is derived would be $1.80, as compared with 30 cents for the horse and 1 cent for the coal. In this comparison we do not speak of the *remuneration* that must be paid for the different kinds of labour used, which is something very different, but simply of the cost of the matrix from which the energy is evolved. In any case whether 6 men, 1 horse or 5 pounds of coal be used, the same amount of "work" is done, the same amount of foot pounds are effected, the same quantum of solar energy is turned into useful work. But when this energy is obtained through men the cost of the matrix (measured by a common money standard) is $1.80; through a horse it is 30 cents, and through coal it is 1 cent. Therefore if work can be done by coal instead of by men or horses, it will evidently be done much more cheaply; and if man can devise a means of substituting fuel energy for human or animal

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* Taking the resistance at 80 lbs. per ton, would almost exactly absorb all the energy of the horse.

energy in the doing of work and making of commodities, the cost of the work and the commodities will be greatly reduced. Such a means has, of course, been devised by the steam engine; and we daily see work performed by one locomotive in a tenth part of the time that would formerly have been required by hundreds of horses and men, and at an amazingly small fraction of the former cost.

It is only during the present century that man has discovered, and been able to apply, the stored up energy of heat in fuel to the performance of work—that man has been able to substitute this energy for that of men or animals. From the days of Jehu to George IVth there was no other way of rapidly moving on land, from one part of the country to another, except by the aid of horses. Now man has discovered the energy of fuel and how to use it, and consequently the cost of locomotion is wonderfully decreased and the rapidity of it as wonderfully increased. A single locomotive on a line of railway with flat gradients, such as the Canada Southern Railway, can easily convey 500 tons of freight, which with the weight of the vehicles would amount to 1,000 tons, a distance of 250 miles in 12 hours. The consumption of fuel required for this would be about 20 tons of coal.[1] To do the same work with horses, at least 300 *pairs* would be required, with 300 drivers, and they would be engaged about the work for not less than 10 days. The weight of food that these horses and men would consume in this time would be about 97 tons. We therefore have 20 tons of coal as—roughly speaking—the "energetic equivalent" of 97 tons of animal and human food; and the coal does the work in a twentieth part of the time required by the men and horses. The locomotive engine, as a doer of work, has also this great advantage over men or horses, that it expends energy only while it is working; when it stands idle we let the fires go out. It is not so with the horse—he must be fed and his energy maintained whether he works or stands idle. There has to go on continuously an expenditure of energy in order that his energy may be available at the time that we desire to use it.

The application of fuel energy to the doing of work other than locomotive has gone forward, during the present century, in a similar manner, and has produced analogous results. Whenever it has been possible to substitute fuel energy for human or animal energy in the thousand and one mechanical operations used in turning out commodities, that substitution has been made, with the result of enormously reducing the cost of production, *because* the energy of fuel is much less costly than the energy of men or animals.

The bent of inventive genius, as applied to manufactures, is always towards designing and perfecting what we call "labour-saving machinery." The true significance of all these inventions—whether they be sewing machines or steam hammers, printing machines or sawmills, reaping machines or locomotives, racing skiffs or triple expansion marine engines—is that they aim at either economising the energy used and thus getting more work out of it than formerly, or substituting a less costly and more efficient energy for that formerly used. No woman would use a sewing machine if she found that with the same amount of exertion expended on the machine she could do less work than she could formerly accomplish by hand. The locomotive engine never would have displaced horse labour if the cost of doing the work by fuel energy had been greater than the cost of doing it by horses and men, or if the locomotive had taken a longer time to do the work than the other agents. The progress of mechanical invention is always, and rapidly, in the same direction, and each day sees the evolution of some new device intended to economize energy. The world is only yet on the very threshold of discovery in the use of heat energy. The steam engine, wonderful though it be, and wonderful though the

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[1] This is arrived at from the figures adduced in the paper before alluded to, "On the Energy of Fuel in Locomotives," vol. lxxxiii Proceedings Institute C. E.

results are that it has effected in cheapening energy, is still a most wasteful and extravagant machine. When man has learnt how to secure much of the heat that is now lost, a ton of coal may be able to do twenty times as much work as now performed, and yet have a large margin for evaporation and radiation. Future ages will see vastly more than at present of the coarse and rough labour of life and the purely mechanical work of manufacturing done by cheap fuel energy, with the result that the cost of producing commodities will be proportionately reduced.

