Week 1: Everything Is Electric
Week 2: Is It Magic, or Is It Magnets?
Week 3: On Your Wavelength: Electromagnetic Waves
Week 4: Physics of Sound & Music
Week 5: Energy, Thermodynamics & The Arrow of Time
Week 6: Push and Pull: Force & Motion
Week 7: Go With the Flow: Physics of Fluids
Week 8: A Warm Planet in a Cold Universe: How the Earth Stays Warm, and Why It's Getting Warmer

Physics Principles

Forms of Energy

Energy Conservation

Power

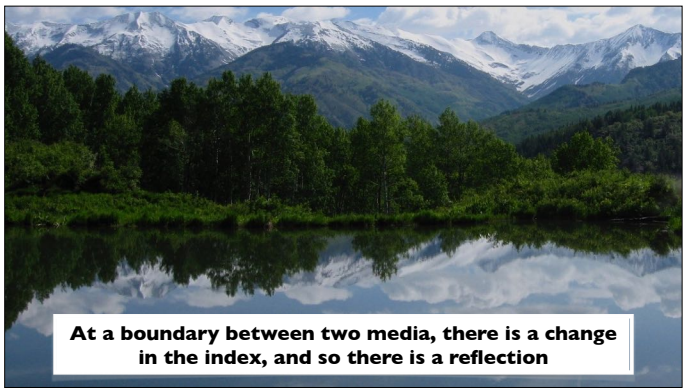
Thermal Energy

Heat Engines

Heat Pumps

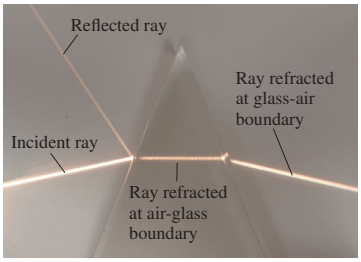
The Arrow of Time

First: A Return to the Rainbow

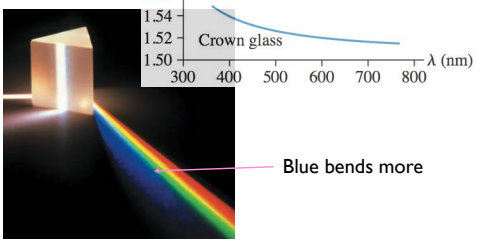


At a boundary between two media, there is a change in the index, and so there is a reflection

A difference in index causes bending (refraction) too.



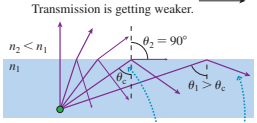
Dispersion



Blue bends more

Total Internal Reflection

Angle of incidence is increasing.
Transmission is getting weaker.

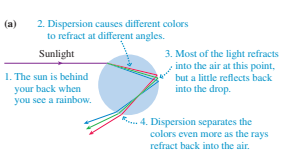


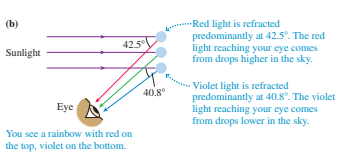
Critical angle is when $\theta_2 = 90°$.
Reflection is getting stronger.
Total internal reflection occurs when $\theta_1 > \theta_c$.

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Critical angle of incidence for total internal reflection

Making a Rainbow





Energy
The universal currency for making things happen.

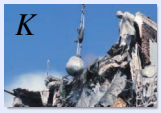
And Energy Has a Special Property

Energy is conserved.
It cannot be created or destroyed.
It can only be converted from one form to another.

This is a law of nature that is universal:
It applies in all places at all times, absolutely.

Energy comes in many different forms.

