Preview

What do you think?

- Imagine a small balloon filled with air at room temperature. Suppose you are holding the balloon in both hands, and you squeeze it into a smaller volume.
    - Has any work been done? Explain.
    - Has heat been transferred into or out of the balloon? Explain.
    - Has the internal energy of the balloon changed? Explain.

Heat, Work, and Internal Energy

- Imagine pulling a nail from a piece of wood.
  - Is this work?
    - Yes, because a force moved the nail across a distance
  - Since work is done, the energy of the nail must be increased. In what way is it increased?
    - The internal energy (*U*) is greater, so the temperature is greater.
  - Now the nail is hotter. What will happen to the internal energy (*U*) of the nail over the next few minutes?
    - The nail transfers internal energy, called heat (*Q*), to the surroundings.

Heat, Work, and Internal Energy

- Imagine placing a balloon over a flask with some water in the bottom. After doing so, place the flask over a flame.
  – Is heat (*Q*) transferred? Why or why not?
    - Yes, because the flame is hotter than the glass.
  – How is the internal energy (*U*) of the water affected?
    - It increases as the temperature rises (*KE* increases) and the water changes into a gas (*PE* increases).
  – Is any work (*W*) done?
    - Yes, in several ways. The steam expands, the balloon moves, and the air outside is pushed away.

Energy in Transit

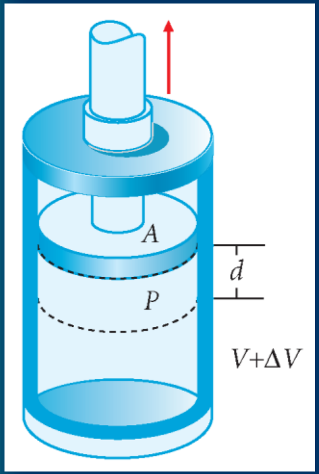
- Heat and work are both energy transferred into or out of a *system*.
- A system consists of the particles or entities chosen to study.
  - The hammer, nail, and surrounding air
  - The flame, flask, water, balloon, and surrounding air

Work Done On or By a Gas

WORK DONE BY A GAS

$$W = P\Delta V$$

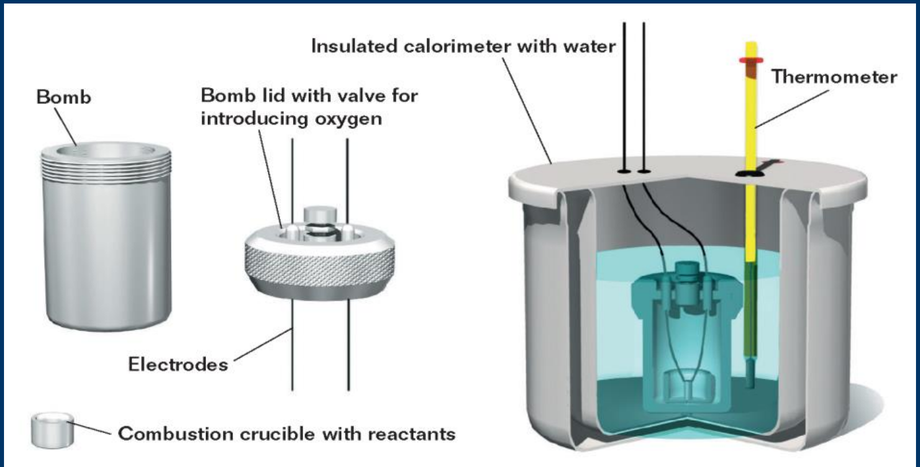
$$\text{work} = \text{pressure} \times \text{volume change}$$



- Work is positive if ΔV is positive or the volume increases.
  - Work is done *by the gas* on the piston.
  - Expanding gases do work on their surroundings.
- Work is negative if the volume decreases.
  - Work is done *on the gas* by the piston.

