PSc 320

Class 3 Combustion, Heat Engines

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Heat Engines

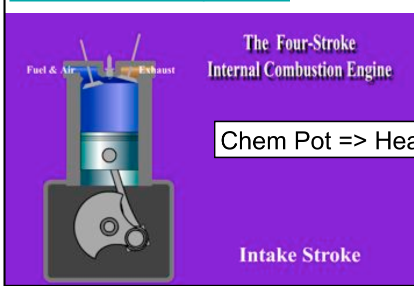
Fuel + O_2 => Heat + CO_2 + (?) => Work

Burning
Combustion
Oxidation

PV = nRT
Pressure * Volume =
number of moles * gas constant * $T_{(Kelvin)}$

Heat Engines
1) You do work on a gas, compressing it (it *takes* work from you)
2) You heat up the gas (a lot)
3) It does (way more) work for you expanding than you did compressing it. Because W = P*V

http://www.animatedengines.com/



OTTO CYCLE

Chem Pot => Heat => (Work)

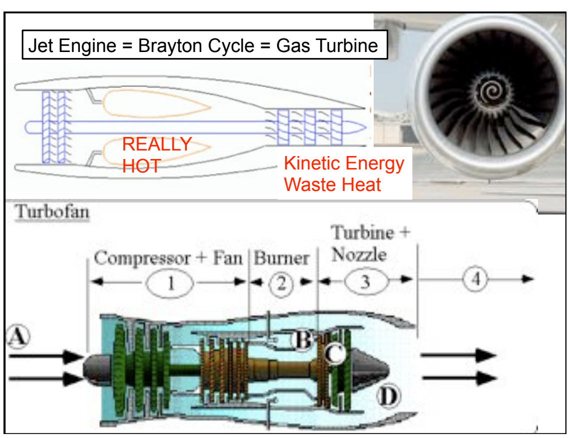
Work = force * distance, P = W/t = Force * speed

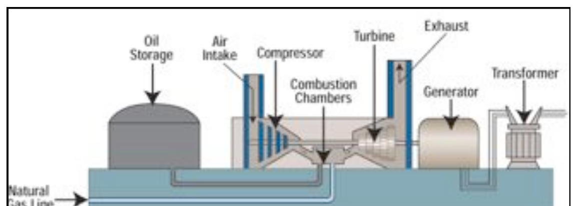
P (rotational) = torque * rotation *rate*

Power (fluid) = Pressure * Flow *rate*

P (electrical) = voltage * electrical current

Jet Engine = Brayton Cycle = Gas Turbine

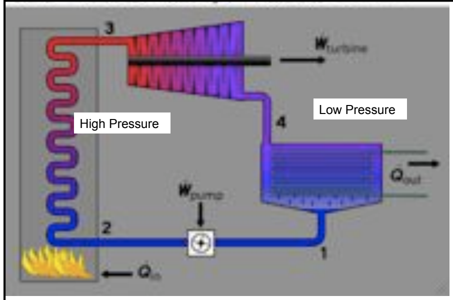




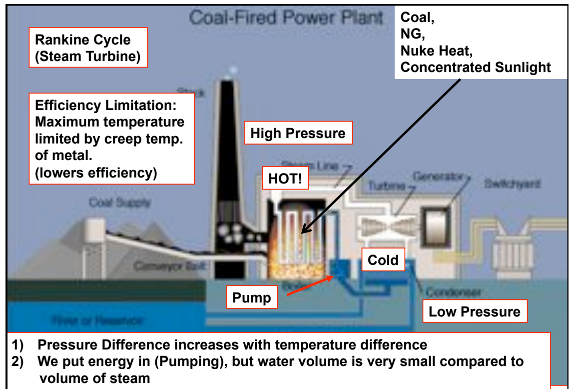
Brayton Cycle ~ Jet Engine

Efficiency Limitation: Much lost heat in Exhaust

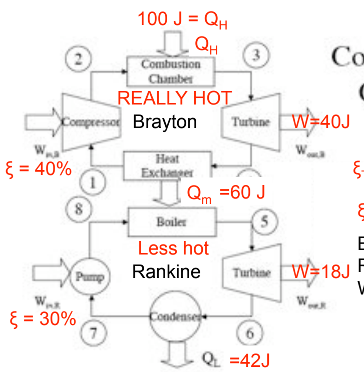
http://www.eas.asu.edu/~holbert/eee463/combustion_turbine.gif



Rankin Cycle, Steam Turbine



http://www.eas.asu.edu/~holbert/eee463/coalart.gif



Combined Cycle

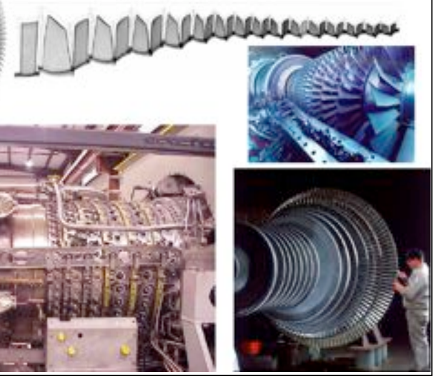
$\xi_T = \xi_B + \xi_R$? >100%! NO!

$\xi_T = \xi_B + \xi_R(1-\xi_B) = 58\%$

Brayton Cycle Hot,
Rankine cycle cold
What could we do?

……….