Mechanical energy:

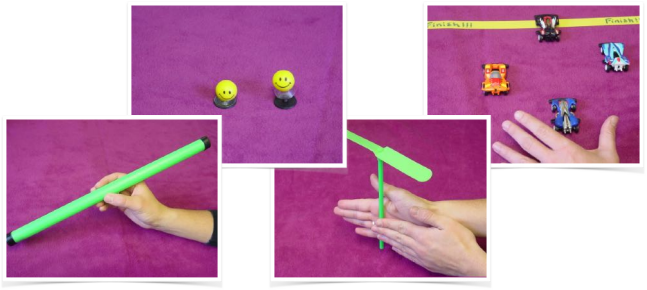


Thermal energy:

Other forms include:

E_{chem} $E_{nuclear}$

Energy Toys

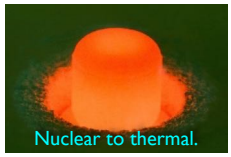


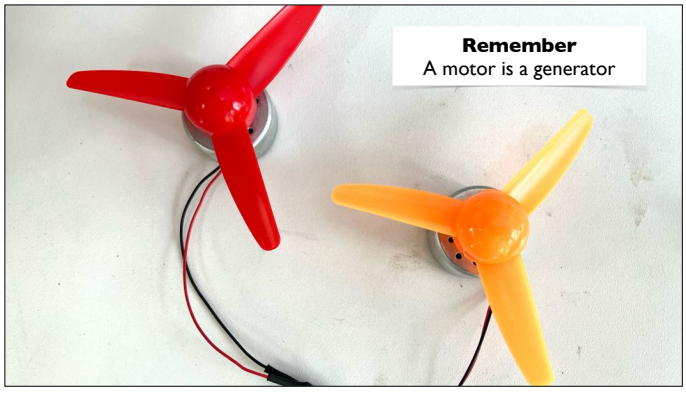
Explain the operation in terms of forms of energy.

Forms of Energy

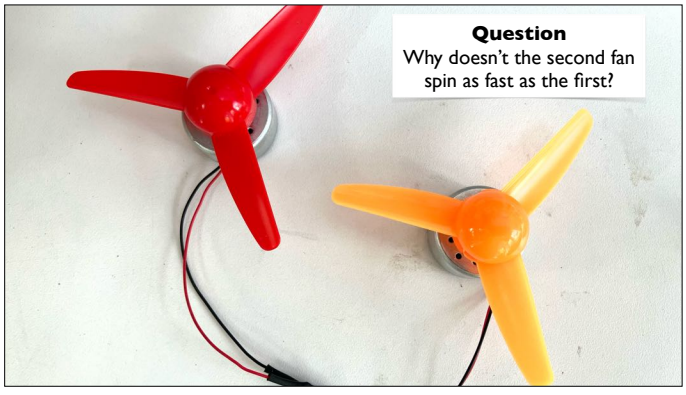
Kinetic energy	Energy of motion. If something is moving, it has kinetic energy. Moving faster means more kinetic energy.
Gravitational potential energy	If something is up high, it has a lot; if something is down low, it doesn't.
Elastic potential energy	Stored in springs, or in springy materials. More stretch means more energy.
Radiant energy	The energy of light and other waves, like microwaves.
Electric energy	The energy of moving charges in circuits.
Chemical energy	Energy stored in the form of chemical: Food, fuel and the like.
Nuclear energy	Energy stored in the nuclei of atoms.
Thermal energy	When something is hot, it has a lot; when it is cold, it has a little.

Thermal Energy is Special.