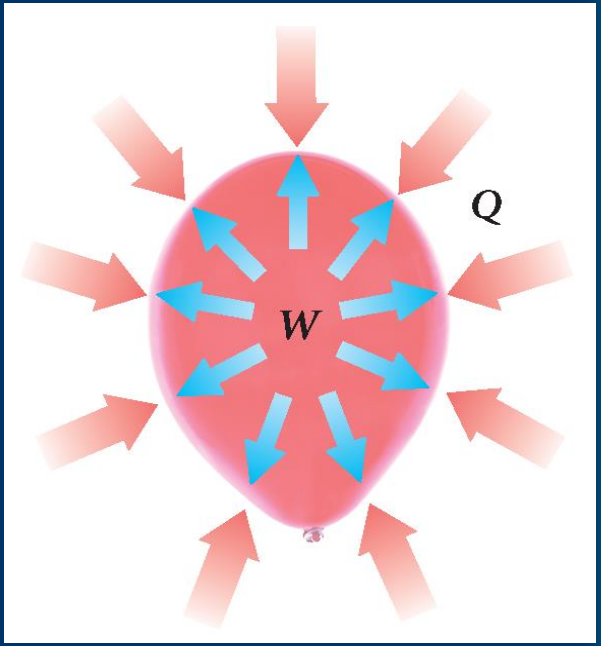
Thermodynamic Processes (*W*, *Q*, and *U*)

- Isovolumetric Process
  - Work (W) = 0 because the volume is constant.
    - Internal energy (U) may change.
    - Heat (Q) may be exchanged.
  - The bomb calorimeter shown below uses an isovolumetric process. Because the walls are rigid, $\Delta V = 0$ and $W = 0$.



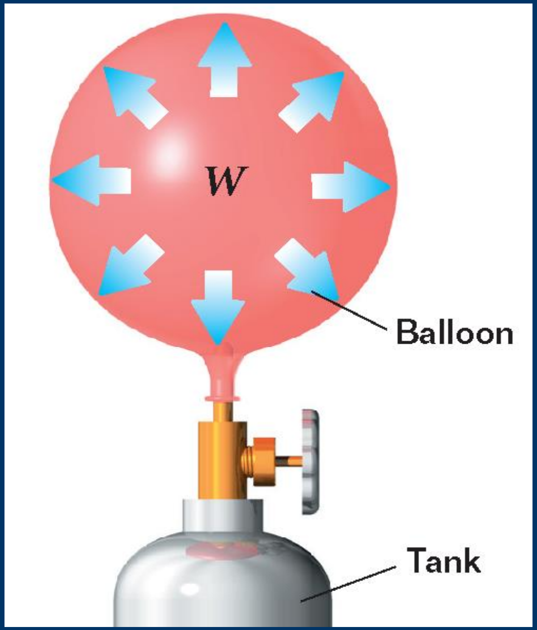
Thermodynamic Processes (*W*, *Q*, and *U*)

- Isothermal process
  - No change in Temperature, so $\Delta U = 0$.
    - Work (*W*) may be done.
    - Heat (*Q*) may be exchanged.
  - A balloon undergoing a gradual drop in pressure is isothermal because it absorbs heat to maintain a constant temperature. As the pressure drops, the balloon expands and starts to cool, but heat enters from the outside air to maintain the temperature.



Thermodynamic Processes (*W*, *Q*, and *U*)

- Adiabatic Process
  - No heat is transferred, so $Q = 0$.
    - Internal energy (U) may change.
    - Work (W) may be done.
  - Filling a balloon from a helium tank is adiabatic. Because the balloon fills so rapidly, no heat can enter or leave the balloon.
  - Very rapid processes are nearly adiabatic.



Comparing Isovolumetric, Isothermal, and Adiabatic Processes

Click below to watch the Visual Concept.

Visual Concept

Now what do you think?

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  - Has the internal energy of the balloon changed? Explain.

Function of Combustion Engines

Mute the sound, and then click below to watch the Visual Concept.

Visual Concept

What do you think?

