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Conservation, confusion and language

In which, because nothing consumes energy and 'the first step to wisdom is getting things by their right names', we wonder why we have again allowed words to confound understanding

Sitting on a hillside we realized Earth doesn't consume energy. It should be no surprise that neither do we. Nor does our energy system. Nor does anything.

So why do we confuse our children? Schools preach the righteousness of energy conservation — and simultaneously teach that energy conservation as an inviolate law of nature. Why do we exhort young people to feel pious about doing something nature does anyway? Do we believe ourselves so omnipotent that nature needs our moral support?

Over the past two hundred years we have come to realize that nature designed its universe with surprisingly few fundamental rules.[1] We call these rules nature's laws. They govern how the universe is assembled and how it behaves. The most sweeping of these laws exhibit an exquisite simplicity. And of these, one of the first discovered is the law that energy is conserved. Repeatedly, we have proven to ourselves that nature designed our universe to work that way. We didn't set the rule. We merely learned what nature decreed.

Let's take a moment to say, as straightforwardly as possible, what the law of energy conservation *means*.

It means that energy can never be 'used up', never destroyed, never consumed. But while never consumed, it can certainly change from one *kind* of energy to another — because energy can exist in many guises. Sometimes it stays in one form for billions of years. But in the right circumstances it can change from one form to another in a wink.

The century between the 1830s and 1930s was a time when people rapidly uncovered nature's fundamental rules. During these hundred years, our faith in the *fact* of energy conservation was sometimes shaken. But whenever that happened, whenever some observation made it seem that energy conservation might be violated, we always found we'd made a mistake. These mistakes were usually rooted in not knowing that nature had another trick for *storing* energy — a way our ignorance had hidden from us. Then, having learned about this new mode of energy storage, the law of energy conservation came out unscathed — came out sitting there smugly, in supreme control.

For example, this happened when we learned that matter, itself, was a form of stored energy. Learning that truth led to understanding nuclear energy — because what we call nuclear energy is simply annihilating material to produce other forms of energy, like heat and light. It is the energy conversion process of the stars, and therefore the process that powers our universe.[2]

[1] Sue, my speech-language pathologist daughter, said, upon reading this sentence "By the way, this has striking similarities to the way humans develop languages." My guess is that others, in widely diverse fields, might feel the same.

[2] Understanding that mass could be converted to more 'usual' forms of energy, like heat, led to our hopes for the peaceful use of nuclear power and to a myriad of often invisible benefits to human well being — benefits now becoming indispensable. It also led to nuclear weaponry. At the cusp of the 21st century it is fashionable to hate the invention of nuclear weapons. But it is war we should hate. Although seldom admitted, nuclear weapons have, so far, greatly diminished the number of people who have suffered and been killed in wars. This started with Hiroshima and Nagasaki. Without those two horrors, it is certain that many more Japanese would have died before WWII ended, and more GIs, Kiwis, Brits, Aussies, Canucks ... as the war slowly ground up lives, island by island and then moved into mainland Japan itself. We oft-forget that more people died in a single night's firebombing of Dresden than died in Hiroshima and Nagasaki combined — and probably more died in the fire-bombings of Tokyo. After WWII the prospect of nuclear annihilation prevented more wars — at least large worldwide wars. We should direct our hate towards war itself — not towards horrific weapons that might have, for a while, persuaded some of us to be peaceful. Above all, we should be intelligent enough to discriminate between beneficial things like nuclear power or nuclear medicine, and nuclear weaponry.

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We should next identify a few ways nature stores energy.

Kinetic energy is the energy something carries by virtue of its speed — like the kinetic energy of a speeding bullet, car or train.

Potential energy (due to gravity) is the energy something has by virtue of its elevation — like the potential energy a famous apple had while clinging to a tree, which when the apple lost its grip, caused the apple to bonk Newton's head.

Electromagnetic energy is energy stored in an electromagnetic field by virtue of the field's intensity — like the energy stored in the capacitor within your car's ignition system and then 'spent' to make the spark.

Chemical energy is stored in material by virtue of the material being out of chemical equilibrium with its environment — like the chemical energy in gasoline that is changed into thermal energy when it's burned.