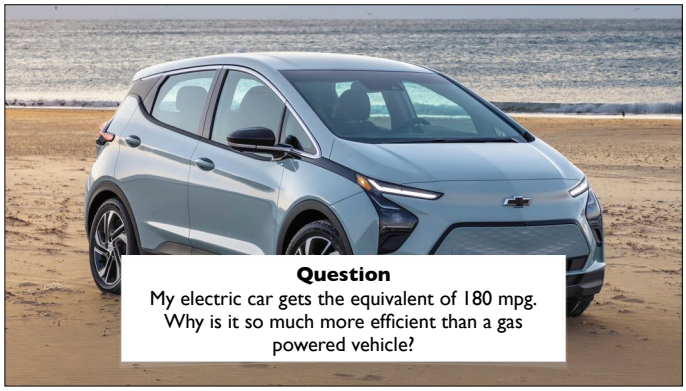




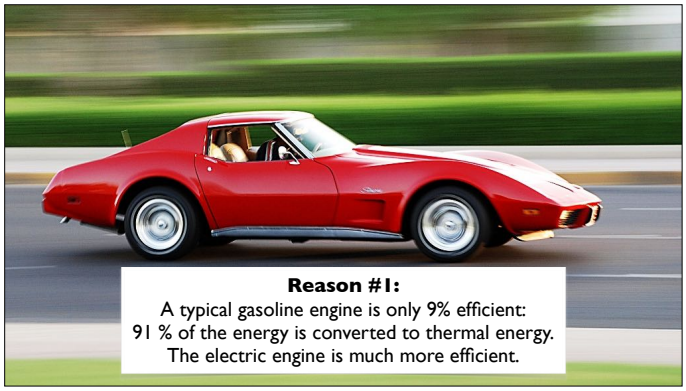
Remember
A motor is a generator



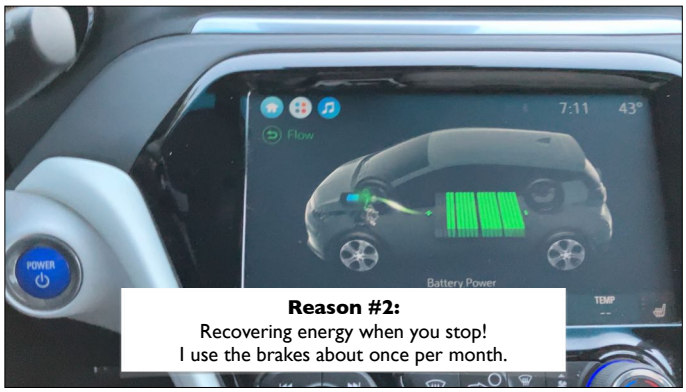
Question
Why doesn't the second fan spin as fast as the first?



Question
My electric car gets the equivalent of 180 mpg. Why is it so much more efficient than a gas powered vehicle?



Reason #1:
A typical gasoline engine is only 9% efficient: 91 % of the energy is converted to thermal energy. The electric engine is much more efficient.



Reason #2:
Recovering energy when you stop!
I use the brakes about once per month.

Power

Transformation: $P = \frac{\Delta E}{\Delta t}$

Transfer: $P = \frac{W}{\Delta t}$

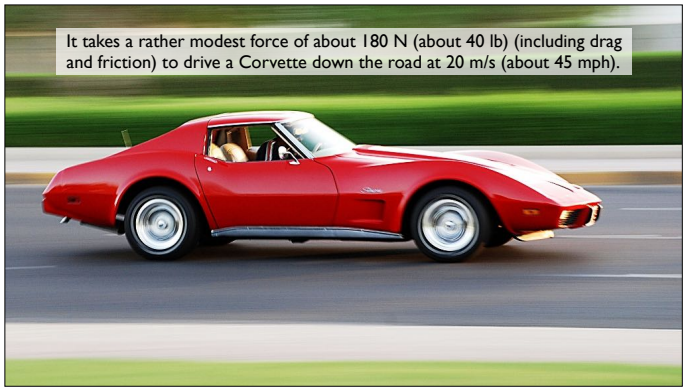
Unit:
J/s = W

Power is a rate...

- Same mass...
- Both reach 60 mph...

Same final kinetic energy, but **different times mean different powers.**

Device	Typical Power
Laptop	10 W
LED bulb for reading	20 W
Television	60 W
Refrigerator	600 W
Vacuum Cleaner	1000 W
Typical Home, Excluding Heating and Cooling	1000 W
Toaster	1500 W
Clothes Dryer	5000 W
Electric Car	1,000 W to 150,000 W



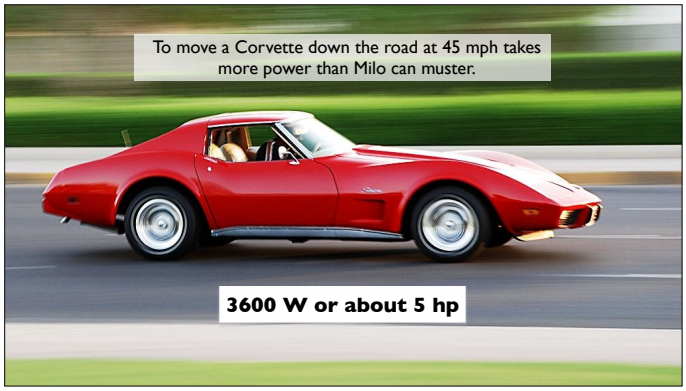
It takes a rather modest force of about 180 N (about 40 lb) (including drag and friction) to drive a Corvette down the road at 20 m/s (about 45 mph).