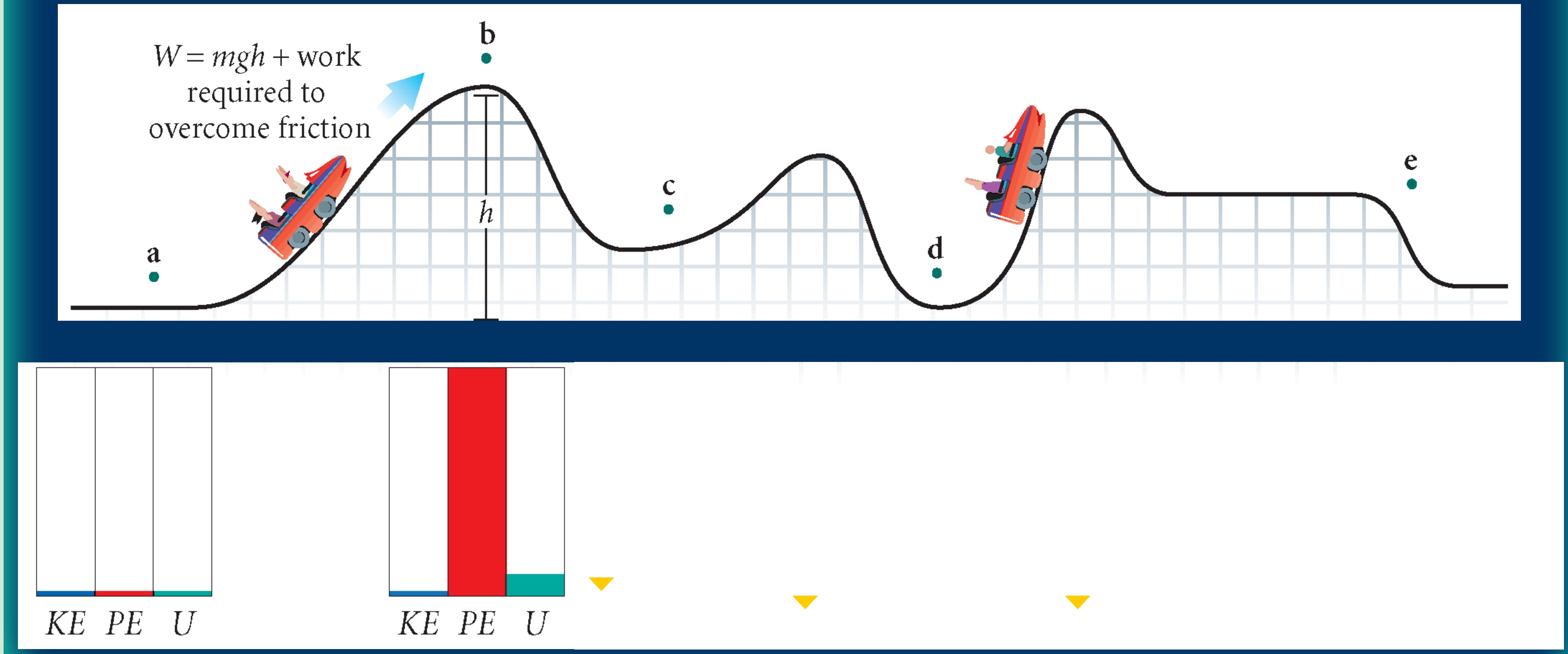
- The 4 strokes are intake, compression, ignition, and exhaust.
    - In which is work done on the gas?
    - In which is work done by the gas on the piston?
    - Which are adiabatic?
    - Which increase the internal energy of the gas?
    - Which decrease the internal energy of the gas?
    - Which transfer heat to the outside environment?

Conservation of Energy

- A "frictionless" roller coaster simply converts *PE* into *KE* and then *KE* into *PE*.
- A real roller coaster has friction, so mechanical energy is not conserved.
  - The track and the wheels have an increase in internal energy (*U*).

Conservation of Energy

Predict the appearance of the bar graphs at points c, d, and e.



Conservation of Energy

Click below to watch the Visual Concept.

Visual Concept

THE FIRST LAW OF THERMODYNAMICS

$$\Delta U = Q - W$$

Change in system's internal energy = energy transferred to or from system as heat – energy transferred to or from system as work

Table 1 Signs of *Q* and *W* for a System

$Q > 0$	energy added to system as heat
$Q < 0$	energy removed from system as heat
$Q = 0$	no transfer of energy as heat
$W > 0$	work done by system (expansion of gas)
$W < 0$	work done on system (compression of gas)
$W = 0$	no work done

First Law of Thermodynamics for Special Processes

Click below to watch the Visual Concept.

