The power to tell time

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Electric clocks have been in use for years, and now electric watches have come into widespread use. We wish to call the attention of teachers to the comparisons of the costs in dollars to the individual and the cost in energy to the national economy of these two instruments for telling time. We hope that these calculations will be introduced to students to improve their understanding of the costs.

A typical electric clock (110 V, 60 Hz) consumes 4 W of power. (Newer clocks consume only 2.5 W.) A 4-W clock will consume $4 \times 10^{-3} \times 24 \times 365 = 35$ kWh of energy per year. If this energy costs \$0.08 per kWh, the cost of operating a 4-W clock for a year is \$2.80. A typical battery for operating an electric watch (the Mallory W2) sells for about \$3 and will operate the watch for approximately one year. Thus we see that the annual dollar cost of operation of the electric clock and the electric watch are roughly the same.

Let us estimate the power required to operate the

electric watch so that it can be compared with the 4 W needed for a clock. The electrical characteristics of the Mallory W2 battery are shown in Fig. 1. The total energy available from this battery is $1.32\text{V} \times 1.04 \times 10^{-4}\text{A} \times 800$ hr $\times$ 3600 sec/hr = 395 J or 1.1×10^{-4} kWh. Thus an electric watch uses energy at a rate of approximately one joule per day. If this watch battery costs \$3 for 1.1×10^{-4} kWh of energy, *the cost of energy is roughly 27 thousand dollars per kWh*!

If this battery can operate a watch for a year (8760 hours) the average current will be much less than the 104 microamperes (μA) of the test data of Fig. 1, and will be $1.04 \times 10^{-4} \times 800/8760 = 9.5 \times 10^{-6}$ A. The average power used by the watch would then be $1.32 \text{ V} \times 9.5 \times 10^{-6} \text{ A} = 1.25 \times 10^{-5}$ W. Even though the clock consumes 3.2×10^5 times as much power as the watch, the clock performs far fewer functions than does the watch. The clock merely counts the number of cycles in an alternating current whose frequency is determined elsewhere, while the watch operates its own internal frequency standard whose cycles it counts.

Let us estimate the impact of electric clocks on the energy economy of the United States. If each of the 2.2×10^8 people in the U.S. has one 4-W clock, the total power required is 8.8×10^8 W, or nearly one thousand megawatts! This is approximately the size of the largest fossil fuel electric generating plants that are built today. (See Fig. 2.) Such a generating plant would require chemical potential energy at the rate of three thousand megawatts which would require 4×10^5 kg of coal per hour. This is the equivalent of a coal train of 100 railroad cars every day and it adds up to nearly four million tons of coal a year. This amount of coal would fill a cube 132 m on each edge. For comparison we note that the present rate of coal production in the U.S. is approximately 700 million tons per year. Thus something on the order of one half of one percent of the coal mined in the United States is used to drive our electric clocks. We would guess that the average number of electric clocks in the U.S. is larger than one per person, so the estimates above are probably conservative.

It is interesting to note that if we proposed to supply four watts through the use of these batteries, one battery might last (395 J/battery)/(4 J/sec) = 99 sec. In one year we would require 3.2×10^5 of these batteries which would cost practically one million dollars!

It is of interest to estimate the amount of energy required to manufacture the W2 battery. It is possible to make a crude estimate even though we have no specific data. Industrial energy for manufacturing processes is purchased at a much lower cost than home owners pay for electricity. If we assume that the \$3 cost of the battery went entirely for energy at \$0.05 per kWh we would arrive at the estimate that about 60 kWh of energy went into the manufacture of this battery. Thus something on the order of 2×10^8 J may be used to produce a device that delivers 395 J to an electric watch. One is tempted to paraphrase Sir Winston Churchill, "Probably never in history has so much energy been used by so many people to produce so little." Although we like to think of technology as leading to more efficient ways of doing things, this calculation suggests that technology may lead us to situations of incredible inefficiency. The intrinsic efficiency of the

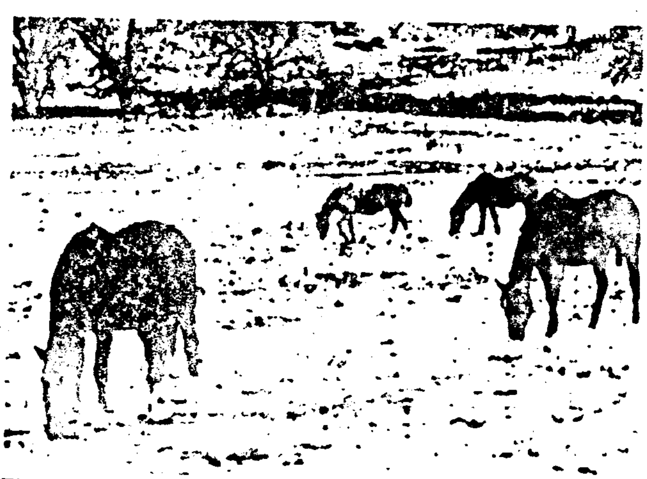

Fig. 3. Four horsepower would replace the electric generating plant of Fig. 2 if one 4-W electric clock per person in the U.S. were replaced by clocks using no more power than is required by today's electric watches.

