

**We wind a simple ring of iron with coils; we establish the connections to the generator, and with wonder and delight we note the effects of strange forces which we bring into play, which allow us to transform, to transmit and direct energy at will.**

**Nikola Tesla**



**Arizona State University**  
**SES 194**

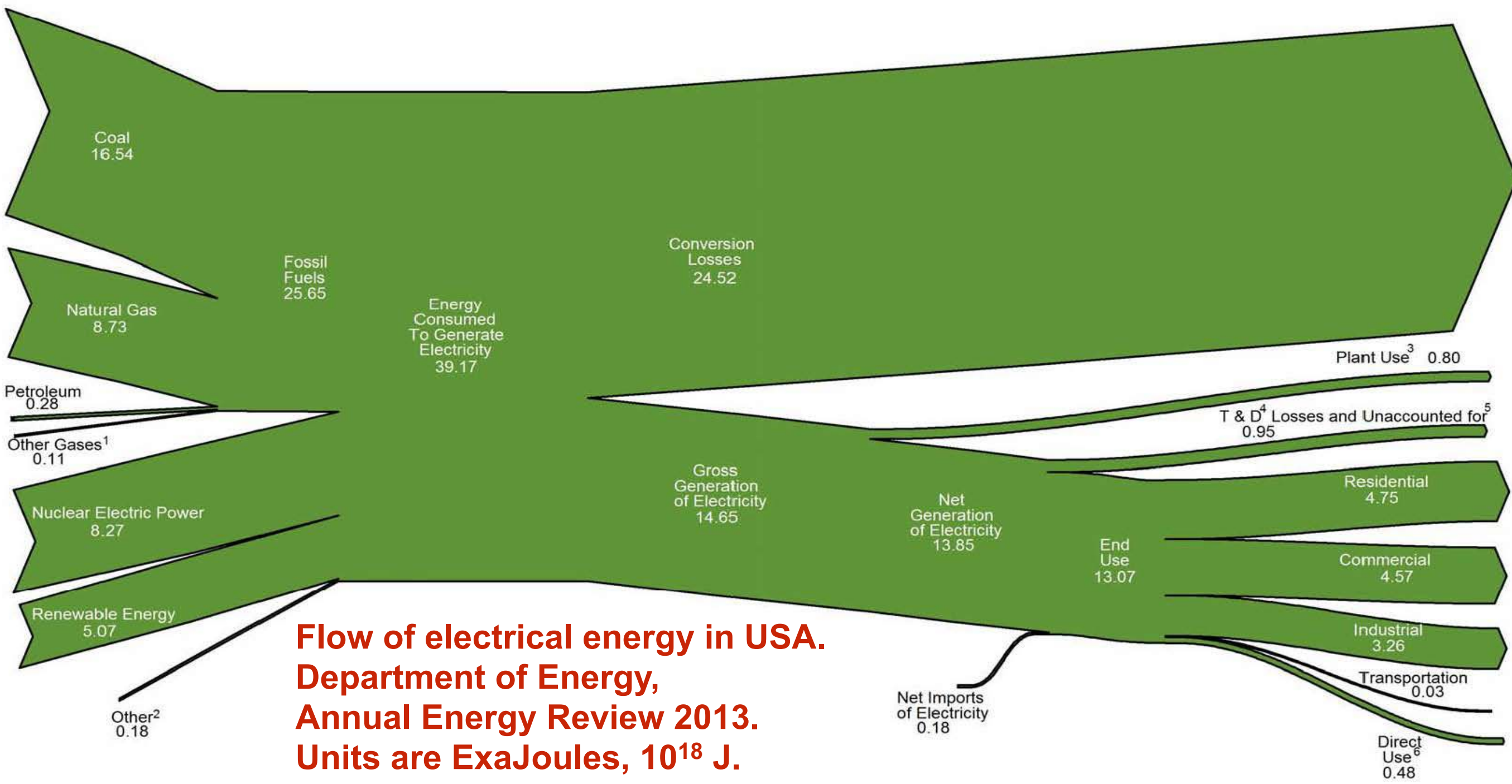