Thermal energy is stored in material by virtue of the vibrational energies of atoms that constitute the material. Thermal energy is what many people call 'heat' — which may help you know what I'm talking about but, in fact, is not correct. The correct thermodynamic name for this mode of energy storage is 'internal' energy. But I decided to avoid the term 'internal' energy because it could be confused with chemical[3] energy that, of course, is also stored internally within material but is identified separately. I hope 'thermal' energy makes sense for most people.[4]

Nature has many more tricks for storing energy, but this is a reasonable list for now.

In contrast to the many ways nature stores energy, nature has only three ways to move energy from place to place.

Heat is the first method. Heat is energy flowing from one location to a second because the first is hotter than the second. One example is energy carried from your stove to your soup because the stove is hotter than the soup. When heat moves through materials — like the stove's heating element and the pot — it's called 'conduction' heat transfer. But heat can also move energy from hotter to colder locations without the use of intervening material. Then it's called 'radiation' heat transfer. Sunlight is the most obvious example of radiation heat transfer — moving energy from a hotter sun to a cooler Earth. The important thing to remember is that heat is energy in motion from one place to another caused by temperature differences. It is not energy stored within material.[5]

Work is the second way energy can move from one location to another. Doing work, your car's transmission transfers energy from the engine to the wheels. A ski lift does work carrying a skier to the top of a ski run — thereby pushing energy from the bottom of the mountain to the top because skiers at the top have more gravitational potential energy than do skiers at the bottom. Work transactions are, by far, the *most significant* deliverable of today's energy systems. The work of mining ore, flying airplanes, pulling trains or pushing ships. And because electricity is ersatz work,[6] our energy system provides the work of running computers, TV sets and CAT-scan machines. Of course I'm using 'work' in its technical sense of lifting or pushing[7] — not in the sense of intellectual work like thinking.

Material movement is the third method of transporting energy. All materials contain thermal energy. Material may also contain chemical, kinetic, electromagnetic, or other forms of energy. The point is that whatever energy is contained within the material will of course be carried along by the material.

A special case of energy carried within moving material is called convection, or convective heat transfer.

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[3] Besides chemical energy, several other energy forms are stored within material, like magnetic field energy if the material is magnetized, or strain energy within a stretched elastic band.

[4] Thermal energy also includes the energy of intermolecular forces and any form of microscopically stored energy that might be moved by heat transfer caused by a temperature difference to, or from, the material. Still, it is probably easiest to think of it as molecular vibration energy. I've said that in lay language it is common to speak of thermal energy as 'heat'. But heat is *not a mode of energy storage*. Rather it is the word used to describe energy *moving* from one location to another by virtue of a temperature difference.

[5] Thermodynamics texts say heat transfer can occur by three modes; conduction, radiation and *convection*. In this paragraph, I have emphasized two, conduction and radiation. That's because convection is a special case of energy transport by material movement. Convection occurs when there is a temperature difference between locations over which the material is moving *and* when we only refer to thermal energy transport, not potential, electromagnetic, etc. I described it this way to keep things as simple as possible but not simpler. I hope it works for most readers.

[6] An explanation will come in a forthcoming IJHE article.

[7] For technical folks, it is fun to remember that work is always the product of an intensive property (a generalized force) multiplied by the change in a cognate extensive property (a generalized displacement). This is perhaps most familiar in the form of an 'everyday' force times an 'everyday' displacement, written in vector format as: $W = \mathbf{F}\,\Delta\mathbf{r}$. But it can be a product of more abstract generalized forces, like pressure, multiplied by change in volume, such that $W = p\Delta v$, or surface tension multiplied by the change in surface area, and so on.

Convection is the transport of thermal energy within a moving fluid — either a gas or liquid — between locations that have different temperatures. One example of convection is the mechanism your car uses to transfer excess thermal energy from the engine's hot cylinders to the radiator. In this case the engine's coolant is the moving fluid. Then, once the thermal energy is in the radiator, convection using the passing air carries it away to the surroundings. Another example is the mechanism a cool breeze uses to carry heat away from your body. It's especially effective if you're bald (like me), not wearing a hat and it's a cold winter's day.