The whole phenomena of production, the whole phenomena of the formation and increase of wealth, can be rightly understood and interpreted only through a proper understanding of this application of energy. Labour is the cause of value; by labour only are commodities produced. The value of the labour absorbed in the production of a commodity defines and limits the value of that commodity. Therefore, as the labour absorbed in producing a commodity decreases in value so will that commodity decrease in value. What is meant by the "value of labour?" We mean the amount and value, as measured by the cost, of labour absorbed in producing the labour. And by labour is to be understood, not merely the labour of human beings, but "energy" in its widest sense, that is, foot pounds of work done by whatever agency the work may be effected. Therefore, if the production of a commodity requires the absorption of a certain quantity of "foot pounds" of work, then the less costly the energy is that is used to effect these foot pounds the less costly will the commodity be. And what is meant by "less costly energy" is that less energy has been absorbed in producing *this* energy than would have been absorbed in producing energy of another kind. The reduce this somewhat complicated statement to a concrete example, take the following:

Suppose there is a certain work to be done of a simple kind, such as pumping water, that might be performed either by human, animal or fuel energy. The quantity of work done, the number of foot pounds raised, the amount of energy expended in any case is the same. Let the quantity of work be 13,200 million foot pounds, which would about represent the daily exertion needed to pump the water supply for a town of 200,000 inhabitants [*] to a height of 135 feet. To use human energy for the performance of this work 6,000 men would be required [†]; animal energy would require 1,000 horses, and fuel energy would require the combustion of about 26,400 pounds of coal [‡], or roughly 13 (American) tons. By any of these agencies we could do the work. Six thousand men, one thousand horses, or thirteen tons of coal: each of them is the "potential" of the effective energy needed to pump the water to the desired height. But see how different is the value of the different energies, and how much more costly the water would be if pumped by the human energy instead of by the fuel. Each of the six thousand men would have to have been maintained and well nourished from birth up to about 25 years of age in order to be capable of putting forth the exertion required, and this represents a very large amount of exertion and energy expended both by himself and others in the providing of food and shelter during that long period. Each of the one thousand horses would also have to have been reared, fed and tended for seven or eight years from birth before being capable of performing the duty above indicated, and this also implies a large expenditure of energy in order that the horse labour may be available when required. But the fuel energy is obtained merely by the expenditure of the energy necessary to extract the coal from the earth. The energy is in the fuel, implanted in it by the sun's rays thousands of years ago, and waiting to be liberated by the process of combustion. It does not require to be built up, as it were, by a

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[*] 12 million (U. S.) gallons, taking 60 gallons per head as the requisite quantity.

[†] Taking the effective energy of each man at 2,200,000 foot pounds per diem

[‡] This is assuming the effective energy of the fuel at 5 per cent. of the total energy, the total energy being 10 million ft. lbs. per pound of coal.

slow and careful process, as in the case of men and horses, but whenever we possess the fuel we have a concentrated mass of energy, ready for immediate use, or that can be stored for use at any future period. The cost of this source of energy is much less than the cost of using men or animals as our source. For when we employ men or animals we have not only to give as the remuneration of their labour the cost of the matrix whence their energy is derived (*i.e.*, their food), but we also have to remunerate the labour involved in producing the man or the horse in the proper strength and condition to do the work; we have to take account of the energy previously expended in a series of years to produce the energy we are about to use. But when we get our work performed by the energy of fuel the problem is different. We are not required to remunerate the sun for the work he did thousands of years ago in storing up his energy in the fuel for us; we merely have to consider the cost and remuneration (based upon the cost) of the machine through which the fuel energy is turned into work, and the cost of the coal. The *energy* in the fuel we obtained with the coal, and it costs us no greater expenditure of energy to dig coal from the earth than to dig stone.

We may make a rough comparison of these three energies by reducing the matrix whence each energy is derived to the common measure of a money value. For the men and horses the matrix is, of course, their food, for the engine it is the fuel.