# **Energy in Everyday Life**

## **Heat Engine Efficiency**

**Frank Timmes**

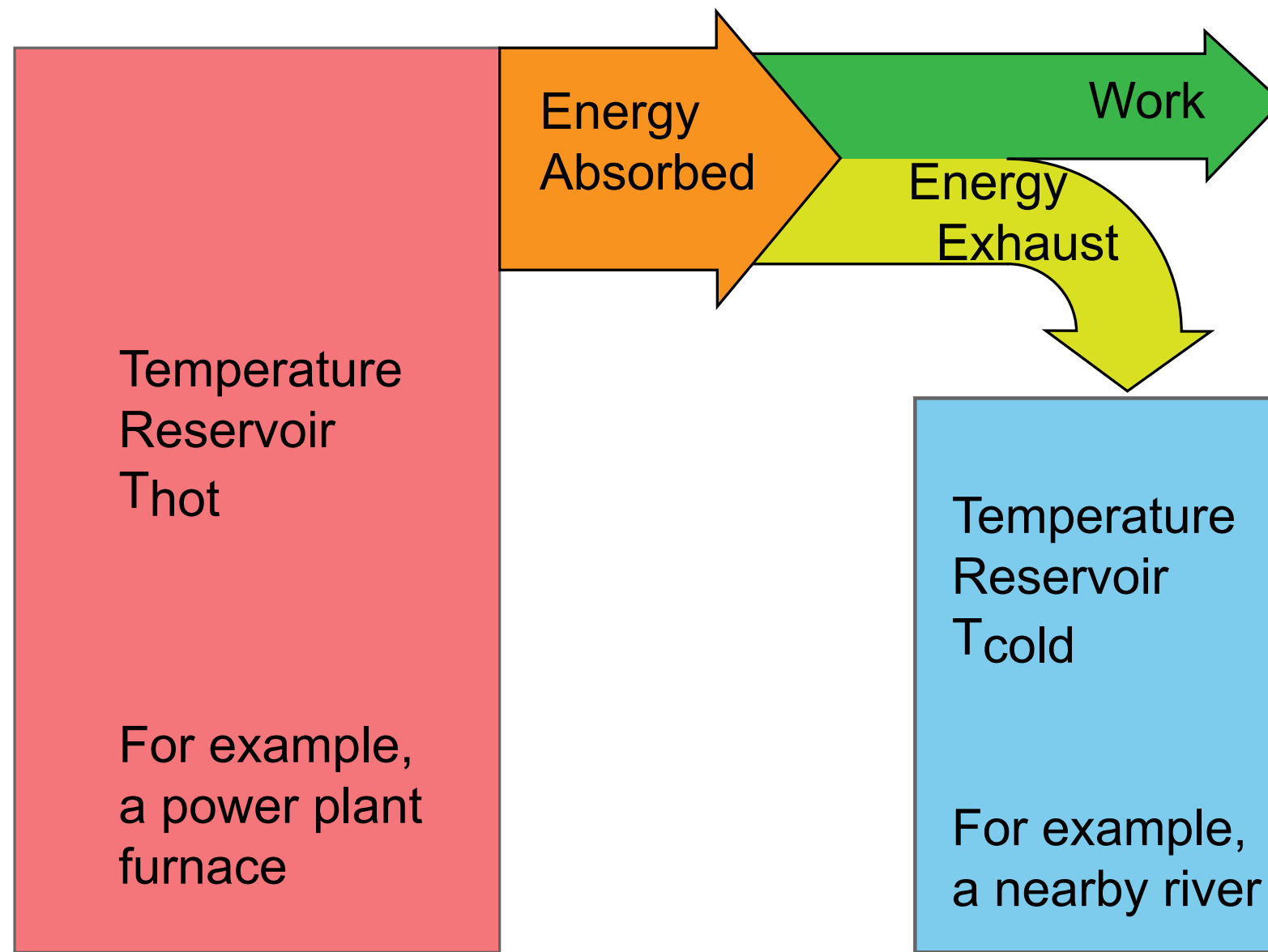
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**Most of our energy generating methods are inherently inefficient: twice as much energy is lost as is used.**