Milo:
Mass: 25 kg
Max pulling force: 200 N

Milo:

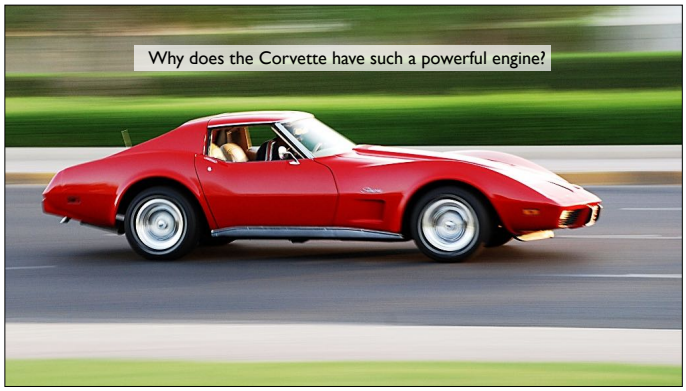
Mass:	25 kg
Max pulling force:	200 N
Max power output:	about 750 W (about 1 hp)
Max sustained power:	about 200 W

To move a Corvette down the road at 45 mph takes more power than Milo can muster.

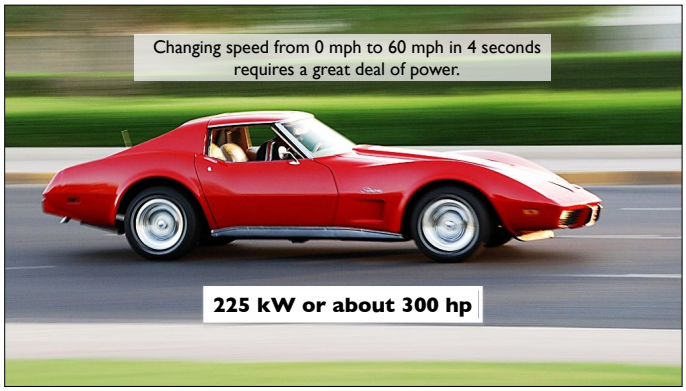


3600 W or about 5 hp

Why does the Corvette have such a powerful engine?



Changing speed from 0 mph to 60 mph in 4 seconds requires a great deal of power.



225 kW or about 300 hp

An elite 70 kg human sprinter can accelerate from rest to 10 m/s in 3.0 s.

The power output is pretty modest….

1200 W = 1.6 hp

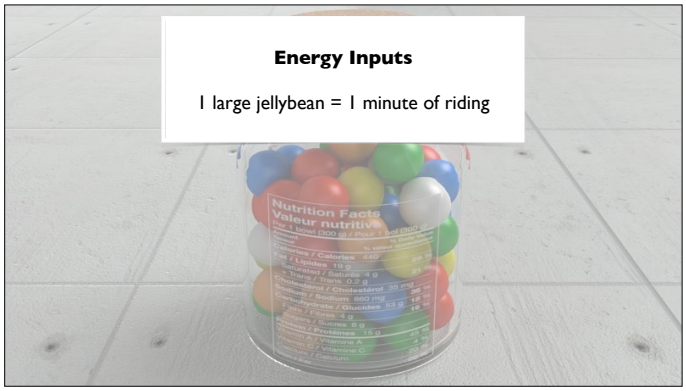
Pedaling my recumbent tricycle at a steady 12 mph requires about 180 W of energy output.

If I cycle at a steady speed of 12 mph, my power output is about 180 W. My body is using about 720 W of chemical energy.

Where does this energy come from?

Energy Inputs

1 large jellybean = 1 minute of riding



When You Make Energy, You Make Water.