Visual Concept

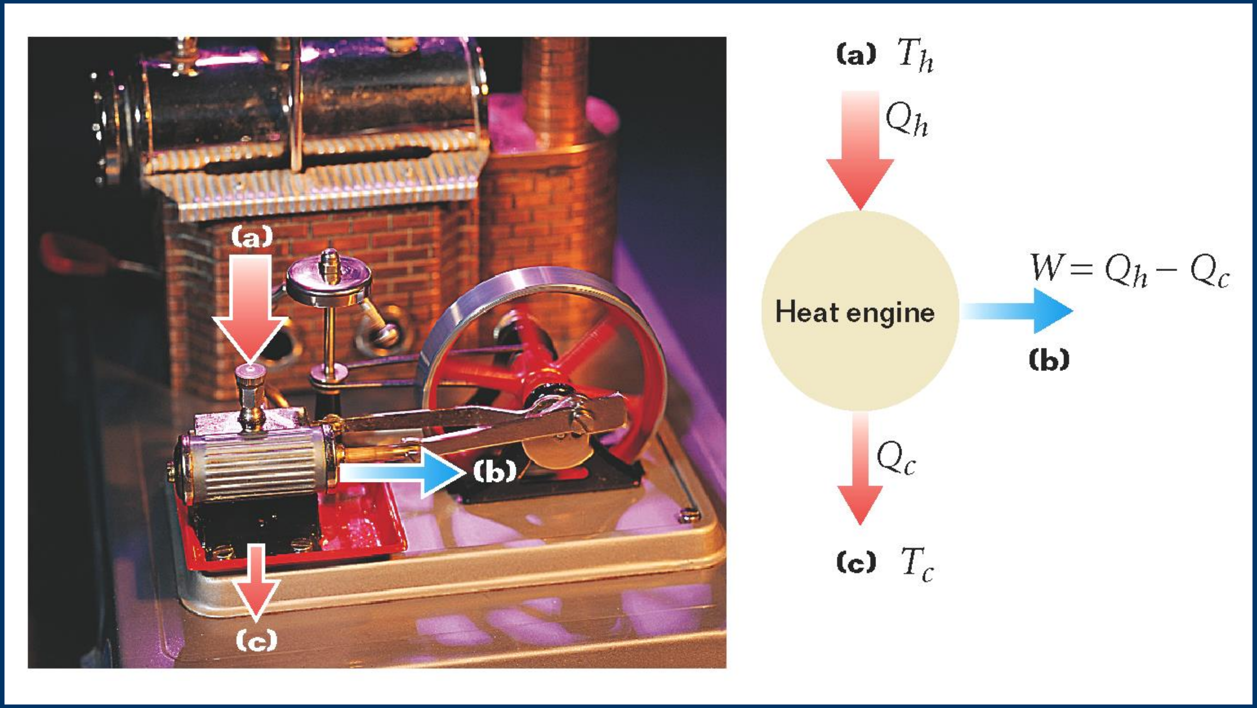
Classroom Practice Problems

- A gas is trapped in a small metal cylinder with a movable piston and is submerged in a large amount of ice water. The initial temperature of the gas is 0° C. A total of 1200 J of work is done on the gas by a force that *slowly* pushes the piston inward.
  - Is this process isothermal, adiabatic or isovolumetric?
    - Answer: isothermal
  - How much energy is transferred as heat between the gas and the ice water?
    - Answer: 1200 J
  - How much ice would melt as a result of this heat transfer?
    - Answer: 3.60 g

Heat Engines

- The process is cyclic, so the working fluid returns to its initial temperature and pressure.
  - $\Delta U = 0$ so $Q_{net} = W_{net}$
- Heat engines take heat from a substance at a high temperature, use that energy to do some work, and then expel the substance at a lower temperature.
  - Internal combustion engines are heat engines.
    - Hot gases do work on the piston and then are expelled to a lower-temperature environment.