The daily food of 6,000 men would cost	$1,800.00
" " 1,000 horses " "	300.00
Thirteen tons of coal " "	52.00

But, as pointed out before, the cost of the food for the men and horses represents only a fraction of what would be the cost of employing these agencies to supply the needed energy. The wages of the men would (in this country at least) be quite four times the cost of their daily food. The cost of the horse labour, including the wages of men required to control and tend the horses would be not less than 3½ times the cost of the horse food. But the cost of the human labour required to superintend and direct the energy of the fuel in the engine would add only about two-thirds to the cost of the coal.* Therefore we may expand the comparison of the cost of labour for doing this pumping work as follows:—

By men, per diem	$7,200.00
By horses " "	1050.00
By coal " "	87.00

This is for labour alone in each case. Nothing is said of the cost of the machinery that would in any event be needed. We can see at a glance now how much more valuable the water would be if the pumping were done by human energy instead of fuel energy. Labour is the cause of value, but human labour in such a case as this would make the water so valuable as to put it beyond the reach of most people. It is only when we use the cheap labour of fuel that the cost of this commodity can be brought low enough to be purchaseable by all, even the poorest. If water were pumped for a city by human labour it would be so expensive a luxury that none could afford to use it. Even slave labour, where the slaves were captured in war, would be too costly. It is only since man has discovered the cheap labour of fuel that it has been possible to pump water to supply the needs of large cities.

This view of labour and energy has been dealt with for the purpose of emphasizing the fact that labour, in the science of political economy, should not mean human labour only, but should be understood as the application of energy to matter. Labour is the basis upon which all transactions connected with the accumulation and distribution of wealth rest, and therefore the problems of labour are those which should first be solved. It is the more necessary to draw attention to the view of labour

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* "A Treatise on Water Supply Engineering," by J. T. Fanning, p. 575, N.Y.; D. Vannostrand.

above set forth, because writers on political economy have almost entirely identified labour with human labour, pure and simple; have, therefore, considered the cost of labour as being almost synonymous with the rate of wages; and—recognizing labour as the cause of value—have reached the erroneous conclusion that a lowering of the cost of production of commodities (and therefore a cheapening of commodities) can be brought about only by—or as dependent chiefly upon—a lowering of the rate of wages. That this conclusion is erroneous the plain facts of every day life abundantly tell us. Commodities have wonderfully decreased in price of late years, and yet wages have risen: the explanation being that commodities are now to a great extent produced by a quite different, and perhaps cheaper, kind of labour from that used seventy-five years ago; and have therefore fallen in value (and in price, as being a measure of value) in accordance with the proposition that "The value of the "labour involved in the production of a commodity is a factor in "defining the lower limit of its exchange value."

When Adam Smith wrote his "Wealth of Nations" (in 1776), the power of applying the energy of fuel to the doing of work was unknown. The steam engine had not been born. His attention was of course directed to human labour, but he has a very instructive example of the difference of the cost of conveying goods by land and by water, drawn somewhat on the lines above followed. The passage contains so much that is interesting, and marks so clearly the change that has taken place in the premises of the economic problem, that it is here transcribed:

"As by means of water carriage, a more extensive market is "open to every sort of industry than what land carriage alone "can afford it, so it is upon the sea coast, and along the banks "of navigable rivers that industry of every kind naturally begins "to sub-divide and improve itself, and it is frequently not till "a long time after that those improvements extend themselves "to the inland parts of the country. A broad wheeled waggon, "attended by two men, and drawn by eight horses, in about six "weeks' time carries and brings back, between London and Edinburgh, near four ton weight of goods. In about the same time "a ship, navigated by six or eight men, and sailing between the "ports of London and Leith, frequently carries and brings back "two hundred ton weight of goods. Six or eight men, therefore, "by the help of water carriage, can convey and bring back the "same quantity of goods between London and Edinburgh as fifty "broad-wheeled waggons, attended by a hundred men, and drawn "by four hundred horses. Upon two hundred tons of goods, "therefore, carried by the cheapest land carriage from London "to Edinburgh, there must be charged the maintenance of a "hundred men for three weeks, and both the maintenance and, "what is nearly equal to the maintenance, the wear and tear of "four hundred horses, as well as of fifty great waggons. Whereas "upon the same quantity of goods carried by water, there is to "be charged only the maintenance of six or eight men, and the "wear and tear of a ship of two hundred tons burthen, together "with the value of the superior risk, or the difference of the "insurance between land and water carriage. Were there no "other communication between those two places, therefore, but "by land carriage, as no goods could be transported from the one "to the other, except such whose price was very considerable in "proportion to their weight, they could carry on but a small "part of that commerce which at present subsists between them, "and consequently could give but a small part of that encouragement which they at present mutually afford to each other's "industry. There could be little or no commerce of any kind "between the distant parts of the world. What goods could "bear the expense of land carriage between London and Calcutta? Or if there were any so precious as to be able to support this expense, with what safety could they be transported "through the territories of so many barbarous nations? Those "two cities, however, at present carry on a very considerable "commerce with each other, and by mutually affording a market, "give a good deal of encouragement to each other's industry."

"Since such, therefore, are the advantages of water carriage, "it is natural that the first improvements of art and industry "should be made where this conveniency opens the whole world "for a market to the produce of every sort of labour, and that "they should always be much later in extending themselves into "the inland parts of the country. The inland parts of the coun-"try can, for a long time, have no other market for the greater "part of their goods, but the country which lies round about "them, and separates them from the sea coast, and the great "navigable rivers. . . . . . In our North American Colo-"nies the plantations have constantly followed either the sea "coast or the banks of the navigable rivers, and have scarce any-"where extended themselves to any considerable distance from "both."[1]

Thus wrote Adam Smith, and the deductions that he drew from the facts presented to him, were undoubtedly sound. At that time man had at his command no other agency for the conveyance of commodities on land than the energy of men or animals; no other agency for their conveyance by sea than the energy of the wind. These energies, widely unlike though they seem, we now know owe their being to the same parentage, the solar rays. Since Smith's day we have discovered how to use the solar energy through the combustion of fuel. This now conveys our goods for us on land as well as on sea; and does it so cheaply, that the difference in cost between land and water carriage is inconsiderable. The results flowing from this it is almost impossible to enumerate. Every part of the country, no matter how far inland or remote from a navigable river, is now accessible to every market in the world. Populous towns that in former times of necessity grew only on the sea coast, or on the banks of large rivers, so that by water carriage their wants might be supplied, are now to be found far inland, distant from any waterway, and yet unconscious of any disability as the result of this position; as instance, the large inland cities of the United States. Without fuel labour and the locomotive, it would have been impossible to have peopled the North American Continent as we see it to-day. The conveyance of commodities enormous distances, and in vast quantities on land, is now scarcely more costly than formerly it was by water, and every day the cost is being decreased. If an all rail route were constructed from London to Calcutta, as doubtless will be done some day, goods of many kinds would be brought by it to England, and the cost of bringing them would be no bar to their use. Since Smith's day, all the conditions of the economic problem have been utterly changed; what appeared to him ridiculously impossible, is now a matter of every day occurrence; and all this has been brought about by the introduction of cheap labour; not such labour as he thought of and wrote about, but labour in the wide sense of the application of energy to matter.

But, though it was not to be expected that Adam Smith should be able to forsee the effect of the introduction of a power that was unknown in his day and generation, it is surprising to find that so great and so recent an author as John Stuart Mill, should have dealt with the question of labour as being confined solely and entirely to human labour. His whole theory of production is built upon this view of labour, with the result that his conclusions are erroneous. The writer is well aware, that in confuting the doctrines of a man so eminent as Mr. Mill, he is doing that which will lay him open to the charge of rashness, but the work is undertaken simply from a desire to set forth the truth on a subject that is extremely difficult and complicated.