Glucose from the digestion of food combines with oxygen that is breathed in to produce...

...carbon dioxide, which is exhaled, water, which can be used by the body, and energy.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Glucose — Oxygen — Carbon dioxide — Water

Glucose from the digestion of food combines with oxygen that is breathed in to produce...

...carbon dioxide, which is exhaled, water, which can be used by the body, and energy.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

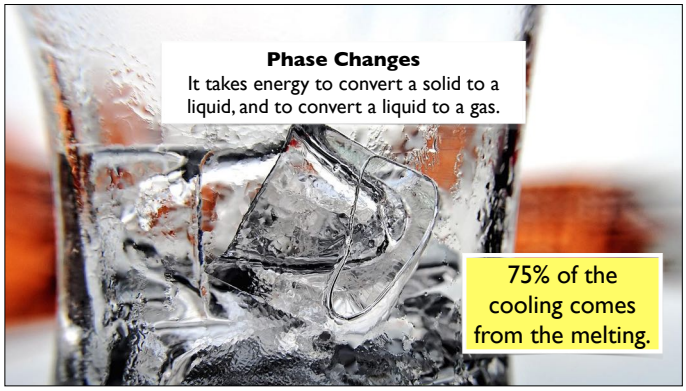
Glucose — Oxygen — Carbon dioxide — Water

Making water

If I cycle at a steady speed of 12 mph, my power output is about 180 W. My body is using about 720 W of chemical energy.

Where does this energy go?

How does my body get rid of the excess thermal energy?



Phase Changes

It takes energy to convert a solid to a liquid, and to convert a liquid to a gas.

75% of the cooling comes from the melting.

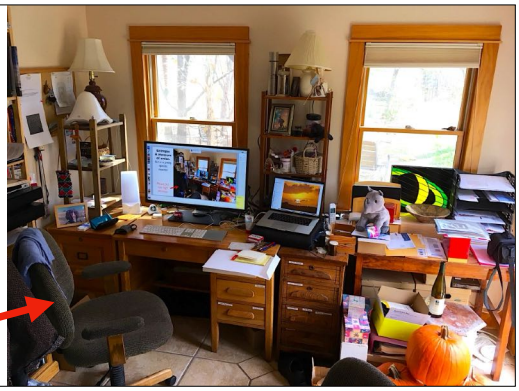
Cooling Cocoa

Why does blowing on a hot cup of cocoa cool it off?

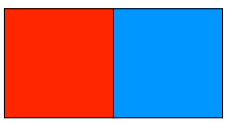
Entropy: A measure of disorder.

But in a pretty specific manner.

Messy, but not high entropy.



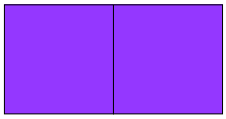
Entropy



Ordered

There is a temperature difference, so you can distinguish between the two sides.

Low entropy

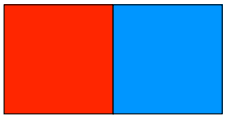


Disordered

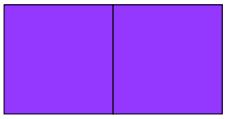
The energy is spread out evenly, so you can't distinguish between the two sides.

High entropy

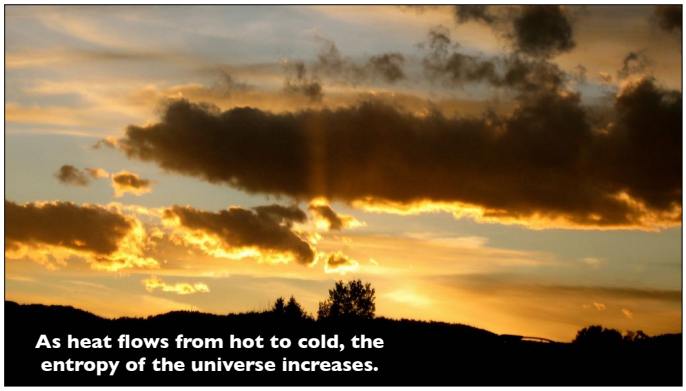
This means an increase in entropy.