Steam Engines



- Hot steam enters (a), does work on the piston (b), and, now colder, it is exhausted to the room (c).

Refrigerators

- Refrigerators are the opposite of heat engines.
  - Heat moves from a lower temperature (inside) to a higher temperature (outside) by doing work.
    - This does not violate the rule that heat flows from hot to cold because work is done to move heat in the opposite direction.
- Air conditioning systems follow the same principle.

Refrigeration

Click below to watch the Visual Concept.

Visual Concept

Function of Combustion Engines

Click below to watch the Visual Concept.

Visual Concept

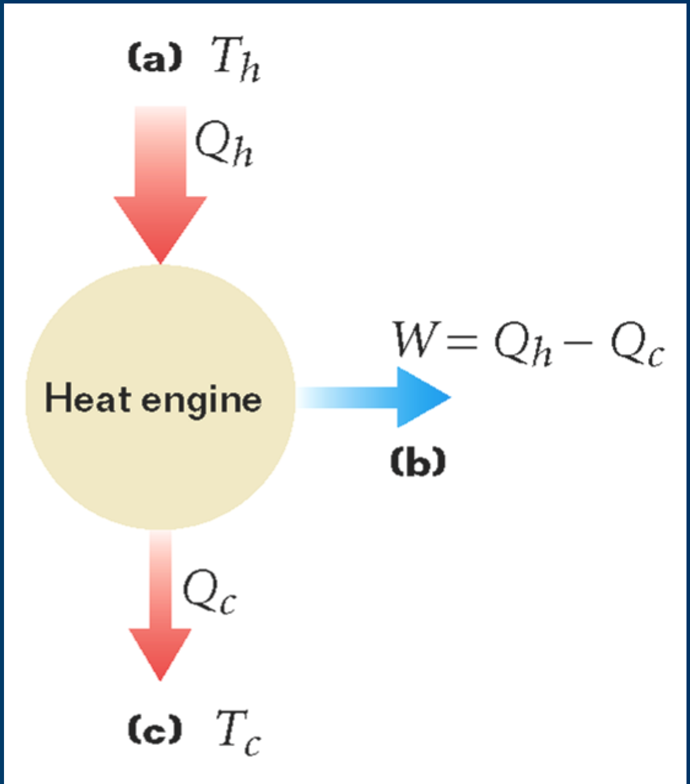
Now what do you think?

- The 4 strokes are intake, compression, ignition, and exhaust.
  - In which is work done on the gas?
  - In which is work done by the gas on the piston?
  - Which are adiabatic?
  - Which increase the internal energy of the gas?
  - Which decrease the internal energy of the gas?
  - Which transfer heat to the outside environment?

What do you think?

- The high cost of gasoline and environmental issues associated with internal combustion engines are important issues. A partial solution to these problems would be more efficient engines.
  - What does the term *efficiency* mean when applied to engines?
  - How efficient do you think present engines are when given as a percentage?
  - Can the efficiency be improved? If so, how?

Efficiency of Heat Engines



- $W_{out} = Q_h - Q_c$
  - Work done is heat added minus heat expelled.
- Efficiency measures the work out as a fraction of the heat added.
  - Suppose 100 J of heat enter the engine and it does 35 J of work. How efficient is the engine?
    - 35% or 0.35

Efficiency

EQUATION FOR THE EFFICIENCY OF A HEAT ENGINE

$$eff = \frac{W_{net}}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

$$\textbf{efficiency} = \frac{\text{net work done by engine}}{\text{energy added to engine as heat}}$$

$$= \frac{\text{energy added as heat} - \text{energy removed as heat}}{\text{energy added as heat}}$$

$$= 1 - \frac{\text{energy removed as heat}}{\text{energy added as heat}}$$

Efficiency and the Second Law of Thermodynamics

- Efficiency = 1 or 100% only if $Q_c = 0$
  - This means all heat input is converted to work with no heat expelled to the environment.
  - The laws of thermodynamics require some heat output for all cyclic processes, so no such engine exists.
- Second Law of Thermodynamics
  - No cyclic process that converts heat entirely into work is possible.

