Energy, heat, and temperature

When thinking strategically about heat, it is important to avoid some common misconceptions.

Misconception 1: One unit of heat is as useful as one unit of electricity or chemical energy.

False. While electrical energy and chemical energy can easily be turned into heat, the laws of thermodynamics don't allow heat to be one-hundred-percent turned back into electrical energy or chemical energy. As energy is converted between different forms, there is an irreversible tendency for its capacity to do useful things to decrease. One unit of heat energy is intrinsically less useful and less valuable than one unit of electrical or chemical energy.

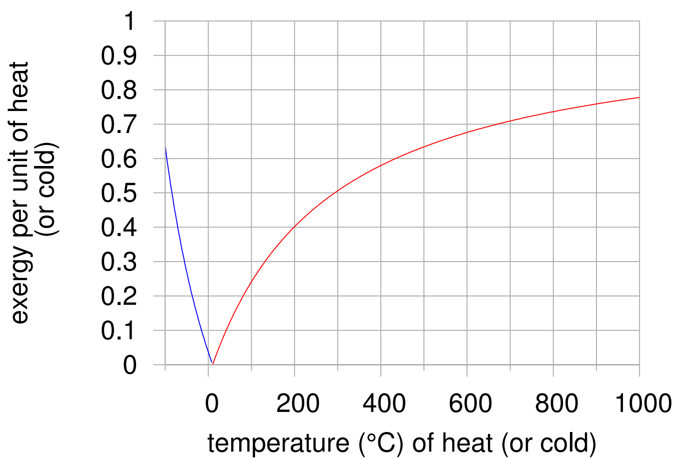

Figure 1.1. The intrinsic value, or exergy, of one unit of heat (red) or cold (blue) as a function of the temperature of that heat (or cold), for an ambient temperature of 10 °C. *[Location: This figure belongs with Misconception 2]*

Misconception 2: A good way to measure the value of some heat is by the quantity of energy in that heat.

False. Quantity matters, but so does quality; the quality of heat depends on how different the *temperature* of that heat is from the temperature of the surroundings. If the ambient temperature is 10 °C then 1 cup of boiling water at 100 °C and 3 cups of water at 40 °C contain exactly the same amount of heat-energy, but the energy in boiling water is more useful: you can easily mix the boiling water with ambient-temperature water to make 40 °C water, but you can't un-mix tepid water back into cold water and boiling water. Engineers measure the "usefulness" of a quantity of heat by its "exergy", which is the maximum amount of electrical energy that could conceivably be obtained from that heat. Figure 1.1 shows, for temperatures above (or below) an ambient temperature of 10 °C, the amount of exergy in each unit of heat (or cold). Heat at 20 °C has much smaller intrinsic value than heat at 100 °C or 600 °C.

Misconception 3: Power stations are "wasting energy" if they turn only 50% of the heat in their boilers into electricity and send the other 50% into the air in cooling towers. This "waste heat" could be put to use, for free.

False. The power stations that are the most efficient at generating electricity work by taking very-high-temperature heat, and turning *part* of it into electricity and *part* of it into near-ambient-temperature heat. This "waste heat" is an essential feature of a highly-efficient thermal power station: for the power station to work, this near-ambient-temperature heat must be delivered to a near-ambient-temperature place. The near-ambient-temperature place does not *have* to be a cooling tower – radiators in a greenhouse or building would work fine too, for example – but there is a widespread misconception that this "waste heat" should be put to other uses. The truth is that the "waste heat" has very little value, because its temperature is very close to ambient (35 °C, say). If we want to make use of a power station's "waste heat", typically a higher temperature is required; many district heating systems, for example, send piped heat at a temperature close to 100 °C. Power stations can produce waste heat at these higher temperatures, but if they do so, then they inevitably produce less electricity (compared to an optimized electricity-only power station). So the "waste heat" isn't free; there is a tradeoff between the amount of high-value electricity produced and the quantity and temperature of heat delivered. If heat is delivered at temperatures useful to industrial processes (eg, 300 °C), typically at least three units of heat can be delivered for each unit of electricity foregone. At lower temperatures (eg, 100 °C), perhaps seven units of heat can be delivered for each unit of electricity foregone.

Combined heat and power tends to be the most efficient use of a fuel in situations where there is a demand for heat that is steady in time.

Misconception 4: Boilers that turn gas into heat with an efficiency of 90% and electric heaters that turn electrical energy into heat with an efficiency of 100% are unbeatably efficient ways of delivering heat.

False. While a 90%-efficient boiler is of course better than a 70%-efficient boiler, it is possible to deliver low-temperature heat with *much* higher efficiency than 100%! Heat pumps use a small amount of electrical energy or chemical energy to *move* a larger amount of heat *from* one place *to* another (for example, from your garden to your house), boosting the heat's temperature from the ambient temperature to a higher temperature. A well-designed heat pump system can deliver at least three times as much heat (at domestic temperatures) as the electricity it uses. Power stations providing heat and power can be viewed as virtual heat pumps, able to deliver between three and seven units of heat for each unit of electricity forgone, depending on the temperature of the delivered heat. Both heat pumps and power stations can deliver more heat, the closer the heat's temperature is to ambient. So for domestic heating, there is a common message: both heat pumps and CHP-driven district heating work more efficiently with *low-temperature heat emitters*; the key steps that enable central heating systems to be run at lower temperatures are to improve building insulation, and to ensure that the radiators are large enough.