That Mr. Mill confines himself to the restricted view of labour as stated above, a few extracts from his work will abundantly

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[1] Wealth of Nations." Chapter III. Book 1.

show. The quotations are from "Principles of Political
"Economy," book i., chapter x., "Of the Law of the increase of
"Labour." The steps of his argument are as follows:—

"Production is not a fixed, but an increasing thing. * *
" * Nothing in Political Economy can be of more importance
" than to ascertain the law of this increase of production;
" the conditions to which it is subject; whether it has practically
" any limits, and what these are. * * * * *
" We have seen that the essential requisites of production are
" three,—labour, capital, and natural agents; the term capital,
" including all external and physicial requisites which are products
" of labour, the term natural agents all those which are
" not. * * * We may say then, without a greater
" stretch of language than under the necessary explanations is
" permissible, that the requisites of production are labour, capital,
" and land. The increase of production, therefore, depends on
the properties of these elements. It is a result of the increase,
" either of the elements themselves or of their productiveness.
" The law of the increase of production must be a consequence of
" the laws of these elements; the limits of the increase of production
" must be the limits, whatever they are, set by those laws.
" We proceed to consider the three elements successively, with
" reference to this effect; or in other words, the law of the
" increase of production, viewed in respect of its dependence,
" first on labour, secondly on capital, and lastly on land."

"The increase of labour is the increase of mankind; of population."

Mr. Mill then proceeds to discuss all the various circumstances and conditions governing the increase of population; the questions of natural fecundity, of marriage, of the circumstances that encourage or check marriage; of the circumstances that conduce to the production, rearing and maintenance of large or small families, etc. In view of what we have been considering, this view of labour is utterly fallacious, and when extended logically —as it is by Mr. Mill—to the question of wages, cost of production, etc., inevitably leads to false conclusions. The increase of labour is *not* the increase of mankind. It is the increase of the application of the energy of motion to matter, but that energy of motion is not necessarily the energy of human beings. By the discovery of how to convert the energy of heat into work a large addition has been made to the amount of labour done in the world, without any increase in the amount of human labour performed,—nay rather, with a concomitant decrease of human labour. A simple invention that secured some of the heat that at present, with our imperfect engines, escapes and is lost, and converted this heat into work, would be an increase of labour; and this without any increase of human workers, or even of the quantity of fuel consumed. This is a matter of such very day occurrence, that people are prone to miss the true significance of the large, broad facts that lie constantly before them. The work of conveying goods from place to place on land is now carried on to an extent never before seen in the world; the labour expended in this is far greater than ever before; but this labour is mainly fuel energy, not human energy. The engine driver, conductor and brakemen on a freight train, are there merely for the purpose of controlling and managing the energy of the fuel; the actual work—the labour of moving the train—is done by this energy and not by the men who control it, just as the foreman of a gang of labourers merely controls and directs the energy of the labourers; the work is done by them, not by the foreman. Adam Smith, with the data at his command would pronounce it impossible that the common necessaries of life could be transported hundreds of miles overland to supply the wants of a large town population; the cost of the labour involved in the transaction; the expense of the hundreds of men and horses needed for the work; would be so great that the town population could not afford to purchase the necessaries of life, in other words they could not exist; and therefore large towns could only grow near the sea coast or on the banks of—or close to—navigable rivers. But by dispensing with this costly human and animal labour, by substituting for it a much cheaper and far more efficient kind of labour, the work that was in Adam Smith's time utterly impossible, is now done every day all over the world, and is so common place a matter that it scarcely attracts any attention. Cheap labour is essential to cheap production, and cheap production is a pre-requisite to the general dissemination among mankind of those comforts, conveniences and luxuries of human life that are essential to the improvement of the race. But cheap labour is not synonymous with low wages, as economists have taught; nor is it synonymous with greater productiveness on the part of the toiling millions. Low wages produce comfort and luxury for one portion of humanity at the expense of the other, and that other by far the larger portion. The workers on low wages, by reason of their small remuneration, could not enjoy the fruits of their labour. Low wages in the long distant past produced the magnificence and luxury of Egypt, Greece and Rome; but what masses of festering, degraded, enslaved, and crushed humanity underlay that gorgeous exterior! The cheap labour that will make the world better and happier—that will elevate humanity—consists in substituting a totally different kind of energy from human energy for the doing of all the coarse and slavish kind of work in the world; it means making coal work, instead of coolies. Electricity and the steam engine will effect the emancipation of labour.