Classroom Practice Problems

- A steam engine takes in 198 x 10^3 J and exhausts 149 $\times$ 10^3 J as heat per cycle.
  - How much work is done during each cycle?
  - What is the efficiency of the engine?
- Answers: 49 $\times$ 10^3 J, 0.247 or 24.7%

Engine Efficiencies

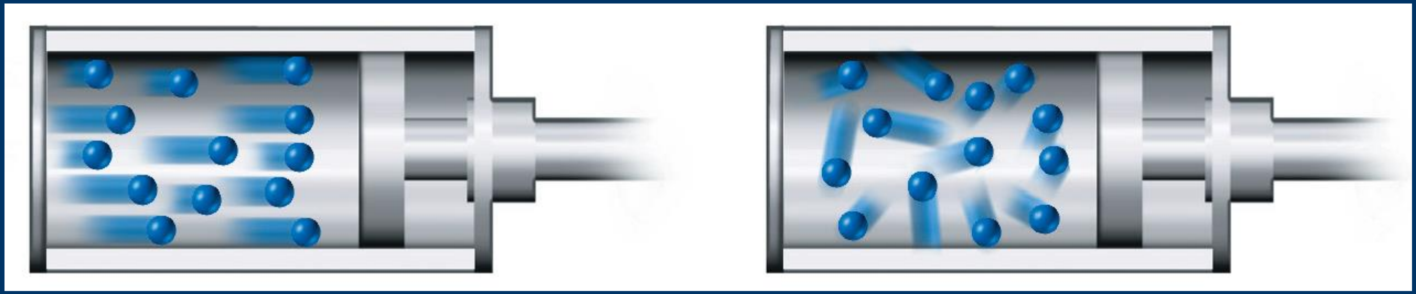
Engine Type	*eff* (calculated maximum values)	*eff* (measured values)
Steam engine	0.29	0.17
Steam turbine	0.40	0.30
Gasoline engine	0.60	0.25
Diesel engine	0.56	0.35

- Friction and heat loss through conduction lower the maximum values to the measured values.

Entropy

- Entropy provides another way to look at the 2nd law of thermodynamics.
- Entropy is a measure of the disorder or randomness of a system.
  - More disorder implies greater entropy.
    - Steam has more entropy than water.
    - Hot air has more entropy than cold air.

Entropy and Work



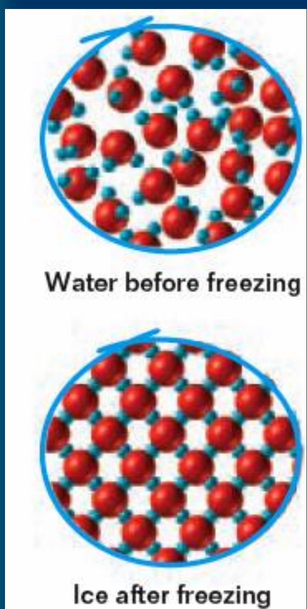
- Which gas shown above will be most effective when doing work on the piston?
  - The gas on the left (because all of the molecules will transfer their energy to the piston)
- Which is the most likely arrangement of molecules?
  - The gas on the right is most likely. The left diagram is highly improbable.
- Which has higher entropy?
  - The gas on the right is very disordered and thus has higher entropy.

Entropy and the 2nd Law

- An equivalent version of the second law of thermodynamics is given below:
  - In all naturally occurring processes, the entropy of the universe increases.
- A tendency toward disorder is related to the waste heat (Q_c) in heat engines.

Entropy and the 2nd law

- Imagine an experiment in which water is left outside to freeze.



  – What happens to the entropy of the water during the freezing process?
    - It decreases because ice is more ordered than water.

  – What happens to the entropy of the air surrounding the freezing water? Recall that the freezing process releases heat.
    - It increases because the air becomes more disordered as it absorbs heat and the temperature increases.

  – What happens to the overall entropy?
    - The increase for the air is greater than the decrease for the water, so entropy increases.

Entropy of the Universe

Click below to watch the Visual Concept.

Visual Concept

Now what do you think?

- The high cost of gasoline and environmental issues associated with internal combustion engines are important issues. A partial solution to these problems would be more efficient engines.
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