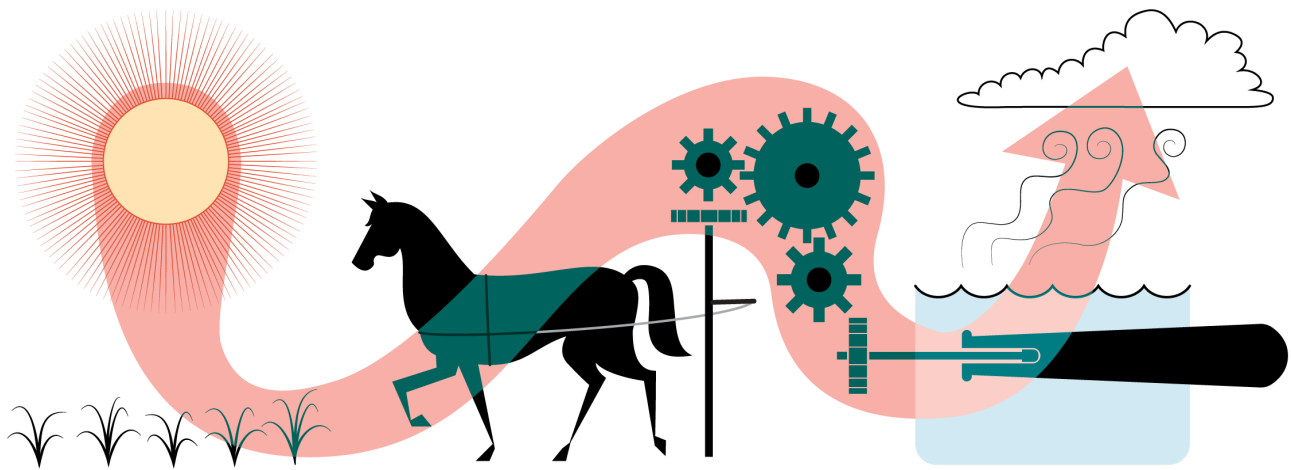


# Teacher Tune-up

## Quick Content Refresher for Busy Professionals

### What is Energy Transfer?



In a sense, the very concept of energy depends on the recognition of its transfers and transformations. That claim might seem odd. Isn't the essence of energy *work*? After all, energy is the capacity to do work (which is, in physics, the application of a force over a distance). And how can transfer and transformation underwrite the concept of energy when potential energy can sit quietly for centuries (as a pebble perched on a ledge, or a chemical bond locked in a lump of coal)?

But consider: until very recently, people did all sorts of physical work, and built ingenious machines, and burned fuel, and flinched at the flashes and crashes of electrical storms, without conceiving of energy. The deep connection between all these things wasn't apparent. For such a key concept, energy is a remarkably *new* idea. And it became an idea partly because, as the eighteenth century wore into the nineteenth, increasingly accurate and precise instruments enabled scientists to measure something being conserved in the midst of change.

For example, in 1798 Sir Benjamin Thompson, Count von Rumford, published his findings on the mechanical equivalence of heat. The dominant idea about heat at

the time was the caloric theory. A subtle gas called caloric was supposed to inhabit objects and flow through pores in solids and liquids. Caloric was thought to be self-repellent, therefore tending to disperse and to move from hotter objects into colder ones. Scientists tried to weigh caloric, to catch it in the act of coming and going, but it was elusive.

Thompson, a military engineer and scientist, had been supervising the manufacture of cannons in Bavaria. Once the cylindrical form of a cannon was cast, a giant drill bit (driven by a horse mill) was used to bore it hollow. The resulting friction created a tremendous amount of heat, and so a water bath was used to prevent the metal from overheating while the boring was done. In the prevailing caloric model, caloric fluid from the cannon was presumed to escape from the metal into the water, which warmed up and evaporated. Curious, and armed with modern thermometers invented by Daniel Fahrenheit several decades earlier, Thompson decided to measure the temperature of the water. Experimenting with blunt bores that could grind away at the iron cannon indefinitely, he found that one could keep generating enough heat to melt the cannon many times over.

So how could an initially cold iron cannon have contained more than enough heat to melt itself? It didn't make sense. The evidence demanded a new model. Thompson proposed the mechanical equivalence of heat. It was not some rarified fluid squeezed from the iron, but rather the *motion of the bore* that was transferred to the metal and water in the form of heat. Suddenly, it seemed reasonable to do various experiments where you measured motion and measured the heat it could generate, and a pattern began to emerge: there was not only a connection, but a *quantifiable equivalence*.

Something (what?) was being conserved while being transferred from one body to another, and while being transformed from one form (the mechanical motion of a horse-mill-driven bore) to another (heat). The mysterious, hard-to-weigh caloric was elusive because it didn't exist. Heat wasn't stuff; heat was the thermal form of something more general that could assume various guises.

It wasn't just mechanical motion transforming into heat. All sorts of measurements were linking formerly disparate phenomena in ways that revealed a new equivalency among them all. A new concept was brewing in the data, and it would need a word.

In 1740, Gabrielle-Émilie Le Tonnelier de Breteuil, marquise du Châtelet had identified an important quantity,  $\frac{1}{2} mv^2$  (an object's mass times the square of its velocity, divided by two); she called it *la quantité de motion*—the quantity of motion—disentangling it from Newton's earlier *mv*, or momentum (mass times velocity). In 1802, speaking before the Royal Society of London, Thomas Young gave du Châtelet's quantity its modern name: "The product of the mass of a body into the square of its velocity may properly be termed its energy."

This  $\frac{1}{2} mv^2$  is what we now call *kinetic* energy, or the energy of motion. We call the energy measured with thermometers *thermal* energy, and understand Thompson's conversion of mechanical energy into heat in terms of a kinetic theory of heat (random motion at the particulate scale of atoms and molecules).

Because of a wealth of accumulated empirical evidence, we also now know that the transformation of mechanical energy into thermal energy in Thompson's experiment is just one verse in a song that extends backward and forward: colliding hydrogen atoms in the sun fuse into helium atoms, converting matter into energy at the extravagant exchange rate signified by the formula  $E = mc^2$ . Sunlight radiates to earth, falling upon a field of oats that convert its electromagnetic energy into chemical potential energy through photosynthesis (with some thermal energy lost to the

atmosphere). A horse eats the oats, and through cellular respiration transforms the oats' chemical energy into muscular motion (with some more thermal energy lost to the atmosphere). The horse clops around in circles, pushing the shaft that turns the gears that drive the bore that grinds at the mouth of an iron cannon. The friction heats the cannon, which heats its bath of water. The water evaporates; the hot steam beats back the molecules in the cooler surrounding air, working (applying force over distance) to claim more space, and thus becomes less dense and ascends by convection.

At every step along the way (in the metabolism of oats and horse, and in the grinding gears of the horse mill), entropy takes its toll, diverting some of the organized, useful energy into disorganized thermal energy. The stream of energy we've been tracing becomes lost in the ambient temperature of the atmosphere. But it's still there, or else re-radiated into space as infrared light, conserved one way or another. And its conservation, its quantitative consistency across its many manifestations, is the reason scientists name it and believe in it.