Having identified the bits and pieces of energy storage and transport, we can have a lot of fun watching the processes nature uses to assure energy is never consumed — watching energy transferred to here, then to there and then plunked down somewhere else.

A car comes round a bend speeding toward a stoplight. It contains a lot of kinetic energy by virtue of its velocity. Some of that energy could smash you if you were foolish or unlucky enough to get in its way. This time there are no unpleasantries. But the light goes red. Brakes bring the car to an orderly stop. To slow down, the car's kinetic energy must be removed — changed into some other form and sent somewhere else. First, heat transfer moves it to the brake drums and pads where it appears as thermal energy. Then most of it is pushed out to the surrounding air (by convective heat transfer) with some slithering off into the axles and wheels (by conductive heat transfer). Later, as the car waits responsibly at the stoplight, its kinetic energy is gone but none of that energy was consumed. Rather it has simply changed its location and form, it now resides as thermal energy within the brakes, wheels, axials and surrounding air.

The increased thermal energy in the brakes means that the brake's molecules are wiggling and waggling more vigorously — hot molecules. You can sense this if you put your hand on the brake disk or pad. Some of the brake's molecular exuberance will be transferred to the molecules in your hand, making the molecules of your hand exuberant too. Then, information about agitated molecules in your hand is telegraphed to your brain — so your brain can tell you that you've just touched something hot, something made up of feverish molecules.

That's the story so far. But let's continue following this energy. We know it can't be changed back into the car's kinetic energy. Thermal energy extracted by cooling the warmed air, wheels and axials can't magically be used to accelerate away from the stoplight. To accelerate we need more energy from the car's fuel. In a later IJHE article we'll talk about *why* we can't use the energy from cooling brakes and must use energy from the fuel. But we know that because the energy in the brakes can't be destroyed it *must* go other places and do other things.

Engineers don't want this thermal energy to stay in the brake material because if it did the brakes will get hotter and hotter with each stoplight, or suddenly appearing skate-boarder. So they design brakes with fins and other means to speed the transfer of thermal energy to the outside world. To help cars tolerate erratic drivers who roar away from one stoplight to screech to a halt at the next, engineers make the brake drums, disks and pads of materials that can resist high temperatures. By tolerating high temperatures, the brakes have more time to push their newly acquired thermal energy into the air — extra time to squeeze it out as heat before the brakes fail from thermal overload.

And so on it goes.

The energy we've been following, now stored as thermal energy of warm air, joins other energy already in the atmosphere. Carried by this marvelous atmospheric conveyor belt — 'convection' belt if you like — this energy embarks on voyages round the world, sometimes helping to build winds or waves or storms that, in turn, can power sailboats or windmills or knock down trees. After all these adventures, the energy we began following when it was the car's kinetic energy is exported to the universe as infrared radiation — sent off on a voyage to engage different worlds, in different corners of the universe, where it will set about doing different tricks.

Of course we've been following where the energy *went*, or might have gone. We haven't speculated on *from whence it came*. You can do that yourself. But you must be prepared for some heavy-duty speculation because, before it became the car's kinetic energy, it had been travelling from one place to another, changing from one form or another, for a very long time. Indeed, it had been travelling hither, thither and yon since the Big Bang brought our universe into existence. It's thought that happened somewhere between 10 and 20 billion years ago. So that little bit of energy has an impressive résumé.

But let's pull back from the deep past. Let's stay with brakes.

People interested in the history of railways know that brakes and wheel bearings have a special place in that history — and gave the fellows in the caboose a special job. Their job was to watch for overheating wheels that might cause structural failures. They would look ahead watching for smoke coming from wheels, especially as the train went round a bend. And when trains stopped they would walk the length of the train feeling the temperature of the wheels looking for 'hot boxes'.