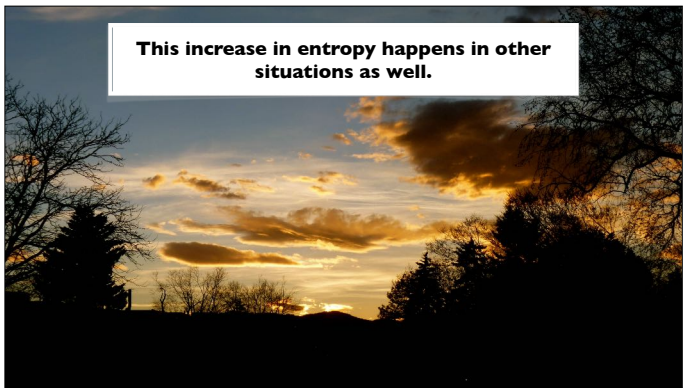


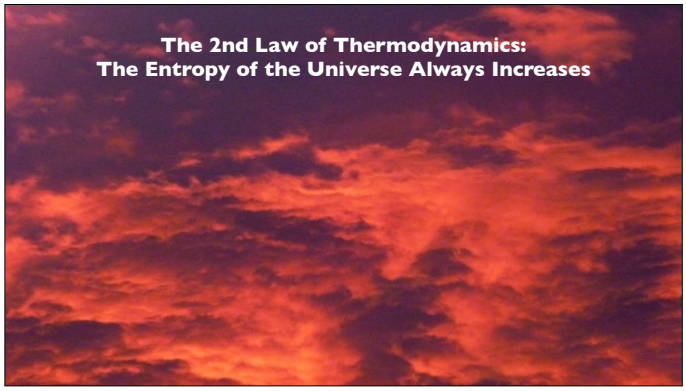
You can tell the difference. There is order.



You can't tell the difference. There is disorder.





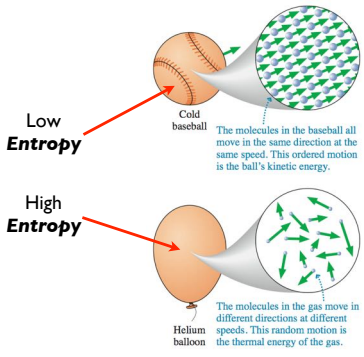


The Second Law of Thermodynamics

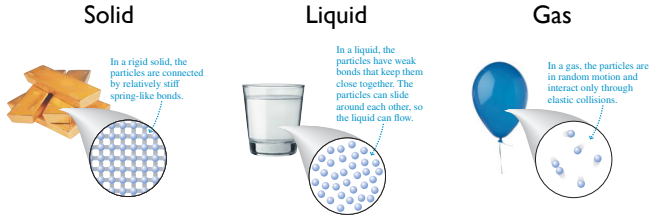
TABLE 11.5 Alternative statements of the second law of thermodynamics

Phenomenon	Related Statement of the Second Law
Heat energy spontaneously flows from hot to cold.	When two systems at different temperatures interact, heat energy is transferred spontaneously from the hotter to the colder system, never from the colder to the hotter.
Entropy considerations limit the possible efficiency of a heat engine.	It is not possible to make a heat engine that converts thermal energy into an equivalent amount of work.
It takes energy to move heat from a cold object to a warm object.	It is not possible to make a heat pump that moves heat from a cold object to a hot object without an external energy input.
The entropy of an isolated system will never spontaneously decrease.	The time direction in which the entropy of an isolated system increases is "the future."

Thermal energy has entropy. Other forms don't.



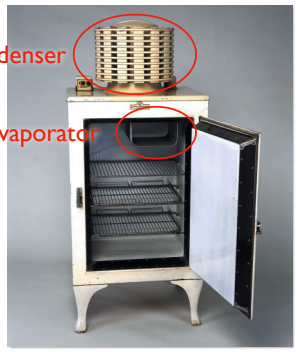
Different forms of matter have different entropy.



