NUMERACY FOR ENERGY AND ENVIRONMENTAL LAWYERS

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As a beginning lawyer long ago, armed only with a Bachelor of Arts undergraduate degree, I entered the energy field technically illiterate. I have sought over the years to remedy that shortcoming. My subject today is numeracy as one component of energy literacy. Literacy, of course, would require a much broader-based understanding—not only of numbers, but also of the environmental implications, the science, the technology, the economics, and the politics behind them. I do not profess to command that literacy. But we all have to start somewhere. Numbers are a pretty good place to begin, and an arena that we attorneys usually enter challenged.

Only a few years back, I reviewed a proposed contract for a suburban California solar project. The recitals said that the capacity of the project was so many megawatts. Then, a clause buried deep within said that the capacity of the project was so many megawatt-hours. This is far from unusual.

The project was moving very fast. We don't always feel comfortable raising our hand to ask the meaning of some acronym new to us, or why sometimes the MW has a little "t" next to it while sometimes the MW has a little "e" next to it. We're reluctant to slow down hard-charging partners, executives, and bankers for inquiries like that. So we leave those questions unanswered, and nurse them year after year. The condition worsens as a more senior lawyer, when you will *never* want to reveal your ignorance to *anyone*.

But this time I was so bold as to raise the question, only to receive the immediate blunt answer that the recital referred to capacity in terms of *power,* while the clause referred to capacity in terms of *energy*. Embarrassed

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to ask anything further, especially about words so common as energy and power, I left the contract as is.

This article provides some resources that cut through that kind of embarrassment, as it can be read in seclusion (by flashlight if you prefer). The goal is to help us all think as informed lawyers and citizens about the quantitative aspects of energy and environmental issues.

Facts and Contexts

It has been a tough time for facts recently. And I'm not only talking about our political climate. I'm talking about the way in which we derive information in bites.

We see a sentence in some document online that is helpful to our position. It confirms what we already think is the case, or it is helpful for something that we're newly trying to establish. So we copy, paste and use that fact. Alternatively, we see a sentence in isolation that is adverse to us. So we take that sentence in isolation and try to attack it, perhaps by attacking the source (or funder of the source) rather than its content. I'm suggesting the first thing to do with a fact, before using it or warding it off, is to understand it—to appreciate it in a nest of concentric circles. First, what is the quantity that's being expressed? Second, what is the proposition saying the world is like today? And third, what follows from the proposition—how does it explain the past or predict the future and fit with other knowledge that you have or can establish, to provide an overall context?

Robust appreciation of facts is difficult in politics, in literature, in sports, in all sorts of areas that we research. We're forever working with bites. I've often found that after I extract a sentence as evidence (or at least evidence of what the author thinks), I go back to the full document and realize there were some nuances. Those nuances don't get captured when we just pull a sentence off of a screenshot, as opposed to reading and digesting a whole piece or an entire exchange of articles.

Living by the sound bite, however, is particularly or distinctively an issue for energy and environmental facts. I'm going to cite two reasons it's challenging by referencing two icons of culture. One is the Tower of Babel described in chapter eleven of the book of Genesis, where the Almighty confounds the builders by causing them to speak in many different languages. The other is a scene from that 1980s cinematic classic, *Ghostbusters*.

The Tower of Babel

The Tower of Babel is an enduring feature of the complicated world in which we live. Saul Griffith, a prominent inventor and environmental advocate, was proud of the fact that he brought his developed-world rate of consumption of energy way, way down. He hung his laundry out to dry outdoors. He biked to work. Most significantly, instead of flying around by jet to various conferences on global warming, he attended by Skype. He did everything he conceivably could to lower his usage. He naturally wanted to show audiences how he or anyone could do so. He reported, with tongue planted firmly in cheek, that when he described his energy use for different audiences, he had to use a bewildering number of units as shown on Figure 1.

FIGURE 1: HOW COULD PEOPLE POSSIBLY BE CONFUSED?[1]

After conservation	*Measured by*	*Before conservation*
2255 watts	Engineers	14437 watts
2255 joules/second	Physicists	14437 joules/second
194 megajoules (MJ)/day	"the French"	1.15 gigajoules (GJ)/day
54 kilo watt-hours (kWh)/day	Electricity people	321 kWh/day
184 kilo British thermal units (Btu)/day	Air conditioning people	1 million Btu (MMBtu)/day
46 kilo-kilocalories (Kcal)/day	Weight Watchers	276 kilo-Kcal/day
184 pico quadrillion BTU (Quad)/day	U.S. Department of Energy	1 nano Quad/day
1.5 gallons (gal) of gasoline/day	Local service station	9 gal gasoline/day
0.0045 metric tonnes of oil equivalent (TOE)/day	ExxonMobil	0.025 TOE/day
3 horsepower (hp)	My grandfather	18 hp
5.4 metric tonnes (0.0000054 Megatonnes) of CO_2/day	Environmentalists	32.1 metric tonnes of CO_2/day
2.2 billion carbon atoms/nanosecond	Chemists	14 billion carbon atoms/nanosecond

[1] Adapted from *Saul Griffith: Climate Change Recalculated* (The Long Now Foundation 2009).

Griffith started by saying that he had brought his energy rate down from 14,000 watts to 2,000 watts. A physicist, however, might run the same calculations in joules per second. (The French in particular continue to express large quantities of energy output in joules.) Here, a single individual's consumption is stated in gigajoules—billions of joules—each and every day. If you're talking to people who price electricity output, the watts or joules won't register. Instead they might want to know about kilowatt-hours over some quantity of time. If you're talking to those who price natural gas, or the fuel inputs of electricity, it might be in terms of British thermal units or Btus. Chemists might be interested in calories, nutritionists in thousands of calories (kilocalories, or food Calories). If you're talking to petroleum companies, you might speak of the equivalent amount of gasoline or oil; to old-timers or auto enthusiasts, perhaps horsepower.

These entries, in each of the left-hand and right-hand columns, are referring to and measuring *the same thing*. Note that I haven't even mentioned the metric system (Système International, or SI) versus United States or imperial measures. Some of these measures *divide* by time (Btu/day); others *multiply* by time (kilowatt-hour); others simultaneously *multiply and divide* by time (kilowatt-hour/day); and others display *no time unit at all* (watt, horsepower). What is going on?

In addition to different units for the *same* concept, different parts of the industry measure and value *different* concepts. A good example is the trade in liquefied natural gas or LNG. Natural gas is one of the principal fossil fuels, and a favored fossil fuel these days. If the production and destination are in the same region, you can transport it by pipeline. But if you're moving it between continents, you do so by producing the gas in the upstream, bringing it to a coast where you liquefy it by bringing it down to 260 degrees below zero Fahrenheit (−168° C), transporting the liquid in special vessels to another country, gasifying it by reheating back into a gaseous state, and selling and using it in the destination.

FIGURE 2: LNG VALUE CHAIN MEASURES[2]

Activity	*Dimension measured*	*Unit of measurement*
Natural gas exploration	Volume of gas	Trillion cubic feet (Tcf) or cubic meters (Tcm or Tm^3)
Natural gas production and transportation	Volume of gas per day, at "standardized" pressure and temperature	Million (MM) standard cubic feet or cubic meters per day (MMScf/day)
Liquefied natural gas (LNG) liquefaction	Mass of liquid per year (adjusted for shutdowns) or per hour (unadjusted)	Million metric tonnes per annum (MMTPA) or metric tonnes per hour (tph)
LNG storage and transportation	Volume of liquid	Cubic meters (m^3)
LNG regasification, or economics anywhere along value chain when comparing with alternative fuels	Thermal energy content, sometimes of gas and sometimes of liquid	British thermal units (Btu), or therms (100,000 Btu), or million Btu (MMBtu)

On the exploration side, the reservoir engineers are concerned with volumes. They express the quantities in a field in terms of trillions of cubic feet in the United States (or cubic meters elsewhere). They'll talk about the rate of production or transportation of gas as being standard cubic feet per day (scf/day), and storage of gas in standard cubic feet. ("Standard" and the little letter "s" refer to a given pressure and temperature.)