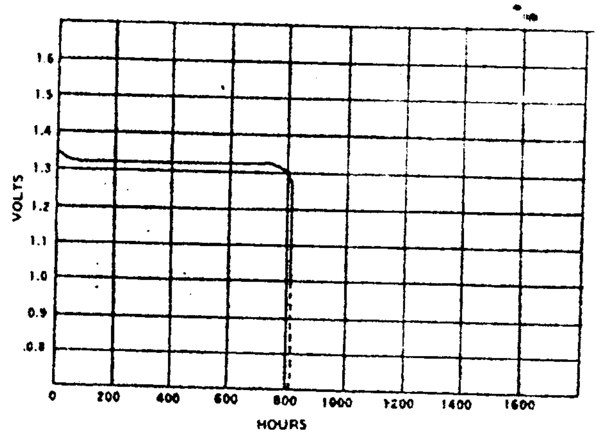

Fig. 1. This is a typical discharge curve of voltage vs time for the Mallory W2 battery for electric watches. The current in this standard test is 104 μA into a 13 000 Ω load at 21° C (70° F). In normal use in a watch this battery supplies a current of approximately 10 μA for a year.

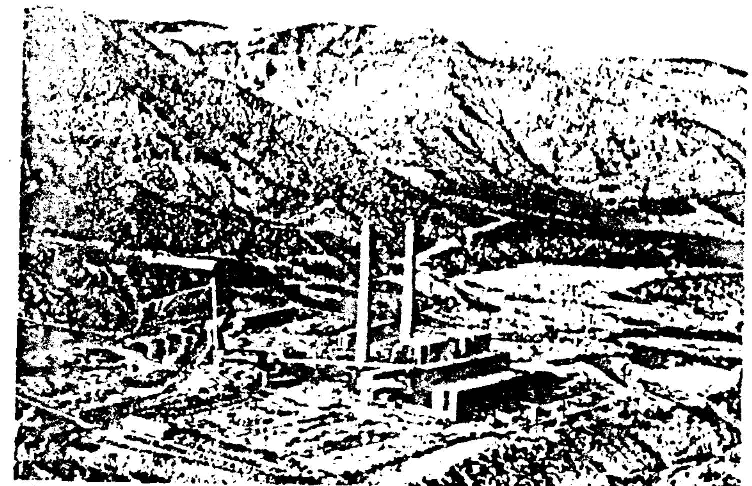

Fig. 2. The Huntington Canyon coal-fired electric generating plant of the Utah Power and Light Company. The generating capacity is 900 MW. Fuel is mined in the canyon at the left and the 345 kV switchyard is just above and to the right of the plant in this picture. It is estimated that the full electric output of a plant such as this is required to operate one 4-W electric clock per person in the United States.

mechanism of the electric watch is probably completely cancelled by the manufacturing inefficiency of the battery needed to operate the watch. This is in accord with our earlier estimate that the annual operating costs of the electric clock and the electric watch are approximately the same.

Let us now estimate the power needed to operate one clock per person in the United States if all clocks used the same power as the electric watch. The answer is $2.2 \times 10^8 \times 1.25 \times 10^{-5} = 2750$ W, or less than four horsepower! Instead of requiring 100 railroad cars of coal a day, we would have a situation where one railroad carload of coal could supply energy to all of these clocks for over 5 years! It is clear that our nation could make significant savings in energy if the existing technology of electric watches was applied to the development of electric clocks.

If 4-W electric clocks were all replaced by clocks that used no more power than is used by an electric watch, the power saving would be essentially 4 W per clock or 35 kWh per year for every clock that is replaced. If an efficient electronic clock costs \$10 more than the 4-W clock the extra energy needed to manufacture the efficient clock can be estimated by the argument used above. It is roughly \$10/\$0.05 per kWh or 200 kWh. Thus the efficient clock would have to operate 200 kWh/35kWh per year or 6 years in order that the energy savings equal the extra energy required to manufacture the more efficient clocks.

It is very instructive for students to recognize that one can make order-of-magnitude estimates of the energy required to manufacture a product by means of this very simple calculation. It is also instructive for students to estimate the amount of savings for various growth scenarios. For instance, the electric power requirements of the U.S. have grown 7% per year for a century. If the number of 4-W clocks grew at this rate for the next 50 years (which is roughly the life expectancy of today's students) the power required for clocks would double every decade and would increase by a factor of $2^5 = 32$. Clocks would then be requiring 32 000 MW. This would correspond to 16% of our present day rate of mining coal!

Our electric watches are fantastically accurate, but we suspect that they have had little effect on our lives because we generally use them to tell us, with great precision, how late we are for appointments. For most of our purposes one hardly needs more than an old fashioned watch that is wound by hand, which makes very little drain on our nation's energy resources, and which is, in a way, a work of art.

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