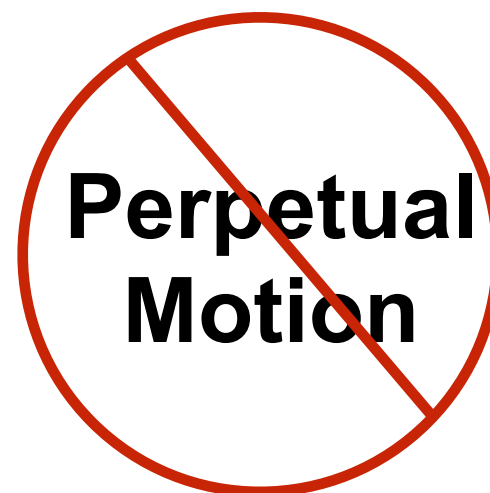
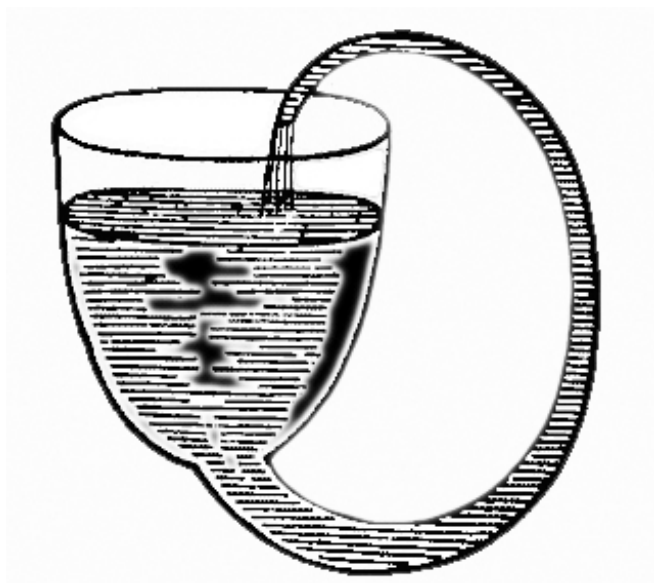
**We have seen that temperature is a measure of thermal energy and that energy is conserved.**

**If work is done, then heat has been transferred or the thermal energy has changed or both.**



**When there is equilibrium, there is no temperature difference. If there is no temperature difference, there is no transfer of heat, so no work can be done.**