Compressors and Turbines

Power Plants and Advantages

Simple Cycle: Usually Rankine (Steam Turbine)
- **Coal, NG, (Nuke, Solar)**
- **Cheap but inefficient (~35%)**
- **More fuel costs, more carbon**

Brayton Cycle (gas turbine): Requires gaseous fuels
- **more efficient (~40%), expensive**

Combined Cycle: Brayton + Rankine
- **NGCC**
- **More expensive, cleaner, more efficient (~ 60%)**
- **Lower fuel costs, less carbon**

Connection to Environment

- Fuel Side: Mining, drilling, transporting
- Waste Heat Side:
  - Increase temperature of body of water
    - Affect fish, algae blooms, etc.
  - Pollutants in waste heat stream
    - Air pollutants
    - Pollutants in waste water stream
- Environmental justice
  - Location, impact & management of power plants

WHO estimates 600,000 deaths in China per year from coal exhaust

Fuel + O_2 => Heat + CO_2 + (?) => Work

Combustion of Fuel for energy

C + O_2 => CO_2 Carbon

Methane: biggest portion of natural gas (NG):
CH_4 + $2O_2$ => CO_2 + $2H_2O$

Petroleum: hydrocarbon chains of various lengths:
$C_nH_{2n+2?}$ + $?O_2$ => nCO_2 + $?H_2O$

Coal: very complex: rich in carbon with O, H, other stuff
$C_nO_?$CRAP + $?O_2$ => nCO_2 + $?H_2O$ + Yuck

(CO_2)/Energy: carbon intensity of our energy

Carbon Intensity of some Fuels:

http://en.wikipedia.org/wiki/Emission_intensity

Fuel	g(C)/MJ	g(CO_2)/MJ
Natural Gas:	15	51
Petroleum:	20	73
Coal:	25	92
Wood:	~ 30	110

$$\frac{CO_2}{\text{Energy released}}$$

Masses (AMU)	
Hydrogen:	1
Carbon:	12
Nitrogen:	14
Oxygen:	16

CO_2: 12 + 2x16 = 44

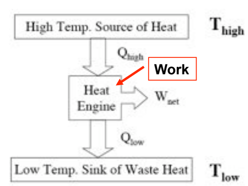
$$\frac{m_{CO_2}}{m_C} = \frac{44}{12} = 3\tfrac{2}{3}$$

CO_2 or C?: You MUST Specify Units

Quiz, #1: In a heat engine:

A)All the work in is changed to heat
B)All the heat in is changed to work
C)Some work is put in, but more work is put out.
D)Heat is put in, and less is put out.
E)Both C and D

Heat Engine



Three Laws of Thermal Physics:

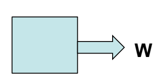
1)Energy must be conserved:
  $Energy_{in} + Heat_{in} = Energy_{out} + Heat_{out}$
  $W_{in} + Q_{in} = W_{out} + Q_{out}$
  $Q_{in} = W_{(net)} + Q_{out}$ or, $Q_H = W_{(net)} + Q_C$

2) Entropy, S (disorder) can only increase
  Heat must always flow from hot to cold

3) Something about absolute zero (0 Kelvin, -273°C)
  – entropy is minimized, you can't ever really get there

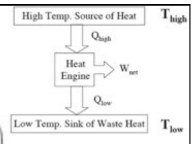
Perpetual Motion Machine of the **First** Kind:
Violates the first law:

1)Energy must be conserved:



CAN'T DO IT!

1st Law Efficiency



$$Efficiency = \left(\frac{what \quad you \quad want}{what \quad you \quad pay \quad for}\right)$$

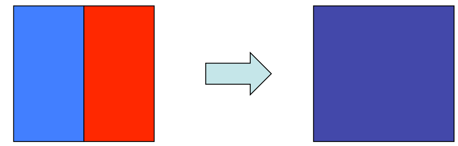
Several names:

η_I =1st Law, Actual, or Thermal Efficiency

$\eta_I = W_{net}/Q_{in} = (Q_{high}-Q_{low})/Q_{high}$ $\quad Q_{high} = W_{net} + Q_{low}$

Denominator is NOT $(Q_{high}-Q_{low})$ because Q_{low} is of no value

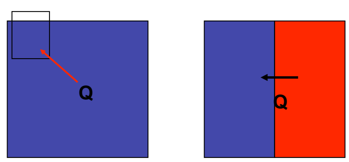
Entropy (disorder) in a nonequilibrium system will increase.



Red Gas Molecules next to
Blue will mix to form purple
More Disorder, More Entropy

How about hot molecules next to cold molecules?
Heat flows from hot to cold.

Entropy (disorder) in a nonequilibrium system will increase.



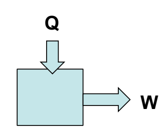
Ice cube melting in water **Cold block in contact With hot block**

When Q goes from hot to cold, Entropy is created
This represents a heat engine with, η=0

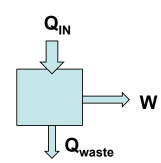
Another Class of Perpetual Motion Machines?

Perpetual Motion Machine of the **Second** Kind:
Violates the Second law:

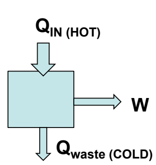
1)Entropy (disorder) can only increase:



No Heat Out
CAN'T DO IT!



Correct, must have exhaust waste heat (cooler than input heat)



Even a frictionless machine won't give you 100% efficiency. It's not about friction… it's about the second law, and your "perfect" or "Carnot" or "Thermal" efficiency

$$\xi \le \xi_C = \frac{T_H - T_C}{T_H} = 1 - \frac{T_C}{T_H}$$

....

Kelvin = Celsius + 273

Work = force x distance, P = W/t = Force x speed

P (rotational) = torque x rotation *rate*

Work = pressure x volume, So Power = Pressure * Flow *rate*

F/~~A~~ x ~~A~~x distance = F x distance = work

Pressure = F/A, [pascal], [N/m^2]

Volume = area x distance, [m^3]