When the gas arrives at the liquefaction plant, the plant engineers don't speak in terms of volume of a gas. What they care most about is the mass of the resulting liquid product that can fit through their vessels and pipes. You've gone from a volume measure of cubic feet or meters, to the processing capacity of an LNG plant in some number of metric tonnes per year, including time for turnarounds, or a rate of so many metric tonnes per hour.[3] It's no longer a daily rate as in the upstream, it's annual or hourly; even the time period is different.

You next get the LNG onto a vessel, where the captain doesn't care about a volume of gas, or a mass of liquid, or a mass per year or per hour.

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[2] *See* SAEID MOKHATAB, JOHN Y. MAK, JALEEL V. VALAPPIL & DAVID A. WOOD, HANDBOOK OF LIQUEFIED NATURAL GAS (2014).

[3] I spell "metric tonnes" thus to help me distinguish that measure (1000 kilograms of mass) from the "short ton" (2000 pounds of weight) used in the U.S. coal industry or "long ton" (2240 pounds) used in some U.S. and U.K. applications. Not everyone does.

The captain cares about volume of liquid, and specifically how many cubic meters of the LNG can be carried.

Then you get to the destination country, or anywhere on this value chain if you're concerned with the economics of the LNG. What is primarily evaluated in those cases is not gas volume of gas, liquid mass, or liquid volume; instead, it's the heating value. Heating value stems from what the gas will be used for—how much thermal energy it is capable of delivering in an application like electricity generation. And so the gas or LNG might be priced in Btus.

There is no escaping the unfinished Tower of Babel in this situation. All of these participants, your clients or counterparties, are concerned with distinct aspects of the energy source or use. No matter how many times the lawyer conducting due diligence reviews tries to turn the pages of documents and ignore the fact that the product in question is described with different units in different tables, there's a reason that these differences persist. The Tower of Babel metaphor is not going away.

"Because Science"

What about *Ghostbusters,* this other icon of culture I mentioned? That one's a little bit more difficult to explain. When I first got ready to talk at classes at Berkeley and Stanford on energy law, I thought I was a complete fraud because I had never taken an energy law class. So I decided to buy a best-selling authority, *Energy Law in a Nutshell.* I figured that since students probably would have this book by the time of final exams, I ought to take it in. When I opened it up, I saw that there was a chapter called "Energy Policy," and a section called "Energy Facts." And I thought "This is terrific, my job is done, I found what I need." Then I read the following: There are "two laws of thermodynamics which play important roles in energy policy. The First Law of Thermodynamics is *conservation*—energy changes form but does not dissipate. Indeed, that is Einstein's famous equation $E=M^2$."[4]

I have some concerns with this statement. First, the First Law of Thermodynamics was coined in 1850, so it predates Albert Einstein.

[4] JOSEPH P. TOUMAIN & RICHARD D. CUDAHY, ENERGY LAW IN A NUTSHELL 53 (2d ed. 2011) (emphasis in original).

Next, the First Law's statement that energy does not dissipate isn't as useful in energy policy as one might think; we tend to be more concerned with *useful* energy, which, according to the *Second* Law of Thermodynamics, *does* tend to dissipate. Third, the reference to Einstein leads the general reader unnecessarily into nuances concerning mass-energy equivalence, energy-matter conservation and the "rest energy of mass." Our sun loses four million tons of mass each second through nuclear fusion, and the applicable energy-matter conservation principles are as complex as any tax regulations. The fourth problem with "Einstein's famous equation $E=M^2$" is that the equation is actually $E=mc^2$. As the holder of a Bachelor of Arts degree, I wouldn't know what to do with the equation in a law practice. But I *do* know that if there was one equation with which we were all supposed to escape childhood, it was $E=mc^2$. (What truly gives me pause is that *Energy Law in a Nutshell* is in its second edition. This page has been looked at by thousands of law students, including students with advanced science degrees, and no one has apparently objected to it.)

But all those concerns are mere quibbles. My real complaint is this: how many more times do you think use is made of the First Law, or $E=M^2$ for that matter, in this energy book? Not many. This is someone saying, "*this is an important subject, darn it, because science*."

You might think this phenomenon is confined to law books, but it recurs elsewhere. I have an excellent university press book on California energy, the preface to which is written by a true hero of renewable energy and energy conservation, Art Rosenfeld. He was a professor of physics at UC Berkeley who spoke early on about the importance of conservation, and how we can increase gross domestic product (GDP) faster than energy consumption. He reports in the preface that by going around his office at Cal and turning off lights on the weekend, he saved "the equivalent of 5 gallons of natural gas." By doing the same throughout the building, he saved "100 gallons of fossil fuel."[5]

I suppose we could figure out what he was trying to communicate. "100 gallons of fossil fuel"? Fossil fuel includes chunks of coal, barrels of crude oil, tanks of natural gas—this is like saying "3.5 bags of shopping mall items." "5 gallons of natural gas"? A gallon is a liquid measure, while natural gas is a gas. I don't think a five-gallon jug of natural gas, at room

[5] PETER ASMUS, INTRODUCTION TO ENERGY IN CALIFORNIA xi (2009) (Preface by Art Rosenfeld).

pressure, would be very much; that seems like a cow burp. More importantly, though, this distinguished physics professor is not attempting to convey information to the reader about a numerical quantity like five or a hundred. He's telling you to "*turn the lights off, darn it, because science*."

There is unfortunately considerable use of numbers of this type. David MacKay, the chief science adviser for the UK Department of Energy and Climate Change, observed that all too often, people select numbers "to sound big and score points in arguments, rather than to aid thoughtful discussion."[6] Hence my citation to the *Ghostbusters* scene where Dr. Peter Venkman, the so-called expert in parapsychology, is asking intrusive questions of a woman who's been visited by a spectre, and her supervisor questions whether they are really relevant. Dr. Venkman looks at him rather coldly and says *"Back off, man, I'm a scientist."*

This use of numbers is what we should want to avoid. We should steer clear of conversations where people are flashing numbers or equations without conveying quantitative knowledge to the intended audience.

"Two examples and a three-part strategy"

Here are a couple of sample facts for purposes of this article. First is a release from the Energy Information Administration (EIA), part of the United States Department of Energy (DOE), pointing out that 80% of the electrical generating capacity of the United States retired in a given year, 2015, was coal-fired. Of 18 gigawatts (GW) of generating facility capacity that were retired in 2015, 14 GW were coal.[7] If you were writing a brief or paper, you can imagine grabbing that article, or more likely just that sound bite, and saying that the mix of power fuel sources is moving away from coal.

Second is a page on the website of the Center for Climate and Energy Solutions (C2ES).[8] The page is focused on carbon capture and storage (CCS), the ability to take CO_2 emissions from coal-fired or natural gas-fired power plants before they enter the atmosphere, and sequester

[6] David MacKay, *Think Big on Renewables Scale*, THE GUARDIAN , Apr. 29, 2009, https://www.theguardian.com/environment/cif-green/2009/apr/29/renewable-energy-david-mackay.

[7] U.S. Energy Information Administration, *Coal made up more than 80% of retired electricity generating capacity in 2015* (Mar. 8, 2016), https://www.eia.gov/todayinenergy/detail.php?id=25272#.

[8] CENTER FOR CLIMATE AND ENERGY SOLUTIONS, *Carbon Capture*, https://www.c2es.org/content/carbon-capture.

them—that is, deposit them in deep underground reservoirs or recirculate them through use in enhanced oil recovery. The Center states that this technology can capture up to 90% of this category of emissions. It tallies 12 active projects around the world, and 22 more on the drawing boards. Finally, it reports an estimate that this technique can achieve 14% of the emissions reduction necessary to keep the worldwide temperature rise below the fabled 2 degrees Celsius. Again, if you were writing a brief or paper, perhaps you'd grab this sound bite and say that CCS will play a vital role. I will return to these two examples in discussing some of the other points.

What follows is a numeracy strategy divided into three tasks.[9] The first task, distasteful as it may be for many lawyers, is to grapple with these numbers. You can't get away from these quantities or from understanding what they do. The Tower of Babel fragments loom over us all.

- With which dimension is your sentence concerned? Understand what aspect of an energy source is being described, like the multiple concepts sized up in the LNG value chain. An LNG plant engineer, a vessel captain, and a gas marketer might be looking at different aspects.