Today, 'tonnage' trains leave the Great Plains of North America, climb westward over the Rocky Mountains and

slide down the other side towards tidewater, carrying wheat, potash, coal and other commodities to waiting ships. By virtue of its altitude, a tonnage train at the Great Divide has a lot of potential energy. You don't want all this potential energy converted into kinetic energy as the train runs down the mountains, or, as it approaches the Pacific it will be in a lot of trouble — and give things in its way a lot of trouble. Let's get a feeling for how much trouble. If a train's potential energy is fully converted to kinetic energy, a train leaving the 7089-foot high Donner pass in the United States would enter San Francisco at 452 mph. Or a train leaving the 1627-meter high Kicking Horse Pass in Canada would come round the bend and into Vancouver or Prince Rupert at 643 km/h.

To avoid these speeds, we must continuously extract potential energy as the train descends, pitch it out in the form of thermal energy, warm the passing air. That means trains must not descend mountains faster than the brakes can absorb potential energy — *and* then shed the energy as heat — while the train loses altitude. If the brakes absorb potential energy any faster, the heat flow from the wheels can't keep up — and they can explode. Not nice. For this reason, it turns out that fully loaded tonnage trains descending maximum railway grades are typically restricted to speeds below about 50 km/h.

Could these ideas save your life? You bet.

If you're driving down a mountain road you should be mindful of this same phenomenon. 'Speed kills' is the safety slogan. And killing speed carries a double whammy when you're coming down a mountain. Because if you want to stop, the brakes must not simply extract your car's kinetic energy, they must *simultaneously* absorb potential energy to account for decreasing altitude. Burdened with this double task, it takes the brakes much longer to bring you to a stop. It gives more time to fly off the edge or hit a moose.

Let us return to trains. Down-bound locomotives have another trick to shed potential energy. Diesel locomotives are *diesel–electric* locomotives. The diesel engines drive electrical generators that make electricity to power electric motors on the axles. However, with the flick of a switch, the engineer of a down-bound locomotive can change the motors so they operate as generators. Behaving as generators, these erstwhile motors suck potential energy out of the train and convert it into electricity. But unlike the product of most generators, this electricity is not used to turn wheels or run TV sets. Rather, by *making* electricity, the locomotive has another way to *get rid* of energy. The electricity is sent to the roof of the loco and run through large electrical resistors — railway men call them toasters — where it is changed into toaster thermal energy. The increased thermal energy pushes up toaster temperature. Finally, the higher temperature squeezes the thermal energy out into the atmosphere.[8]

It's all very simple. Similar energy transitions are happening all the time. It is what nature decreed when she established a universe where energy is conserved. And I think it's fun to walk through our world watching energy jump, as my favorite authors [1] might say,

> "*from there to here,*
> *from here to there,*
> *funny things are everywhere*."

Which brings me to people who forget that energy is conserved — a misunderstanding abetted by the populist admonition, "we should conserve energy".

These people include inventors of new machines that, the inventors say, *produce* energy. They claim their machines can produce more energy than the machine receives. With the glee of someone about to save the world, the inventors are heard to exclaim, "it will put the oil companies out of business".

After many failures, these inventors are oft drawn to mechanical engineering professors as a court of last resort. Confronted with their tenacious hope, I feel a discomfiting mixture of pity and despair. I don't like to discourage. But encouragement is licence to drain yet more of some family's modest savings into bits of useless wire and wheels scattered about the garage. Almost always the inventors are unwilling to explain to me how the thing works — for fear I'll steal their idea. Almost always they haven't got a patent. Almost always — even without the benefit of an explanation of 'how it works' — if the thing *did* produce energy like the inventors say it does, it would violate

[8] If the trains were fed from an electrical catenary, the electricity made by down-bound trains could be fed back into the catenary to help pull other trains back up the Rockies. Turning to a more futuristic scenario: I was once asked to prepare a report for Canadian National Railways that, in part, was to determine if a down-bound fuel cell locomotive could reverse its fuel cell to operate as an electrolyser. The electrolyser would use electricity (manufactured when the motors were reversed to make them generators) to manufacture hydrogen that could be stored on-board and later used to feed the fuelcell, thereby helping to pull the train back up the mountains on its return journey. The answer was: in principle, yes! But at the time the report was written, fuelcell and H_2 storage technologies would have needed much improvement. I wonder what the study would say today?

nature's law of energy conservation. So the invention can't be doing what the inventor claims it's doing — and often sincerely believes it's doing.