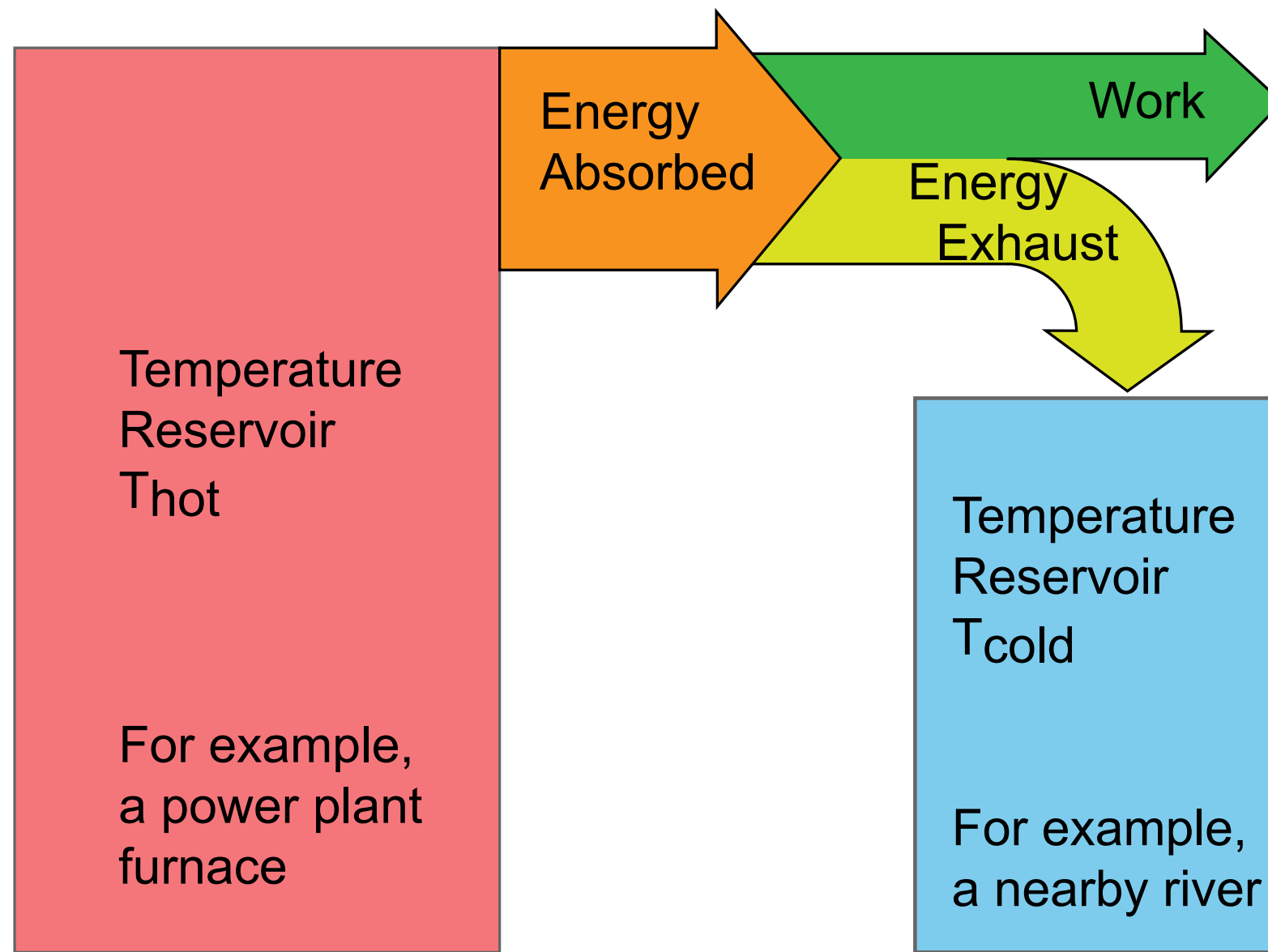
**It is impossible for a machine to take heat from a reservoir at a certain temperature, to produce work, and to exhaust heat to a reservoir at the same temperature.**





**For doing work with a machine, we define efficiency as the ratio of the work done to the energy used to run the machine.**

$$\text{efficiency} = \frac{\text{work output}}{\text{total energy input}}$$



**At a given temperature, there is a total energy in the motion and bonds of the atoms and molecules in a material.**

**If all this energy could be used to do work, we would have the maximum possible efficiency.**



**For our idealized heat engine, we'll assume that all steps can be reversed and retraced.**

**Our ideal engine absorbs heat from a reservoir at temperature  $T_{\text{high}}$ , does work, and exhausts the remaining heat into a reservoir at temperature  $T_{\text{low}}$ . Our engine has an efficiency**

$$\begin{aligned}\text{efficiency} &= \frac{\text{work output}}{\text{total energy input}} \\ &= \frac{\text{energy input at } T_{\text{high}} - \text{energy exhausted at } T_{\text{low}}}{\text{total energy input}} \\ &= \frac{T_{\text{high}} - T_{\text{low}}}{T_{\text{high}}}\end{aligned}$$

**Even though this is an ideal engine, the efficiency is **not 100%** since some energy must be exhausted at a lower temperature.**



**As an example, consider a coal-fired power plant with a boiler temperature of 400 °C (673 K) that uses a local river at 20 °C (293 K) to cool the spent steam.**