- In which unit is the dimension being measured? If you have documents from both Europe and the U.S., or from both the solar industry and the oil industry, you can imagine they might well use different units to describe the same thing, Tower of Babel fashion. Such units need to be, and can be, compared.

- What's the order of magnitude? Million, billion, trillion—for most of us, these are simply rhyming words that we can't understand without some frame of reference.

The second task is to look at what I'm calling the static context. The sentence containing a number or numbers often must be assessed at a point in time. Is it describing a relative share like a percentage, or an absolute amount? Is it making a comparison of one source or use with other sources or uses, or does it need to be so compared? If a time period or

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[9] A very helpful general guide to numeracy is JANE E. MILLER, THE CHICAGO GUIDE TO WRITING ABOUT NUMBERS (2d ed. 2015), particularly her "Seven Basic Principles" (pp. 13-36).

country is described, what do the experiences of other time periods and countries look like?

The third task is to look at what I refer to as the dynamic context. This sentence has now been evaluated as of a moment in time, but what should we do with it? Are we meant to predict the future with it? If so, how could this proposition stand up or fail over time? What types of changes, limits, risks, or opportunities might arise that could make it a better or worse prediction?

We should understand the quantity, evaluate the static context, and assess the dynamic context. Then and only then should we make judgments as to how to use a fact, or how to combat it, and what to look for in the way of further facts.

Energy Concepts

The first step in number-grappling is to wrestle with the physical dimension. A common experience for a beginning energy lawyer is coming home to your first Thanksgiving dinner as an adult, and some relative of yours saying "That's very nice, dear. What is energy?" Well, how would *you* define energy to someone? Many of us progress through our careers from graduation to retirement without thinking about fundamentals.

The concept, like so many, goes all the way back to Aristotle. Energy (*energeia*), he defines rather metaphysically, is the potential of a thing to actualize into its completed state.[10] Until the nineteenth century, the word isn't used much more precisely. David Hume complained that natural philosophers used "energy" just as a way of describing something that is unusually intense—to say that one object is more "energetic" than another. By the time we come to your high school classes, you may dimly recall that energy was crisply defined as the "capacity for doing work." And you might think that since this definition was in one of your big textbooks, it represents an advancement over Aristotle.

Let's get some plain thinking from a graduate of Far Rockaway High School in Queens, New York, Dr. Richard Feynman, Nobel Prize winner in physics. Feynman confessed our limited understanding:

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[10] *See* ARISTOTLE, METAPHYSICS, Book IX, 1047a; Joe Sachs, *Aristotle: Motion and Its Place in Nature*, INTERNET ENCYCLOPEDIA OF PHILOSOPHY, http://www.iep.utm.edu/aris-mot/.

> In physics today, we have no knowledge of what energy is. We do not have a picture that energy comes in little blobs of a definite amount. It is not that way. However, there are formulas for calculating some numerical quantity, and when we add it all together it gives "28"—always the same number. It is an abstract thing in that it does not tell us the mechanism or the *reasons* for the various formulas.[11]

Here is the First Law in action. There is a menagerie of interactions in a system, and in principle you can measure all of them at a moment in time and add them up in the same dimension and unit. If there is then a change in the system, and you measure them all at a second moment in time, you're going to wind up with the same bottom-line number. We may not have a unified understanding of all the associated events—from massive solar electromagnetic flares, to moving a block up a ramp as you did in high-school physics problem sets, to electrons jumping off solar panels, to subatomic nuclear interactions of matter particles. What we do know is that each time you add the energy measurements before and after a change, they sum to the same number. It is a "black box" variety of knowledge, where we know more about the total than we do about many of the components. That opacity should give us a little bit of humility when we use the term "energy."[12]

What we really measure are forms of energy, each of which represents *the capacity to change a system*. So your textbook is right, energy is indeed "the capacity for doing work," but only if you define "work" in a very arcane way: Work is a process that produces a change—which can be a change of location, of speed, temperature, composition—in a system, not just in an object itself.[13] If I were Aristotle, I would be demanding my teacher grant me partial credit for my original answer.

A bucket of water lying on the ground represents what looks like a pretty low state of energy. But if you imagine that suddenly a sinkhole appears next to that bucket of water, so that it's perched on the edge of a

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[11] RICHARD FEYNMAN, THE FEYNMAN LECTURES ON PHYSICS 4-1 (1963) (emphasis in original). Feynman provides a colorful thought experiment based on the hidden children's blocks of Dennis the Menace.

[12] *See* JENNIFER COOPERSMITH, ENERGY: THE SUBTLE CONCEPT (2010), and her lucid discussion of Carnot, Joule, Clausius, Maxwell, and Feynman.

[13] See the deceptively titled VACLAV SMIL, ENERGY: A BEGINNER'S GUIDE (2d ed. 2017). *See also* VACLAV SMIL, ENERGY AND CIVILIZATION (2017).

distance, we have a system that has potential energy. If that water falls, it generates kinetic energy, which in turn can be converted into electric energy. We lawyers don't work with total energy so much as we deal with different forms. We loosely talk about "energy generation," but what we mean is that an electrical form of energy is being generated, having been converted from some other form.

FIGURE 3: CONVERSION OF ENERGY FORMS (LAWYERS' EDITION)

From: To:	*Potential gravitational*	*Kinetic*	*Electric*	*Thermal*	*Chemical*	*Electromagnetic radiation*	*Nuclear*
Electromagnetic radiation			Electromagnetic radiation	Thermal radiation			
Chemical				Boiling, Dissociation	Reactions	Photosynthesis	Ionization
Thermal (conduction, convection, radiation)		Friction	Resistance heating	Heat exchange	Combustion (rapid oxidation)	Solar absorption	Fission, Fusion
Kinetic	Falling object systems (water) *[$mv^2/2$]*	Gears	Motors	Thermal expansion, Internal combustion	Metabolism, Muscles		Radioactivity
Electric		Turbine generators			Fuel cells, Batteries	Solar cells	
Nuclear							
Potential gravitational		Elevated object systems *[mgh]*					

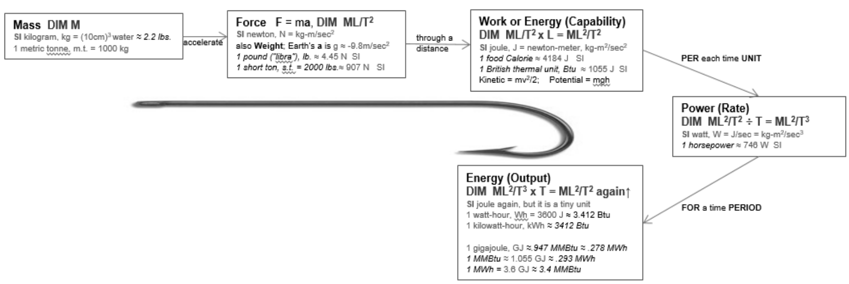
You may faintly remember from your textbook this kind of chart, in which one form of energy is converted into a different form. I've reduced and simplified that chart so it has most relation to another important unit: lawyer-hours. These are the forms of energy that might show up in a law practice.

You can see that, in my example, the potential gravitational energy of that bucket of water perched on a ledge could be converted into kinetic energy as a falling object system. You can pass that kinetic energy through a turbine generator and generate electric energy. You can then pass that electric energy through a toaster and get heat and a little light. And of course, each of these stages can involve some efficiency losses, usually conversion to some uncaptured and dissipated amount of thermal energy.[14]

I struggled with the dimensions and units I had heard throughout my energy law career. I've already confessed to you my struggle with Energy and Power, Capacity and Output, Watts and Watt-hours. Eventually, I developed the metaphor of a fish hook.

The feature of a fish hook I use is that if you go a certain distance from the eyelet, you find two parts that serve very different purposes—one is the shaft and the other is the barb, connected by a curve. They are the same distance along the hook, yet somehow related. This shape is what I found helpful in trying to understand the terms that energy business people use in our transactions.