To say, as Mr. Mill does, "that the increase of labour is the increase of mankind," is to ignore the progress that the world has made in scientific knowledge, and in the practical application of that knowledge, during the present century. To argue that increase of production, resulting from increase of labour, can be brought about only by an increase of human labourers, or an increase in their efficiency, is to lose sight of what men of science have been doing during the past 50 years. Labour has increased and production has increased, not by adding to the laborers, but by dispensing with the labourers; not by rendering their labour more efficient, but by using a different source whence to derive the energy their bodies formerly supplied. To attempt at the present day to furnish all the labour required to carry on the world's daily life, from the energy of men and animals would result in the complete break down of the social machine. Every large town would in a short time be reduced to starvation. The share of the world's labour that is now borne by fuel energy is almost beyond our power to measure; but if any catastrophe were suddenly to deprive us of this power, and we were to be reduced to the energy of men and animals to carry on our work, we would then realize how labour has been silently and steadily increasing during past years independently of human labourers. To continue all the land-carrying trade of the world with men and horses only, to do all our factory work, spinning, weaving, sawing, turning, iron working, etc., with only the energy of man, would be an utter impossibility. Already the world is absolutely dependent upon the energy of fuel to do its work, and to ignore this energy and this labour in any treatise upon Political Economy is certain to land us in false conclusions.

Labour, in the world of work and trade, now means to a very large extent applying the energy of fuel to matter; human labour is being gradually and steadily relegated to the higher work of guiding and controlling fuel energy. As Nasmyth, the inventor of the steam hammer pointed out, "What every mechanical workman has to do, and what every boy can do, is not " to work himself, but to superintend the beautiful labour of the " machine."[1] Every year sees a larger amount of the labour of the world performed by fuel energy; a larger amount of this

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[1] Nasmyth's evidence before the Trades-Union Commission, quoted by Karl Marx, "Capital" Vol. II: Chap. XV., p. 268.

energy substituted for human energy. In the future, to an extent now unforeseen by us, the work of the world will be done by fuel energy, or at least by energy other than human; human energy will be almost solely employed in merely directing and controlling the inanimate energy of fuel or electricity. The cheap labour resulting from this wide application of energy, will not only largely decrease the cost of production of commodities, but will also largely increase the quantity produced. Commodities will therefore be more widely disseminated among mankind; in other words a far larger portion of the human race will enjoy the comforts and luxuries of life then at present enjoy them. What are luxuries now—far beyond the reach of the poorer classes—will then be necessaries at the service of all. The work of the human toilers will be in a far greater degree than at present, merely directive, controlling and managing the inanimate energy that labours. Humanity will be lifted to a higher plane, removed from the brute-like toil that has constituted the daily life of millions in past ages.

The distinct tendency of modern times, since the introduction of fuel energy, is towards a rise of wages and a fall in the price of commodities. Production in these days is a very inexact index of the quantity of human labour employed in any trade. It is first necessary to know what sort of energy is used in turning out the commodities. Increase of production is now most frequently accompanied by a large reduction of human labour employed. More "foot pounds" of work are of course done in turning out the greater production, but these foot pounds are obtained from coal, and not from labourers. What is necessary to low cost of production is cheap labour: we have obtained cheap labour in fuel energy—not in low wages. The cheap fuel labour of these modern days is coincident with higher wages, and greater comfort among the labouring classes than has ever before been seen in the world.

Mr. David A. Wells, in his book entitled "Recent Economic Changes"[1]—a book that is full of most interesting reading to engineers—has collected a great many facts proving the truth of the foregoing statements. Even within the last fifteen or twenty years, to go no further back, great changes have been effected in the substitution of fuel energy for human energy. During so brief and so recent a period as this, fuel energy has (in the United States) displaced human energy to the extent of forty-five per cent in the making of agricultural implements; fifty per cent in the making of shoes; about forty-five per cent in the making of carriages, and thirty per cent in the making of machines and machinery.[1] In the cotton mills of Rhode Island, in 1886 as compared with 1840, eighty per cent of human energy has been displaced by fuel energy, calculating from the production,[2] while wages have increased sixty per cent. Perhaps the most striking example of the change that has taken place, and is still taking place, is to be found in the manufacture of pins. Adam Smith, in the "Wealth of Nations,"[3] writing in 1776, shows that then, as the result of the division of labour, ten men could in a day turn out 48,000 pins; and Smith points to this as a wonderful result from a very simple cause; as no doubt it is. Mr. Wells prints this passage from the "Wealth of Nations" in a parallel column with an extract from a report to the United States Government, made in 1888, on Technical Education;[4] which report shows that now, in a factory where seventy pin making machines were at work, tended by only five men in all, 7,500,000 pins are turned out per diem. To do this amount of work in Smith's day the labour of one hundred and fifty-six men would have been required; now only five, and these five merely for the purpose of guiding and controlling the fuel energy. In this in-