I wish these inventors had understood nature's principle of energy conservation before they purchased their first box of screws. They are most often bright, have the best entrepreneurial spirit, have families standing behind their dream. If they had understood what nature allows and what she doesn't, then, who knows, their inventiveness might have really paid off.

Misguided inventors and their earnest investors are cruel to themselves. But government programs founded on mushy policies like 'energy conservation' are cruel to all of us. Unlike the results of misguided inventors that affect a few families, misnamed government programs burbling conventional wisdom often elevate foolishness into a major economic mistake.

The preposterousness of thinking we need reinforce a fundamental law of nature with statement of moral objective might be explained — well, perhaps not explained but at least better understood — by searching out the origins of the phrase 'energy conservation'.

As so often, the first origin is the careless choice of words — a familiar theme of these chapters. The second article of this series *Turning Out the Lights* [2] talked about foolish actions that resulted when we transformed an 'oil embargo' into an 'energy crisis'. When we use the phase 'energy conservation', I expect most people really mean 'energy efficiency'. I expect they mean they want our energy system to operate as efficiently as possible — in the belief that efficiency means we will use our natural resources as sparingly as possible, to provide the best possible services with the least possible environmental intrusion, at the lowest possible cost. Stated this way, the objective is appropriate and important. Indeed, the pathway to this objective is the pathway to a brighter 21st century.

The second origin of 'energy conservation' comes from thinking of energy as a commodity, like coal or oil. If you believe we could use up all the oil in the ground, then it's reasonable to use it sparingly — to 'conserve' oil in the ground by leaving it there. Although both data and logic persuades that civilization will never run out of coal, oil or natural gas in the way most people think of running out, there are still good reasons to use them sparingly — chief among these is to reduce CO_2 emissions. But that is an idea expressed rather simply by 'reduce oil consumption'. We don't need 'energy conservation'.

When we have a simple, direct phrase like 'energy efficiency', why not use it? Why confuse our children — especially the bright ones so often troubled by paradoxes in adult exhortations — by misnaming this important idea by calling it 'energy conservation'? For that matter, why confuse ourselves?

Early in his book *Consilience*, Edward O. Wilson speaks of the Chinese saying "The first step to wisdom is getting things by their right names" [3]. Upon reading this, it struck me that the objective was wisdom, not mere knowledge. We could easily trivialize 'naming correctly' as no more than the rote memorization of arbitrarily assigned monikers — at best dignified as knowledge but certainly not elevated to wisdom. The ideas of these articles may not break through to wisdom but, with luck, I hope they help understanding. This hope underpins my obsession with getting things by their right names. I was delighted to learn the Chinese thought it important too.

A dandy example of getting things by their wrong names is the admonition that 'conservation is an energy source'. This is a double-barreled shotgun of nonsense.

Pellets from the first barrel splatter muddy thinking on the fundamental principle of energy conservation. Energy conservation must not be hijacked to serve as political slogans. It must be kept firmly on its throne as a central law of nature. It's not good enough to say: "Oh! Everyone knows what we mean by 'conservation is an energy source' " — and go on to say it means to use energy efficiently, or to demand fewer energy services. It is simply not correct to say. "Everyone knows what we *really* mean". Everyone doesn't.

Pellets from the second barrel shatter understanding of what energy sources are and what they aren't. Sometimes people call electricity or hydrogen or gasoline 'energy sources'. They aren't. They have the role of energy currencies. Yet misnaming 'conservation' an 'energy source' is much *more* misleading than calling electricity an energy source. Conservation has no business being identified as any component of the system — it's neither a source, nor currency, nor technology nor service. Naming it part of the energy system chain confuses what energy systems are and how they work.

Use the word 'conservation' where it's meaningful, where it works, where it *is* the right name. Let's try to conserve justice, freedom, above all rationality — and sometimes the last few in a bag of peanuts. But let's rid ourselves of 'conservation is an energy source'.

