We often quantify rate of things, and energy is no exception:

\[
\text{Power} = \text{rate of doing work}
\]

e.g., \( W = Fd \)

\[
P = \text{power} = \frac{\Delta W}{\Delta t} = F \frac{\Delta d}{\Delta t} = Fv
\]

Units: mks \( \frac{J}{s} = \text{Watt (W)} = \text{Nm/s} \)

English \( 1 \text{ hp} = 746 \text{ W} = 0.75 \text{ kw} \)

cgs \( \text{erg/s} (\text{no special name}) \)

Practical example: suppose car is traveling 80 mi/hr = 36 m/s constant speed.

Requires force of \( F = 2000 \text{ N} \) to counter air resistance.

\[
\Rightarrow P = Fv = (2000 \text{ N})(36 \text{ m/s}) = 72,000 \text{ W}
\]

\( P = 96.5 \text{ hp against air drag} \)

Problem with air drag is \( F \propto v^2 \)

\[
\Rightarrow P \propto v^3
\]

Power skyrockets as speed increases. If 160 mi/hr \( \Rightarrow P \rightarrow 96.5 \text{ hp} \times 2 = 193 \text{ hp} \).
Another common energy unit multiplies power (rate of energy) times time

\[ 1 \text{ kW} \times 1 \text{ hr} = 1 \text{ kW-hr} \]
\[ = 1000 \text{ W} \times 3600 \text{ s} = 3.6 \text{ MJ (mega Joules)} \]

- Typical toaster \( P = 1 \text{ kW} \) (or hair dryer)
  Toast takes 1 min = 60 sec

\[ \Rightarrow E = (1 \text{ kW})(60 \text{ sec}) = 60 \text{ kJ} \]
\[ = (1 \text{ kW})(1 \text{ hr}) = \frac{1}{60} \text{ kW-hr} \]

\[ \text{MG&E: } 14 \text{¢/kW-hr} \text{ (my latest bill)} \]

\[ \Rightarrow \text{cost} = \frac{1}{60} \text{ kW-hr} \times 14 \text{¢/kW-hr} = 0.23 \text{¢} \]

- 100 W light bulb \( \times 1 \text{ hr} = 0.1 \text{ kW} \times 1 \text{ hr} = 0.1 \text{ kW-hr} \)

\[ \Rightarrow \text{cost} = 0.1 \text{ kW-hr} \times 14 \text{¢/kW-hr} = 1.4 \text{¢} \]

- Frostless Refrigerator \( 600 \text{ W} = 0.6 \text{ kW} \)
  1 Day: \( 0.6 \text{ kW} \times 24 \text{ hr} = 14.4 \text{ kW-hr} \)
  \[ \text{cost: } \$2 \]
Energy Efficiency

\[ \text{Efficiency} = \frac{\text{"useful" work/power}}{\text{input work/power}} \]

Ex. Human climbing a mountain

\[ \text{Work} = \text{mgh} \]
\[ m = 70 \text{ kg} \]
\[ h = 5,000 \text{ ft} = 1500 \text{ m} \]
\[ \Rightarrow \text{work} = 70 \text{ kg} \times 9.8 \text{ m/s}^2 \times 1500 \text{ m} = 1 \times 10^8 \text{ J} \]
\[ = 1 \text{ MJ} \]

Input = food  
1 food "calorie" = 1 kcal = 4184 J

How many food calories?  
Say 4000 food cal = 16 MJ

\[ \Rightarrow \text{efficiency} = \frac{1 \text{ MJ out}}{16 \text{ MJ in}} = 6\% \]

Ex. Automobile

\[ \text{thermal efficiency} = \frac{\text{engine crankshaft power}}{\text{fuel burning power}} \leq 20\% \]

\[ \text{mechanical efficiency} = \frac{\text{power at wheels}}{\text{crank shaft power}} = 80\% \]

\[ \Rightarrow \text{total efficiency} = 20\% \times 80\% = 0.2 \times 0.8 = 16\% \]

Storage

Most of fuel energy goes into waste heat

Problem \[ \Rightarrow \text{Compare electric motor} \approx 100\% \text{ efficiency} \]