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[1] New York: D. Appleton & Co., 1890.

[2] "Recent Economic Changes," p. 28, note. The above calculations have been made from data furnished in Mr. Wells' note.

[3] Ibid: p. 50. 3 "Wealth of Nations." Book I. Chapter I.

[4] Recent Economic Changes," p. 59. The report is by U. S. Consul Schoenhoff.

stance practically the whole labour has been displaced by fuel labour. We may assume that the same amount of "work" is done, of "foot pounds" absorbed, in making 7,500,000 pins to-day as in Smith's day; but there is this difference, that now we obtain our foot pounds from the energy of heat evolved in the combustion of fuel, whereas in Smith's time it was obtained from the food consumed by one hundred and fifty-six men. Numerous other instances, all shewing the same tendency to substitute fuel energy for human energy in the doing of work, could be furnished; and the reason for this substitution, and the effect of it, is always the same, viz., to reduce the cost of production of commodities.

Perhaps it may be objected that such displacement of human labour by fuel labour is not beneficial to the human race; that the workers thus thrown out of employment are necessarily placed in hard straits. But this objection, though at first sight reasonable, is not valid. Though the workers are displaced in particular handicrafts and occupations, yet the great increase of production caused by the employment of fuel labour in such trades, causes a vast development of employment for human labour in related occupations and trades. The introduction of fuel labour has been of great benefit to the human race, as is shown by the unparalleled increase of population that has taken place during the present century since the introduction of fuel labour. Population will increase just as fast as, and no faster than, the means of subsistence increase. Now the effect of the introduction of fuel labour has been largely to reduce the price of commodities, and to increase wages; in other words, the means of subsistence has been brought within the reach of a much larger number of people than formerly, and have been supplied more amply and fully. Therefore, population should increase. That it has increased wonderfully, statistics amply prove. In the 300 years from 1300 to 1600, the population of England and Wales did not double (2,500,000 to 4,812,000); in the 200 years from 1600 to 1800, it did not double (4,812,000 to 9,335,000); but between 1801 and 1888, it has increased over three times (9,335,000 to 28,600,000), besides the very large numbers that have been thrown off by emigration. The nineteenth century has been much more favourable to the expansion of the human race than any preceding century, because the introduction of fuel labour has rendered the means of subsistence so much more easily attained.

To the Engineer—the Civil or Mechanical Engineer—the view of labour set forth in the preceding pages can hardly fail to be of interest. Our work consists mainly of devising means for substituting other energy for human, in the doing of all kinds of work, and in preparing ways for the more complete attainment of this. All kinds of steam-driven, hydraulic or electrical machinery, have this object in view; so too, has the construction of all railways, canals, electrical railways, cable car systems, etc. The root idea is always to economise energy, to substitute a less costly for a more costly energy, to make the energy we are at present using do more work if possible than it formerly did. The effect of this is to reduce the cost of producing those commodities that are necessary for the sustaining and developing of human life, and to supply those commodities in greater profusion. Our work has been so thoroughly done,—triple expansion marine engines have so reduced the cost of conveying commodities, and cheap energy the cost of producing them—that politicians have felt themselves called upon to interfere, and by taxation to nullify the results that our labours would otherwise produce. "Protection," as it is called, counteracts what science achieves. But the discussion of this would lead to matters foreign to a society of engineers; and, therefore, having reached this point, this already lengthy paper may fittingly be brought to a conclusion.

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