FIGURE 4: THE ENERGY FISH HOOK



I arranged the physical concepts in that hook shape. Mass and force I will leave to the reader; you may dimly recall them from high school. What I'm interested in here is the curve starting with energy, curling to power, and swinging to energy output. (I warn you, I am going to employ multiplication and division.)

In capital letters in Figure 4, I show that whether you're in a metric system or the U.S. system, and whether you're using units used for chemistry or physics or engineering, there is a dimension (DIM) that is unchanging. Whether you measure a length using meters or feet, there is just one dimension, length, which I'm calling L. In the box where *energy* is meas-

[14] That is why measures of power in fossil-fuel, nuclear or geothermal applications refer sometimes to the thermal energy of the input (MWt) and other times to the electrical energy of the output (MWe).

ured, the dimension is mass times length squared, divided by time squared (DIM ML^2/T^2). All of the different units that are used to talk about energy have that dimension—whether you're using joules, calories, Btus, or anything else. (The joule, for example, is one kilogram times (meters squared) divided by (seconds squared).) If you work out all the equations for kinetic energy ($mv^2/2$), potential energy (mgh), and yes, even nuclear energy (mc^2), amazingly they all share the dimension ML^2/T^2.

The next concept is how rapidly energy is being processed. That's where we get to the *power* term—energy per a time unit. When you calculate miles per hour, you divide miles by hours, right? It's the same drill here: energy divided by time. The dimension of *power* winds up being mass times length squared divided by time *cubed* (DIM ML^2/T^3). All units that define power, including both the watt and the horsepower, share that dimension.

The last fish hook concept is what output results when power, the energy per unit of time, operates for some length of time—thus, power for a time period. We just *divided* energy by time to get the power. Now we *multiply* the power by some unit of time. What is our new dimension? Lo and behold, just like my fish hook analogy, we have swung around to the same dimension as that of our original energy measurement (DIM ML^2/T^2).

I compare this, hardly scientifically, to the difference between a high school yearbook and a high school reunion. In a high school yearbook you might see classmates who are voted as being "most likely to be a millionaire," "most likely to see the world," "most likely to have love affairs." Your classmates can vote, based on the capability of students to do those things. Then you all come to the reunion ten, fifteen, twenty years later, and ask "Well, how much money was generated? How many passport stamps were there? How many broken hearts?" You use the same units that you were talking about for *capability* in talking about the *output*. You're measuring different things and you're looking at them in a different way, but the dimension is the same.

In principle, you could curl backwards and use the joule to define the output (and, as Saul Griffith reported, the French often do just that). For big business transactions, you'll see that joules are tiny, so larger base units are often adopted. This is where you will find the watt-hour and various multiples—the kilowatt-hour, the gigawatt-hour, and so forth.

Now my difficulty with the concept of "capacity" was laid bare. Capacity can refer to energy, as the capacity to do work or the accumulated production or consumption of the capacity to do work. But capacity can also refer to power, as the capacity to convert one form of energy into another useful form at a particular rate of output per unit of time. In renewable energy projects, for example, a "capacity factor" identifies how much of a generation project's maximum or "nameplate" capacity of power is actually used in expected applications.

I had trouble seeing how "capacity" could apply to a rate as well as an output. I read a lot of advice online trying to explain it, including long blog postings. There was one short post in the middle of the wordy explanations that said, in its entirety, "it was a mistake to name the watt." I thought about that little comment over time, and I realized it was very insightful. The watt is defined as being the joule-per-second. So the unit that *doesn't* have a time in its name, the watt, is the time-dependent rate. The unit that *does* have a time in its name, the watt-hour, is *not* time-dependent—that is a quantity of energy output that's produced.

It's as if, instead of using "miles per hour," we had defined the mile-per-hour to be the "James," in honor of Rob James, energy lawyer. Then we would say that our car operates at a speed of 60 Jameses. Instead of having 400 miles' worth of gas in your tank (energy capability, sort of), traveling 60 miles an hour for 2 hours, and going a distance of 120 miles, we would travel at a speed of 60 Jameses to go a distance of 120 James-hours.[15] If we had kept everything in joules, I think we would all be better off.

Of Queens, Whales and Watts

The joule, the calorie, the Btu, and the watt-hour are all used to measure the same thing, whether energy capability or energy output. How do you ever operate with all of them? Lawyers will often see several of these units used at the same time on different pages of the documents they review on a single project. Here is a nontraditional way of visualizing the connections among these units.

[15] A parallel confusion arises with the length measures of "light-years" and parallax-seconds or "parsecs," with words reminding us of time prominently displayed in the names of the units. Generations of filmgoers are pondering Han Solo's boast about making the Kessel Run in less than 12 parsecs.

FIGURE 5: THE BRITISH THRONE UNIT HAS A THOUSAND JEWELS

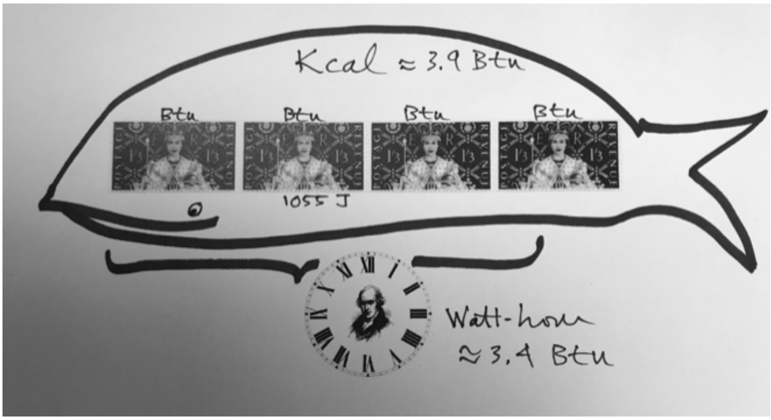
$$\boxed{\textbf{1 Btu} \approx \textbf{1055 J}}$$

When I think British, I can't think of anything more British than Queen Elizabeth II. The Queen is resplendent in her dazzling crown, her brilliant necklace and other accoutrements of state, all bedecked with gems. You can imagine that she is sitting in an elaborate chair that itself is encrusted with diamonds and sapphires. By herself, she's just a queen; by itself, it's just a chair. But together they are a "British throne unit." This British throne unit has precious stones all over. This is my way of remembering that the British throne unit has a thousand "jewels" (1 Btu ≈ 1055 J).

If you are groaning right now, you are welcome. I rather like that pun. But I defy you to forget this: *The British throne unit has a thousand jewels*.

Of course, if you had four British throne units, you'd have 4,000 jewels. Why do I throw out four, by random events? Well, four Btus is about the size of a food calorie (1 Kcal ≈ 3.9 Btu ≈ 4184 J), the big Calorie that we use in nutrition and physical fitness. In my next image I needed to have something that could swallow multiple monarchs that reminds me of food. I came up with a whale as being the symbol of a food calorie. You can see that four Queen Elizabeths slide comfortably down inside its intestinal tract.[16]

FIGURE 6: FOUR ENERGY UNITS



[16] Students have pointed out to me that whales, in the wild, are not reginavores. In conditions of captivity and stress, and given the opportunity, who knows what they might do?

As a rule of thumb for a food calorie, I give you the great contribution of American cuisine to the world of pastries—the Pop-Tart. (I told you I was dealing in icons of culture.) An individual Pop-Tart has about 200 food calories. So an individual Pop-Tart has about 200 whales (200 Kcal), about 800 Queen Elizabeths (793 Btu), or over 800,000 jewels (836,800 J). That gives you some frame of reference as to these numbers and how quickly they would add up if you were working on a transaction of any scale. That is why we see prefixes like *giga-* and *tera-* in our work.

The final unit I'll wedge in here is the watt-hour. At the bottom of my image you'll see James Watt, the improver of the steam engine. He's inside a clock to indicate that what we measure here is not watts—the watt, remember, is the joule per second—but the result of operating at a joule per second, for an hour. Let's see, sixty seconds times sixty minutes … carry the three … this winds up being exactly 3600 joules. So you can display all of these units in one image and see at once the relationships among the food calorie, the Btu, the watt-hour, and the joule.

What we lawyers can take away from this are three lessons.