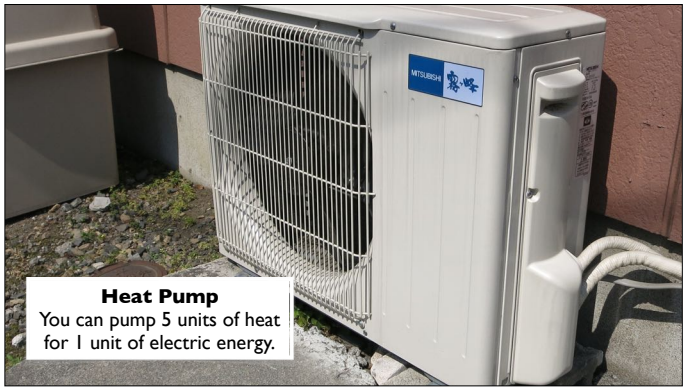
Freezing is hot???
Why does heat come out of the pack as it freezes?

How does entropy change?
What happens to the entropy of the pack as it freezes?
The entropy of the surrounding environment?

Heat Pumps

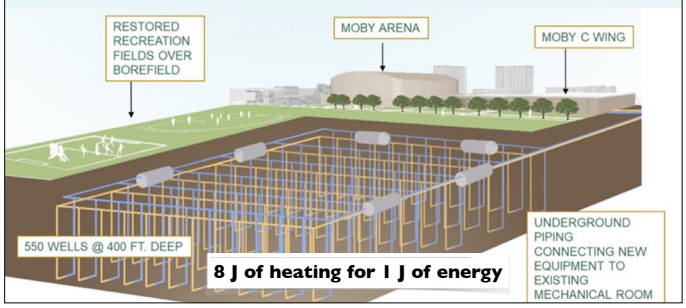


When You Stretch a Rubber Band…
…you straighten out the polymers.

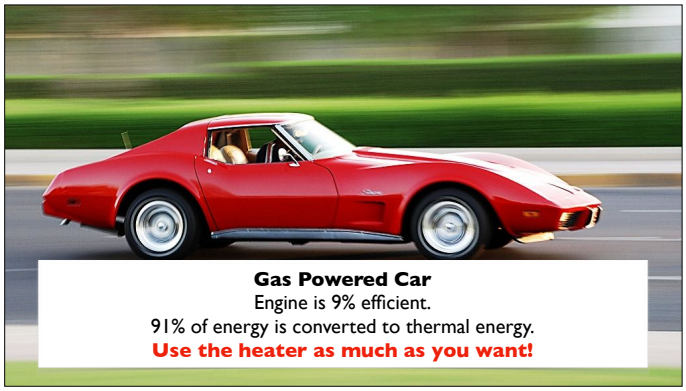


Heat Pump
You can pump 5 units of heat for 1 unit of electric energy.

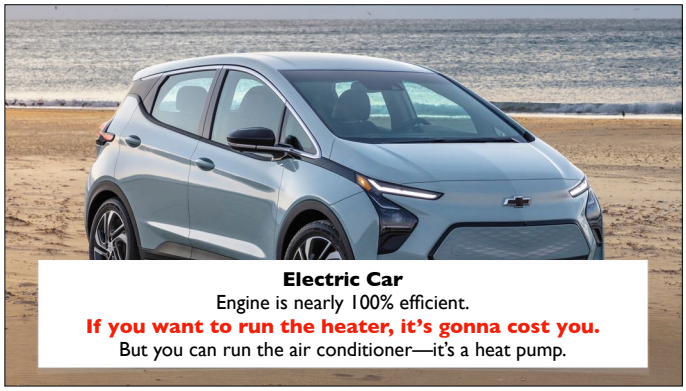
50°F water from underground used for cooling system.
50°F water from underground used to make 120°F water for heating system.



Electric Heater
1 unit of heat costs
1 unit of electric energy

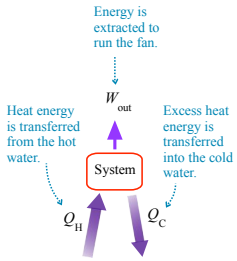


Gas Powered Car
Engine is 9% efficient.
91% of energy is converted to thermal energy.
Use the heater as much as you want!