I was talking about this with my friend Ken Hare when he said, "Muddled language is a specialty of English. You wouldn't find it happening in French." I thought Ken's an interesting idea. I love the English language, with its

freewheeling willingness to adapt, change, and unabashedly import words from other languages. Most English speakers have few hang-ups when our language evolves — often so quickly that the meaning of English words can morph within decades and lose recognition over one's lifetime. ('Gay' had one meaning when I was a child, but quite another today.) Sustaining rivalries between English and French that have lasted from the middle ages, English speakers often smile smugly at what they see to be French language paranoia — sooner or later proving their point by huffing: English doesn't need an *Académie française*.

I enjoy the flexibility of English, enjoy its willingness to import 'foreign' words to help express nuances, enjoy how the great English language magazines like *The New Yorker* continuously expose us to new and creative phraseology, enjoy rereading William Zinsser's chapter on evolving usage in his book *On Writing Well* [4]. Occasionally, I tweak English a bit myself. But sometimes, precision in language, getting things by their right names, is important. Sometimes a little French fussiness would help.

Of course we should know when we can enjoy the license allowed by our rich language and when we must fight to keep ideas precise. And we better know the difference.

Before bidding *au revoir* to these ideas, I'd like to return to the cultural objective, as distinct from the scientific principle, of how 'energy conservation' is misused. Many people intend this phrase to mean, 'reduced energy use'. That is reasonable. But as we've observed before, civilization does not have an insatiable desire for energy — although it may have an insatiable desire for energy services. That truth can be our salvation — for two reasons.

First, at a fundamental level most energy services require little, often zero, energy (if the technologies delivering the service are ideal). Some services could, in principle, even give back energy — like my imaginary return trip from Paris to Victoria described in the fifth article of this series *The Energy System* [5].

Other services, like lifting skiers up a mountain, will always require energy input. But most services, like moving people and goods from one place to another, if the technologies were perfectly efficient would require little or no energy input. It is the *way* services are delivered that requires energy. But there is tomorrow. Nurtured by the creative imagination of our children, grandchildren and great-grandchildren, tomorrow will continue bringing more service for less energy. There is no end in sight.

Second, we must remember that to use energy is not consuming energy. Using energy means extracting from flows of energy that something-of-value we wondered about during our afternoon on a hillside. And so we must channel energy flows — guide them to where we want to extract our something-of-value, to where we want the energy service. However channeling energy usually means channeling material — like coal, or oil, or waste products like CO_2. It is material, not energy, that causes problems. But since moving energy usually means moving material, it follows that using less energy normally means moving less material. So we arrive at a surprising conclusion:

- The environmental rationale for reducing our demand for energy services is to reduce the material flows that accompany energy transactions.

Therefore we should seek ways to move energy without moving a lot of material. Electricity is one way. Hydrogen is pretty good too, because the mass/energy ratio of H_2 is about three times lower than most other fuels. So when we judge the relative benefits and disadvantages of various sustainable energy sources an important question should be:

- What materials will be needed to build the source-to-currency transformer technologies and what material flows will result from its operation?

I have scorned words that dishevel thinking. Yet I don't, necessarily, scorn the intended objectives. Whenever appropriate, using fewer energy services can both clean the place up and enhance lifestyles.

I enjoy riding my bike to work, to downtown, to wherever I can get away with it. Besides the exercise, little things make biking more fun. One route takes me past an elementary school, often about the time the children are hopping, skipping and jumping off to a new day. When on my bike, I exchange smiles and nods of recognition with the pensioner who controls the crosswalk. But if I drive — because I'm late, or it's raining too hard, or I've got some other excuse — although I nod to the crosswalk guard from my steel and glass cocoon, he never sees me. Strange, but I'm saddened to miss this bit of human contact. Biking reduces my call on energy services — but not my quality of life.

But I feel differently when reduced energy services *do* diminish quality of life. There is little value to you, or to society, in sanctimoniously sitting about in the dark shivering — or frying.

We should enjoy life. And while enjoying, we should continue seeking ways to use less energy while providing more service. Rich societies are best positioned to do the finding. Indira Gandhi said, "Poverty is the worst

polluter''. Crackling words, clear message, cutting truth. So let us attack poverty. A straight-up-the-middle attack will be to build better energy systems. But to do that we must understand what better systems are. It will help if we get things by their right names. Because words do shape actions.

This is the eleventh in a series of articles by

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