- Number 1: Btus, food calories, and watt-hours are on the same order of magnitude. If you have a number in one of these three units, we can compare it fairly directly to the other two units. If you want to remember that the watt-hour and the food calorie are about three (3.4) or four (3.9) times as big as the Btu—God bless you, that will be very helpful.

- Number 2: What is comparable to the other energy units is not the watt, but the watt-hour.

- Number 3: The most important thing to remember is that at industrial scale, the joule is a deeply silly unit. It is way too small by itself to be used in any kind of adult transaction.

You will see other conversions in my Appendix table. An excellent table in a more traditional equation format is published by the American Physical Society.[17] Conversion tables are a tired literary genre; the rows of numbers and equivalents march down the page like dusty terracotta tomb war-

[17] AMERICAN PHYSICAL SOCIETY, *Energy Units*, https://www.aps.org/policy/reports/popa-reports/energy/units.cfm.

riors. I think it's more memorable to visualize the main ones. I challenge you to unsee my images. They're haunting my dreams, I can tell you.

Zillions, and "Howbigizza"

We come to orders of magnitude. This is where I say you have to suspend your belief in your ability to do things. You cannot look over a Washington, D.C. crowd and say "That's a million people," or "a million and a half people." (Present company addressed.)

A hundred, you can get your hands on. But if you've ever tried to look through an address list for an alumni event, a thousand is a lot. It's very difficult, I think, even to consider that many. When you get up to millions, billions, and trillions, they are indeed rhyming words more than quantities you can directly comprehend. Your intuitions are unreliable. A million seconds ago? You can kind of conceive that; that was last week (11 days). A billion seconds ago, though, most law students had not been born (32 years). And a trillion seconds ago, your ancestor might have been going out on a date with a Neanderthal, which may explain some things (32,000 years). Trebled orders of magnitude, leaping a thousand times at a step, are hard to fathom. The number that routinely shows up in energy policy discussions is a Quad—one quadrillion British thermal units, a thousand trillion. Any time you have a quadrillion of anything, it is strong evidence that the base unit was too tiny to begin with. The EIA will make statements like "the United States consumed 97 Quads in 2016." Nobody can intuit what that means.[18] It might as well be a zillion for many of us.

What you need, as an energy or environmental lawyer, is to have some rules of thumb—know the scales of phenomena that are important in your area of practice that give you some sense of very large (or very small) quantities. That's why I compiled a few measures that I picked up over the years, which I nickname "howbigizza."

- *How big is a power plant?* A large wind turbine, operating at maximum speed in a great location, might produce at up to one megawatt. (Remember that a megawatt is a power rate, a million joules per second.) A huge power plant might be capable of pro-

[18] In the same vein is HEWITT CRANE, EDWIN KINDERMAN & RIPULDAMAN MALHOTRA, A CUBIC MILE OF OIL (2010) (world consumed the equivalent of three cubic miles of oil in 2009).

ducing up to 1,000 megawatts, or a gigawatt; that might be enough power, at a typical load, to power a very large metropolitan area. By visualizing large wind turbines and large power plants, we can visualize a megawatt and a gigawatt.

A conventional plant powered by fossil fuel is typically in the 300 to 600 MW range. Individual trains, including cogeneration units, are often in the 49 to 100 MW range. Wind farms and solar arrays range widely from residential projects of 5 kW to industrial-scale projects in the hundreds of MW, although the nameplate capacity of renewable projects may differ significantly from the actual power rate based on when the sun is shining or the wind blowing (measured by a "capacity factor."). A nuclear power plant can be several GW, and the power of the Three Gorges hydroelectric complex in China is reportedly over 22 GW.[19]

- *How big is an oil refinery?* When I started in the oil business, you could have told me about an oil refinery that had 30,000 barrels per day of capacity. Every single day it was processing 30,000 barrels of crude. That's over a million gallons, or close to five million liters. That sounds like a huge number. But as I kept working in that area, I learned that a 30,000 barrel facility is relatively tiny. In the industry, a refinery of that size would be referred to as a "teapot."

A major oil refinery is usually in the six digits of processing capacity in barrels per day. The biggest refineries in Los Angeles are 200,000 to 300,000, on the Gulf of Mexico there are a few that run up to 600,000, and in Asia and Venezuela there are a few that are really complexes of multiple refineries running up to nearly a million or more.[20]

- *How big is a kilowatt-hour?* Rules of thumb can be used for energy output, not just processing or power rates. If your project involves the kilowatt-hour, think about leaving your high-functioning big-screen TV set on all day, or your air conditioning on for half the afternoon. Attach the numbers you're using to real-world objects or events you know.

[19] *See* William Pentland, *World's 39 Largest Electric Power Plants*, FORBES, https://www.forbes.com/sites/williampentland/2013/08/26/worlds-39-largest-electric-power-plants/#67ee488758da.
[20] *See* HYDROCARBONS TECHNOLOGY, *Top 10 Large Oil Refineries*, https://www.hydrocarbons-technology.com/features/feature-top-ten-largest-oil-refineries-world/ (last vis. July 6, 2018).

- *How big is a coal train?* A locomotive set may haul 120 cars each carrying 120 short tons, for a total transport load of 15,000 short tons.[21]

- *How big is an oil or LNG tanker?* Oil tankers can range in capacity from 200,000 to 2 million barrels, with some outliers. A single LNG tanker might carry 145,000 cubic meters of LNG, equivalent to 60,000 metric tonnes of LNG, or 3 billion cubic feet of regasified natural gas.[22]

Here is a light-hearted example combining dimensions, units and orders of magnitude. The display of the popular Peloton exercise bicycle shows the rider's "output" in watts but the "total output" in kilojoules.[23] Usually we expect "something" and "total something" to be in the same units, but here the terms are not only in different units, they are measuring different concepts—"output" is power but "total output" is energy. It seems more natural to describe the total output from operating at a rate of so many watts to be in watt-hours, the end of the fish hook, not curling backwards around the fish hook to joules. Then again, "Peloton" conveys a French vibe, and being able to claim a scientific-sounding result of "836.8 kilojoules" in the health club may produce something of a *Ghostbusters* impressive effect. Just remind the braggart that 836.8 kilojoules … is a Pop-Tart.

More seriously, I note that being able to convert between units allows you to participate better in policy discussions. More for color than for comprehension, consider the two graphics in Figure 7; they are hard to read in print, but the originals are each a web-click away. The one on the left with the stripes is from the *BP Statistical Review of World Energy*. BP, being an oil company, takes all forms of energy production and converts it into what? It converts it into oil. So here you have the oddity of these lines corresponding to nuclear, wind, solar and geothermal energy being converted into how much oil they represent. BP is a great source for world-

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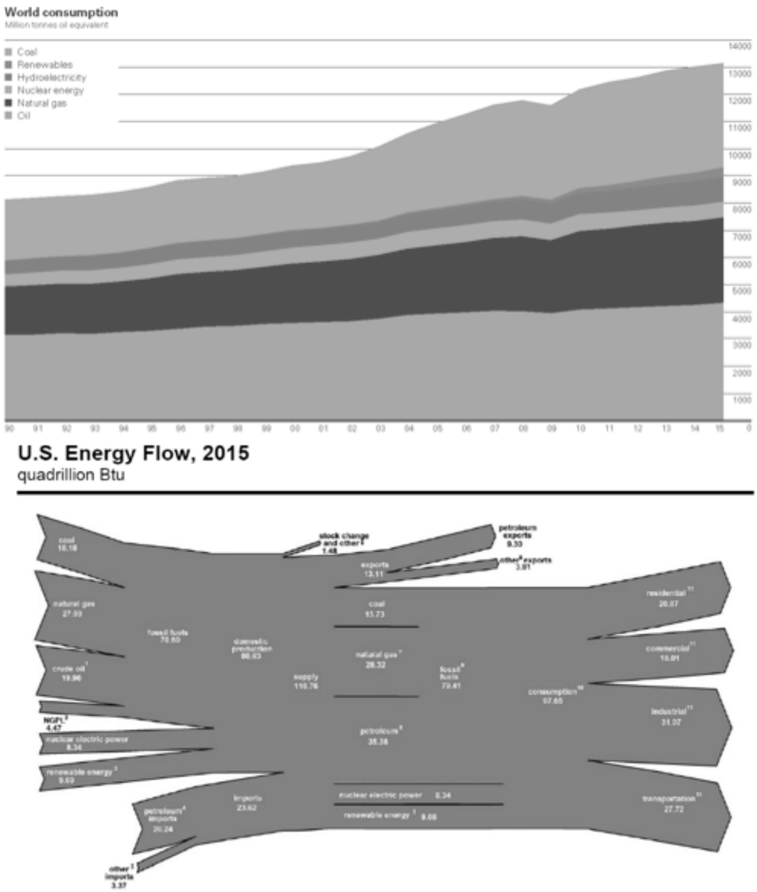
[21] COLORADO UNIT COAL TRAINS, *Unit Coal Train Frequently Asked Questions*, http://www.mattsplace.com/trains/coal/coaltrain_basics.htm.