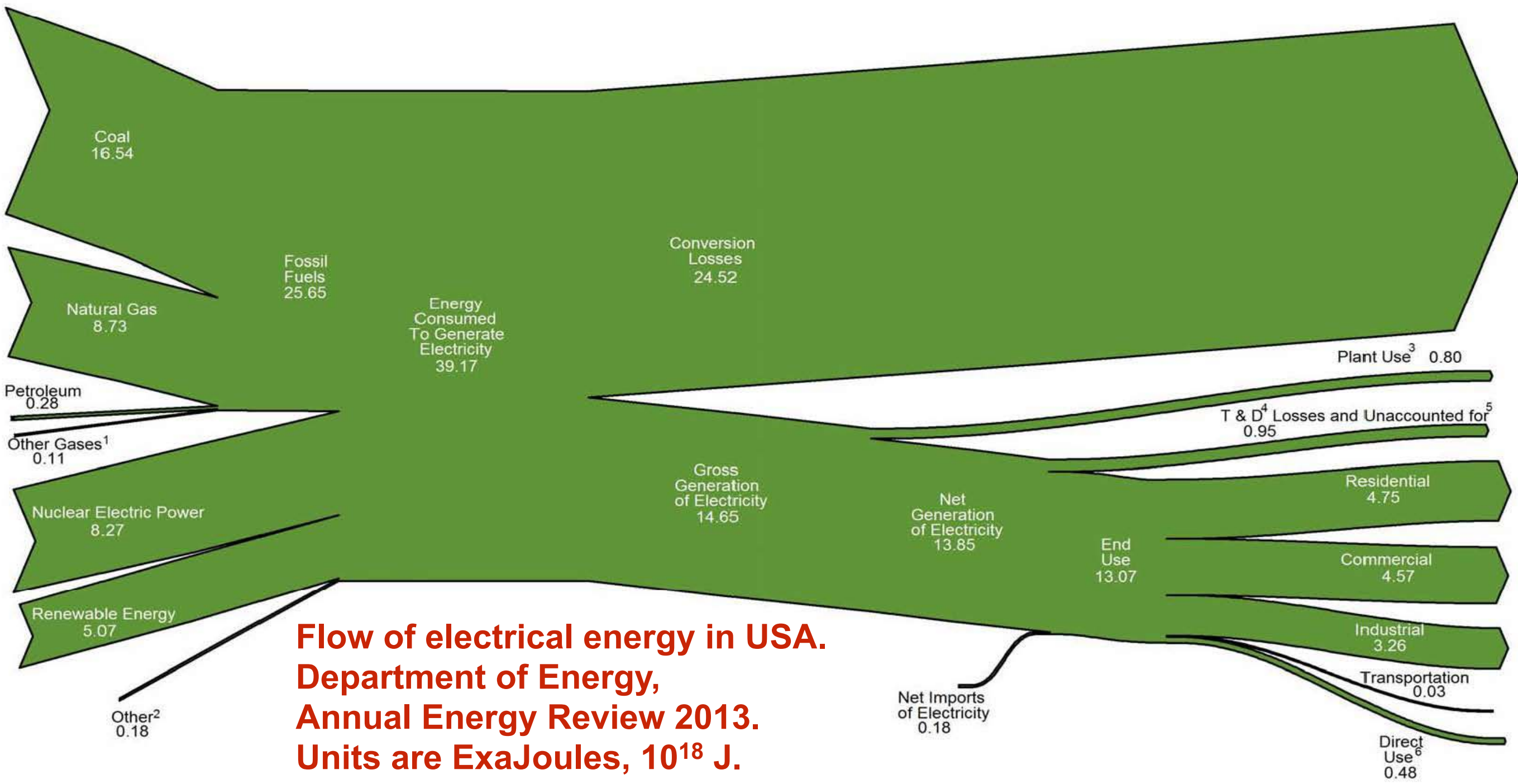


**The maximum efficiency of this power plant is**

$$\text{efficiency} = \frac{T_{\text{high}} - T_{\text{low}}}{T_{\text{high}}} = \frac{673 - 293}{673} = 0.56$$

**This power plant cannot be any more efficient than 56%.**

The actual efficiencies of US fossil-fuel power plants rose from 24.5% in 1950 to 33% today. We can take 1/3 as the actual efficiency, about half of the ideal maximum efficiency.



Flow of electrical energy in USA.  
Department of Energy,  
Annual Energy Review 2013.  
Units are ExaJoules,  $10^{18}$  J.