

efficiencies were always substantially smaller than 100%. Now we can understand this better. Before we start up a steam engine to generate work, we have an amount of coal and a bucket of cold water. We fill the boiler of the steam engine with the cold water and ignite the coal in the furnace to heat the water. Steam will form and drive the pistons of the steam engine. In addition to the steam formation we also generate a lot of hot gases from burning the coal. After some time all the coal is burned and the steam engine cools down. In the condenser we have collected cold water from the condensation of the steam. Thus at completion of the process we are left with ash, a bucket of cold water and, of course, a certain amount of work we have generated by our steam engine. However, we also created entropy because the entropy of hot gases and ash is higher than the entropy of coal. We can also say that coal is a more ordered substance than the hot gases and ash it is converted in. From Chapter 2 we know that the First Law demands that the amount of energy (ΔU) enclosed in the coal is converted into an amount to generate work (ΔW) by the heat generated from the combustion. But we know that the entropy extracted ($\Delta Q_{\text{hot}}/T_{\text{hot}}$) from the hot reservoir needs to be compensated by the entropy (heat) given to the cold reservoir ($\Delta Q_{\text{cold}}/T_{\text{cold}}$) such that $\Delta Q_{\text{hot}}/T_{\text{hot}} = \Delta Q_{\text{cold}}/T_{\text{cold}}$ (remember for a Carnot process ΔS must be zero, see Chapter 2). In this way the entropy is responsible for keeping the efficiency smaller than 100%⁵³.

We found that Boltzmann's atomistic interpretation of entropy gives us greater insight into the secrets of how nature really works. It shows that ever-increasing entropy is simply nature's progress toward more probable configurations. Another way of stating this is to say that nature tends to go from order to disorder. This progression also explains why spontaneously occurring processes are virtually irreversible, and why the arrow of time is *almost* certain to go in only one direction.

⁵³ At the risk of confusing the reader I refer to the discussion on fuel cells in Appendix VIII. In fuel cells the chemical energy enclosed in fuels is directly converted into electrical energy. Thus no heat conversion is involved and as a result the efficiency can be much higher than in coal fired power plants.