[22] U.S. ENERGY INFORMATION ADMINISTRATION, *Oil tanker sizes range from general purpose to ultra-large crude carriers on AFRA scale* (Sept. 16, 2014), https://www.eia.gov/todayinenergy/detail.php?id=17991); MOKHATAB, et al., *supra* note 2, at 507. Most LNG market participants carry conversion charts, such as the 40-page *Natural Gas Conversion Pocketbook* of the International Gas Union (2012) or the shorter conversion chart of Poten & Partners, that help them navigate the different units and dimensions that arise in their business.

[23] PELOTON, *Track Your Performance*, https://onepeloton.com/classes#/track-your-performance.

wide production and consumption, year by year for many decades. It adds the sources to produce a number of metric tonnes of oil equivalent. You can't easily read it, but it's over 13 billion tonnes in 2015.[24]

FIGURE 7: AN ENERGY ROSETTA STONE



1 TOE ≈ 40 MMBtu

[24] BP PLC, *BP Statistical Review of World Energy* (June 2016), https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf.

The second graphic comes from the EIA, part of the DOE, which has inherited the responsibility to deal with the Federal Power Act and civilian atomic energy uses. Its focus is electricity, and fuel sources for electricity are typically valued for their heating content, and sold by the Btu. Here you have the opposite oddity of energy sources that are not used for heating, let's say petroleum that's going into making plastics, being converted into Btu. The EIA's chart shows that about 97 quadrillion Btus were consumed in 2015 in the United States.[25]

Before today, you might gawk at these two charts and throw your hands up. How would anyone deal with such radically different units? My answer today is yes, you can. You can use Rosetta stones, like the one in the lower left-hand corner of the Appendix. You'll see there's a magic equation that says a metric tonne of oil equivalent is about 40 million Btu.[26]

If you make that conversion, in either direction, suddenly the two charts make sense. You can estimate that there are about 530 Quad Btu produced worldwide, according to the BP chart, and you are told that the United States is consuming 97 Quad Btu, according to the DOE chart. If you start to play with those, you can see the idea that the United States might be using or producing 18% of world energy starts to make sense.[27] You can get these pieces of data to communicate with each other, instead of turning the pages and saying "It's hopeless; different people have built their own data sets for only their own purposes."

The Static Context

I bet you're happy we are now out of the numbers part of this presentation. Let me move on to the contexts, and first the static context. We should try to detect what the author is trying to establish. Whether the source is an institute singing the virtues of carbon capture and storage, or

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[25] U.S. ENERGY INFORMATION ADMINISTRATION, *Annual Energy Review* (Sept. 2012), https://www.eia.gov/totalenergy/data/annual/diagram1.php (showing an earlier version).

[26] Here's a quick detour. You'll see some charts that say that this conversion is "39.68 million Btu." That requires some heroic assumptions or else is false precision. Oil quality and density, gravity as it's called for liquids, vary widely; the amount of heat content that would be equivalent to a tonne of Arabian versus California versus North Sea crude oil would be significantly different. Any time that someone reports an aggregate or average number like "39.68," I would be distrustful. I've reduced my conversion here to one significant digit, namely a four.

[27] The math is 13.25 billion TOE × 40 million Btu/TOE = 530 Quad (a billion times a million is a quadrillion!). And 97 for the U.S. divided by 530 for the world is 18.3%.

a government agency citing the rapid retirement of coal-fired power generation, what is the source trying to achieve? View statements in that light. Extending good faith to all sources, we should not judge them entirely on each factual statement; their entire argument and body of work deserve consideration. They may volunteer or concede other facts that help to provide a full picture. Then again, people don't introduce facts without a reason. There's probably a reason that of all the facts in all the world, someone decided to present this particular fact to you. Ponder why that is.

If someone gives you a relative number, like "80% of all retired energy capacity in a year was coal-fired," ask for the absolute number. How much coal-generating capacity was out there in the first place? If someone tells you that renewable electricity generation rose by 15% last year, ask "Increased from what to what?" What is the absolute figure or figures?

Flipping it around the other way, I suggest that if someone gives you an absolute number, ask for the relative proportions. If someone tells you that twelve CCS projects are under way, ask how much of a contribution would twelve CCS plants make to reduction of emissions from coal-fired generating plants. What percentage of total carbon emissions from the coal life-cycle does this represent? In short, *if someone gives you a relative, ask for the absolute. If someone gives you an absolute, ask for the relative.*

If someone gives you a number for the year 2015, that's great; it's good to know what that number is. Ask how that compares to what was happening in other years. If someone tells you that United States coal-fired generating capacity was being retired at an 80% clip, ask what was happening elsewhere. If 14 gigawatts of coal-fired generating capacity was being retired in the United States, it would be relevant if we were told "India's coal consumption grew fastest in the world in 2014."[28] Has there merely been a shift in the places where coal is being deployed, rather than a retreat on a global scale?

If the statement applies to one source, ask what is happening at the same time to other sources. Renewable production of electricity went up in 2015. But so did electricity generated from natural gas. Renewable

[28] THE HINDU BUSINESS LINE, *India's coal consumption grew fastest in the world in 2014: BP* (June 10, 2015), https://www.thehindubusinessline.com/news/indias-coal-consumption-grew-fastest-in-the-world-in-2014-bp/article7302198.ece.

power generation went up by 15% in 2015, while gas generation went up only 2%. The natural gas base is so large, however, that more gas generating capacity was added (0.48% of world energy production) than wind, solar, and geothermal capacity combined (0.40% of world energy production).[29] A benchwarmer can be the most improved player on your team, year after year, and still not yet be a starter.

The Dynamic Context

When I say dynamic context, I'm talking about how a quantitative sentence is supposed to influence your thinking about the future. If renewable electricity generation rose 15% in 2015, what does that imply for 2020? Does that statistic mean that over a period of a few years there's going to be a complete displacement of other generation sources by the one whose 2015 growth outstripped that of the others?

What could happen to that one-year snapshot? There are economic issues of supply, demand, and interest rates. There are regulatory issues like coal safety regulations. There could be changes in technology, like the prospects for efficient large-scale energy storage. People had discounted U.S. natural gas production in the 1990s—a lot of us were working on projects to import gas to the United States. Then hydraulic fracturing was deployed on a large scale, based on separate technologies that had been developed since the 1940s, and now we're working on projects to export gas from the United States.

There could be new crises or shortages. Or there could be a resolution of existing conflicts. Overhanging the price of oil for some time was the anticipation that production from Iran would enter world markets through settlement of a long impasse. Might there be changes in the existence or the handling of externalities? Could growth rates be affected by new taxes or regulations, to address either positive or negative side-effects? Could there be changes in subsidies or penalties, or in tax incentives?

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[29] *See* BP PLC, *BP Statistical Review of World Energy* at 4-5 (June 2016), https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf. Eventually, consistent and compound growth in wind and solar generation may predominate, with renewables power growth exceeding natural gas power growth in 2017. *See* BP PLC, *BP Statistical Review of World Energy* (June 2017), https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf.