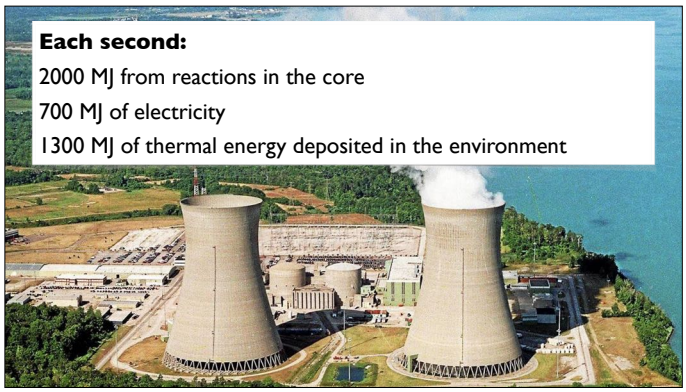


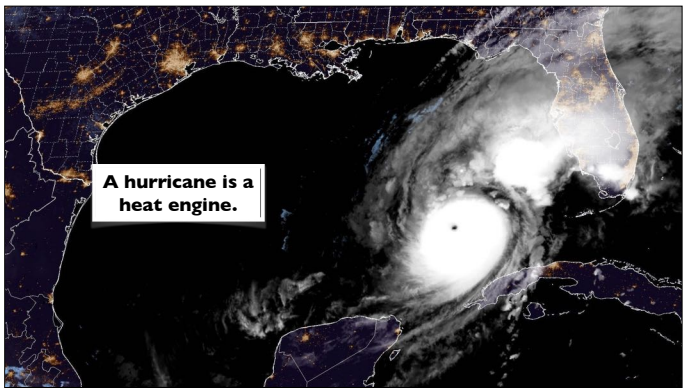
Electric Car
Engine is nearly 100% efficient.
If you want to run the heater, it's gonna cost you.
But you can run the air conditioner—it's a heat pump.

Heat Engines



Each second:
2000 MJ from reactions in the core
700 MJ of electricity
1300 MJ of thermal energy deposited in the environment

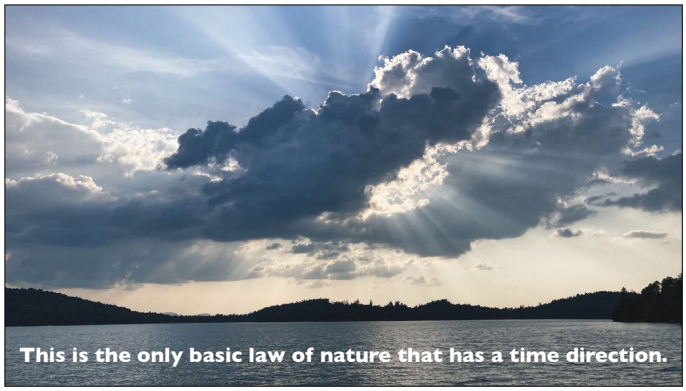




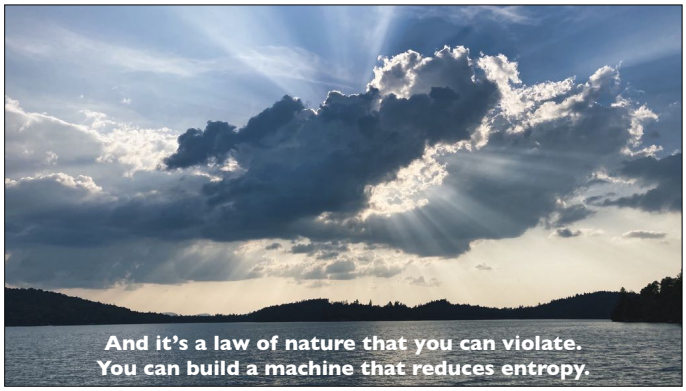
A hurricane is a heat engine.

The Arrow of Time
What distinguishes the past from the future?

Entropy is higher in the future.



This is the only basic law of nature that has a time direction.



And it's a law of nature that you can violate.
You can build a machine that reduces entropy.