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23. THE SKINNY ON EFFICIENCY ☆

In which we take a closer look at what efficiency means, why it's important and how it should and should not be evaluated.

How would you define the efficiency of the postal service, of studying for exams, of generating electricity? We use the idea of efficiency all the time. For many activities, like studying, the answer will always be squishy, opinionated, hard to justify. But when asked of energy technologies, like powerplants or lightbulbs, efficiency can be explicitly defined and quantitatively answered. Moreover, for evaluating energy technologies few templates are more important. Efficiency doesn't just shape the energy and financial cost of energy services; it also tells much about its environmental intrusion. If we can improve the technical efficiency of delivering a service, we will proportionally reduce environmental damage.

Once again, let's begin our discussion with our trick of looking at the meaning of words. People use "efficiency" to mean the degree to which the performance (of something) approaches ideal performance. Although the idea is clear, getting an explicit definition for efficiency is often difficult. How would you find a simple, clear, meaningful, numerate definition to quantify your efficiency of studying for an examination?

Fortunately, the efficiency of energy conversion technologies can be explicitly defined—as the numerical ratio of actual performance to ideal performance, expressed as the ratio of output (say, as electricity) divided by input (say, as steam to drive the turbines). Indeed, the American Heritage Dictionary defines efficiency as "The ratio of the effective or useful output to the total input in any system".

The ability to quantify the efficiency of an energy system is important because it tells us two things:

- how wasteful the system is today, and
- how much improvement might be possible tomorrow.

While both are important, strategically the second may be the more valuable. To illustrate, consider two energy conversion technologies, one operating at 30 percent efficiency and another at 90 percent. Let' s imagine technical improvements take the performance of each technology "halfway to perfect".

It's reasonable to imagine technical advances that could improve the efficiency of the first technology from 30 to 65 percent—the halfway mark towards "perfect." This would increase output by more than 100 percent. (Or, if output is held constant, reduce the energy use and environmental intrusion by more than 50 percent.) These large margins point to opportunities for engineers to engineer and, if they're successful, for investors to invest.

For comparison, an equivalent halfway-to-perfect improvement in the second technology would bring the efficiency from 90 to 95 percent—an increase in output, or reduction of cost by about 5 percent. Not as attractive a goal. Moreover, typically, it's very difficult to improve performances within the 90–95 percent range.[1]

Efficiencies give valuable information for both engineers and investors—if these efficiencies *correctly* quantify what efficiency *means*. "Ay, there's the rub!" Today, efficiencies calculated for energy technologies often bear no relationship to what efficiency means.

Let's review the situation. The efficiencies of energy technologies are defined as the ratio of outputs (from the process) to inputs (that power the process.) That's OK. The flaw comes when we use *energy* rather than exergy for both numerator and denominator. It's an error that can bite both ways. Sometimes the actual performance is overrated; at other times, it's underrated. And on both sides the errors can be very large.

Refrigerators and heat pumps are technologies where energy-ratios overestimate efficiencies, giving efficiencies between 200 and 300 percent. Yet, the refrigerator's actual efficiency is seldom greater than 30 percent and often less. Heat pumps are just refrigerators—except they refrigerate the outdoors in order to heat your home, while refrigerators heat your kitchen

☆ "Skinny": slang for "inside information," or "the real facts," or "the truth."

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[1] In practical terms, the *true* efficiencies of modern energy conversion technologies are commonly above 50 percent, but are rarely higher than 95 percent

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in order to cool your beer. So heat pump efficiencies, if defined by energy-ratios, give the same kind of silly numbers as refrigerators—often sillier. It's why heat pump manufacturers use the phrase "coefficient of performance", rather than efficiency. Refrigerator manufacturers usually avoid the issue entirely.

In contrast, the conversion of steam energy to electrical energy is a case where energy- ratio efficiencies underestimate performance. These under-estimated efficiencies have led to the misleading accusation that electric utilities waste more than half their energy by throwing it out as heat into lakes or cooling towers. Correct (but meaningless) numbers are vicious weapons in the hands of those whose purpose is to mislead. Later, we'll find that the energy value of the heat wasted is seldom more than three percent of the total energy—no where near the "more than 50 percent" sometimes implied by those whose avocation, if not occupation, is attacking large corporations.

In spite of the misleading nature of these accusations, we can often find appropriate uses for this otherwise "waste" heat—in spite of its low-energy grade. The adjective "appropriate" is key. We can use it for warming our homes, growing tomatoes, supporting fish farms, sometimes even providing process heat for manufacturing. And it points to a codicil prize. Exergy analysis greatly simplifies finding appropriate services for energy currencies that, today, we frequently throw out as waste. Often currencies unsuitable for one task are suitable for another. By thinking in terms of exergy we frequently see opportunities staring us in the face.

The flipside is also true. I've been embarrassed by people who should know better asking rhetorical questions like, "Why don't we use the waste heat from nuclear powerplants to produce hydrogen?" A little knowledge of energy grades would give the answer—allowing these bright minds to focus on ideas that might work.

During this introduction to the idea of technical efficiencies, I've spoken of straight-up device efficiencies. Individual technology efficiencies certainly affect our five-link [1] *systemic* efficiency—but they are not the only determinant. Many additional factors contribute, of which perhaps the most important is *time*. For example, we must consider the time-distribution that different sources follow when they deliver energy—and how well this delivery is this matched to when the energy is needed. The answers are very, very important when we decide how to best integrate a mix of energy sources—like how to best deploy renewables, such as wind and sunlight that deliver energy on their own unpredictable schedule, or nuclear, which likes to deliver its energy at constant, steady rates.

Later in this series of articles, we'll return to time match and mismatch and how hydrogen can sometimes be a matchmaker. But for the next leg of our voyage, "What we have to gain?" [2] we'll focus on individual technologies and how, using our newfound knowledge about exergy efficiencies, we can shed light and banish nonsense.

This is the twenty-third in a series of articles by

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