There could be limits to growth rates. The price per unit of output is dropping rapidly for solar panels and wind turbines, but there are land use, tax policy and energy storage headwinds that should give us pause before we infinitely extrapolate on an exponential growth curve for renewable projects

What other resources are needed to make this energy source successful? Much of the wind and solar power generation has been achieved in the places that are easiest to develop. While distributed generation is gaining in popularity, many proposed utility-scale projects would be located further away from population centers, in places that may pose greater environmental issues (dealing with endangered species, for example). Transmission will also be a limiting factor. The oil industry has endeavored to finance and build a Keystone XL pipeline and a Dakota Access Pipeline, traversing parts of the country that are neither reaping royalty income nor benefitting from consumption. The product travels underneath or near rivers and reservations, causing the landowner and neighbor concerns about which we hear. On the electricity side, if you are facing the prospect of a high-voltage tower crossing your land, it doesn't matter much to you whether it's carrying "green electrons" from a windfarm or "brown electrons" from a coal-burning plant.

In general, if you have digested the fact that something was true at present, proceed to look at the dynamic context. How is a fact about today relevant to a policy or economic decision for tomorrow?

The Biggest Statistics of Them All

Let's apply this strategy to some interesting and sometimes jarring facts.

The most significant facts of all, which should be known to everyone who is interested in energy and environmental issues, relate to world population and resources today and say twenty years from today. (Pick a shorter or longer time horizon if you like.) I am embarrassed that I did not have a good grip on these three sets of numbers before researching them for this presentation.

- *How many people will be here on Earth?* There are about 7.5 billion of us in 2017. How many people are expected to be here twenty years from now? Estimates vary, but one that assumes ongoing improvements in women's rights and education is 8.8 billion—about a 17% increase, way down from prior growth rates but still a lot more people in absolute terms.[30] You may believe a different estimate based on different assumptions.

- *How much wealth will those people share?* GDP is a controversial measure of wealth let alone happiness, but it is a statistic readily available to us. World GDP in 2016 was about $75 trillion (US GDP being $18 trillion of that).[31] If we expect the billions of people living in the developing world to attain the higher levels of health, nutrition and living standard of the developed world, what would world GDP need to be twenty years from now? You can see that GDP would need to rise much faster than population. Would it double or triple, to $150 or $200 trillion? Or do you envision scenarios of $100 trillion, in which the developed world radically cuts back while the developing world perhaps is content with less of an improvement?

- *What energy is needed to accommodate those people and that wealth?* As noted above, world energy usage right now is about 530 Quads. We certainly can't expect production to rise as quickly as GDP—thanks to Professor Rosenfeld's work, we know that we can conserve, and that we can use energy much more efficiently per incremental unit of GDP than we have done in the past. But to power the developing world, energy production would need to rise, and rise faster than the population growth. What output do you think would be needed? Maybe 750 Quad? But how would you do that if your policies suggest the reduction or cessation of fossil fuel production, which currently is over 500 Quad? Can you generate and transport, say, 750 Quad of renewable energy to the population by the year 2037?

I could add other resources or constraints to this list (cubic meters or acre-feet of potable water; tons of atmospheric carbon; numbers of spe-

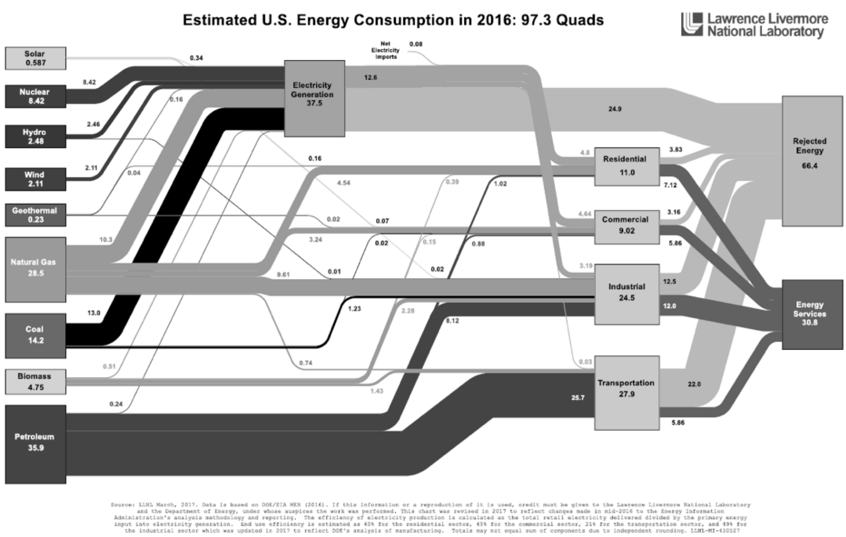
[30] UNITED NATIONS, WORLD POPULATION TO 2300 (2004), http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf.
[31] U.S. CENTRAL INTELLIGENCE AGENCY, CIA WORLD FACTBOOK (2016), https://www.cia.gov/library/publications/download/download-2016/index.html.

cies) but you get the idea. If you have a vision for our energy and environmental future, please think of those 1.3 billion additional people, imagine the calls by 6 billion people in developing economies for greater resources, and consider the ways to produce those hundreds and hundreds of quadrillions of Btus. See if your vision still holds in that broader frame.

Other Applications

W analyzing sources, we should consider the energy used for all applications, not just those for electricity generation. Take a look at Figure 8, the annual U.S. energy consumption flow chart published by the Lawrence Livermore National Laboratory and the DOE.

FIGURE 8: U.S. ENERGY FLOWS[32]



When people talk about renewable generation increasing 15% in 2015, they typically focus on the use of renewable sources for power generation. But that is just one stream of energy use, albeit an increasingly important

[32] Originally obtained from Lawrence Livermore National Laboratory's website, https://flowcharts.llnl.gov/. The 2017 version is currently available (as of July 8, 2018) at https://flowcharts.llnl.gov/content/assets/images/energy/us/Energy_US_2017.png.

one. That stream is represented in the box titled "Electricity Generation 37.5" atop the figure. That is 37.5 Quads, out of the 97 Quad U.S. total. We still live in a world that does not only have electricity; it has ships, and airplanes, and food that is produced using nitrogen fertilizers derived from natural gas. It's a world with concrete made with cement calcined at extremely high temperatures. There are ways to use electricity for these purposes, including fuel cells and other emerging techniques, and more are coming; but they're clearly not the ones in predominant use today. When people talk about renewable sources displacing other sources, remember the "37.5" box and all the other boxes capturing how we presently use energy for other applications.

Granting equal time, though, I acknowledge carbon capture faces steep challenges in scaling to large-scale application. The twelve active and 22 proposed CCS plants cited by the Center for Climate and Energy Solutions will only recover megatonnes of CO2, whereas the world output of CO2 is in gigatonnes. Some contend that a majority of the depleted oil and gas and saline reservoirs of the world would be needed to sequester our industrial CO2.[33]

These comments about renewables and CCS are not made to denigrate the efforts of all of us engaged in their evaluation and development. Along with efficiency gains and adaptation, a decarbonized energy system is our future. But how quickly that future arrives—whether during our careers or those of our children or grandchildren—will depend more on the emergence of new technology than on political decisions to encourage development of favored existing technologies. That outlook is based not on ideology but on taking a candid approach to these numbers.

As I was preparing for these presentations, I encountered two New York Times headlines. One read: "China Aims to Spend At Least $360 Billion on Renewable Energy by 2020" (Jan. 5, 2017). Applying my framework, I wondered how much money China was going to be spending in this same time period on coal and coal-fired generation. I wondered what investments other countries were making. I wondered whether this 2017-2020 time period was unusual. In short, I asked myself whether

[33] Berend Smit, Ah-Hyung Alissa Park & Greeshma Gadikota, *The Grand Challenges in Carbon Capture, Utilization, and Storage,* 2 Frontiers in Energy Research 55 (2014), https://www.frontiersin.org/articles/10.3389/fenrg.2014.00055/full.

$360 billion was or wasn't a remarkable number. Sure enough, just a few months later another headline on a story by another reporter showed up in the same newspaper: "Why China Wants to Lead on Climate, but Clings to Coal (for Now)" (Nov. 15, 2017). It reported that coal use and coal-sourced carbon emissions in China actually rose in 2017. Both these articles are truthful. But knowing more about the entire picture is useful. These two reporters should have lunch together more often.

The Path of Efficiency and Technology

I don't want to end this article on too much of a downer, so I want to emphasize the importance and promise of efficiency and technology. Since the first oil shock of the 1970s, the contributions of demand reduction and innovation have exceeded the contribution of new energy sources. If we had today the same vehicle fleet economy standards that were in effect in 1973 and the same efficiency levels in factories, offices and homes, our energy consumption would be much higher.[34]

The Livermore chart in Figure 8 shows, in the light gray, the waste heat (back to the *Second* Law of Thermodynamics) dissipated in various uses. You'll see that efficiency in the home, the office, and the factory is fairly high. Where you see the largest inefficiencies are in the generation of electricity and in transportation—in how little of the fuel's energy content turns the generators and propels the vehicles forward. There are great fortunes, business transactions and billable hours to be created in these areas of potential efficiency gains. These could outstrip, if you look on the other side of the chart, the current renewable energy contributions. Projects that involve combined-cycle generation, co-generation, and other efficient techniques are highly valued.

The path of efficiency and technology is also the path to a more egalitarian distribution of energy. Countries with emerging economies have the benefit of being able to leap immediately to light-emitting diode (LED) illumination and other more efficient techniques. New technologies will spur great environmental and economic gains—more so than government restraints on industrial output, and more so than on shifting subsidies and penalties between existing fossil and existing renewable sources and processes.

[34] *See* JAMES L. SWEENEY, ENERGY EFFICIENCY (2016).

• • •

My plea is to understand numerical propositions before you use them or fight them. Know your energy concepts. Know their dimensions. Don't trust yourself on orders of magnitude. Instead, find yourself rules of thumb. Don't be intimidated by the fact that your measurement is in a different unit than someone else's measurement. There are ways to convert from one unit to another, whether you remember the British throne unit or not. Know how one dimension or unit relates to others. Know how you could make a Btu relate to a volume to a mass. The links in any value chain have to talk at least to their adjacent links; as a lawyer for any of those links, you should be able to speak their language as well.

Moving from the numbers to the proposition itself, I ask that we consider the static structural context. If someone gives you a relative number, like a percentage, ask for the absolute number. If someone gives you an absolute, ask for the relative. Ask: What's so special about 2015? What's so special about the United States? What's so special about power generation? What's so special about any one source or use, one country, or one year, if that is the single data-point that is offered to you?

Then consider the dynamic context. Say: "Okay, now I appreciate your snapshot. *What follows*?" What does it mean for the future? How can its inherent prediction be affected by macroeconomic conditions, politics, interdependent decisions, other actors, or other essential resources?

Numbers are only one piece of energy literacy. But we have to start somewhere, and numbers are where we lawyers have the most ground to make up.[35] We tend to be intimidated by our lack of scientific background and by the pace of energy projects. Attorneys who demonstrate that they can work with quantities help themselves as well as the parties. We can make these charts, graphs and numbers not only speak but sing to each other. We can harmonize their voices. Our colleagues and clients will appreciate it.

One parting request: Kindly expect your own factual statements to stand up to this same level of scrutiny. When *you* use a quantity, please imagine that there is somebody out there in your audience who enjoys complete energy numeracy and utter energy literacy.

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[35] *See* Carole Silver & Louis Rocconi, *Learning From and About the Numbers,* 5 J. OF LAW (4 J. LEGAL METRICS) 53, 55 (2015) ("[I]t is not unusual for law students to explain their decision to attend law school as related to an aversion to numbers.")

APPENDIX: ENERGY NUMERACY CHART

ENERGY NUMERACY: UNITS

Robert A. James Pillsbury Winthrop Shaw Pittman LLP

ENERGY UNITS dimensions, **DIM**: Mass, Length, Time; units: **SI** **Système Internationale**, *United States customary*

Mass DIM M
SI kilogram, kg = $(10cm)^3$ water ≈ *2.2 lbs.*
1 metric tonne, m.t. = 1000 kg

accelerate →

Force F = ma, DIM ML/T^2
SI newton, N = kg-m/sec^2
also **Weight**; Earth's **a** is g ≈ -9.8m/sec^2
1 pound ("libra"), lb. ≈ 4.45 N SI
1 short ton, s.t. = 2000 lbs. ≈ 907 N SI

through a distance →

Work or Energy (Capability)
DIM ML/T^2 x L = ML^2/T^2
SI joule, J = newton-meter, kg-m^2/sec^2
1 food Calorie ≈ 4184 J SI
1 British thermal unit, Btu ≈ 1055 J SI
Kinetic = mv^2/2; Potential = mgh

PER each time UNIT

Power (Rate)
DIM ML^2/T^2 ÷ T = ML^2/T^3
SI watt, W = J/sec = kg-m^2/sec^3
1 horsepower ≈ 746 W SI

FOR a time PERIOD

Energy (Output)
DIM ML^2/T^3 x T = ML^2/T^2 again↑
SI joule again, but it is a tiny unit
1 watt-hour, Wh = 3600 J ≈ 3.412 Btu
1 kilowatt-hour, kWh ≈ *3412 Btu*

1 gigajoule, GJ ≈ *.947 MMBtu* ≈ *.278 MWh*
1 MMBtu ≈ 1.055 GJ ≈ *.293 MWh*
1 MWh = 3.6 GJ ≈ *3.4 MMBtu*

1 barrel of oil ("blue barrel"), bbl = 42 U.S. gallons (≈158.76 liters SI)
1000 standard cubic feet of gas, Mcf ≈ **1** million Btu or MMBtu (≈28.3 m^3 SI)
1 barrel/day, bpd ≈ 50 m.t./year **SI**
1000 bpd ≈ 2 trillion Btu per year
1 m.t. LNG ≈ 1.2 TOE, 9 BOE, 53 MMBtu

Equivalents
(often consolidated as barrels or metric tonnes of oil equivalent (BOE, TOE) or as Btus converted into joules (J) or watt-hours (Wh))

***Contents** (varying by qualities)*

	Crude oil, m.t.	Crude oil, bbl	Natural gas MMBtu	Anthracite coal, s.t.	kWh per unit	Specific energy, MJ/kg	Carbon content, kg C/GJ	Carbon emission, kg CO_2-eq/kWh
Crude oil, various qualities	X	TOE 0.14 m.t.	TOE 0.02 m.t.	TOE 0.7 m.t.	TOE 11,630/m.t.	42	20	0.26
Crude oil, various qualities	BOE 7.3 bbls	X	BOE 0.18 bbls	BOE 5 bbls	BOE 1700/bbl	42	20	0.26
Natural gas, standard	40 MMBtu	6 MMBtu	X	20-25 MMBtu	300/MMBtu	52	14	0.2
Anthracite (hard) coal	1.5 s.t.	0.20 s.t.	0.05 s.t.	X	6000-8000/s.t.	29	26	0.34

Sources:

International Energy Agency, World Energy Outlook, 2016

World Energy Council, World Energy Resources, 2016

U.S. Energy Information Administration, Annual Energy Outlook 2016

BP Statistical Review of World Energy, 2016

☞***Conversions are approximate and based on a mix of qualities. This chart is exclusively for educational purposes, not legal, business or engineering purposes!***

\# \# \#

ENERGY NUMERACY: UNITS

Robert A. James *Pillsbury Winthrop Shaw Pittman LLP*

ENERGY UNITS

dimensions, **DIM**: **M**ass, **L**ength, **T**ime; units: **SI Système Internationale,** *United States customary*

Mass DIM M
SI kilogram, kg = $(10cm)^3$ water ≈ *2.2 lbs.*
1 metric tonne, m.t. = 1000 kg

accelerate

Force F = ma, **DIM ML/T^2**
SI newton, N = kg-m/sec^2
also **Weight**; Earth's **a** is g ≈ -9.8m/sec^2
1 pound ("libra"), lb. ≈ 4.45 N SI
1 short ton, s.t. = 2000 lbs.≈ 907 N SI

through a distance

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1 British thermal unit, Btu ≈ 1055 J SI
Kinetic = $mv^2/2$; Potential = mgh

PER each time **UNIT**

Power (Rate)
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SI watt, W = J/sec = kg-m^2/sec^3
1 horsepower ≈ 746 W SI

FOR a time **PERIOD**

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