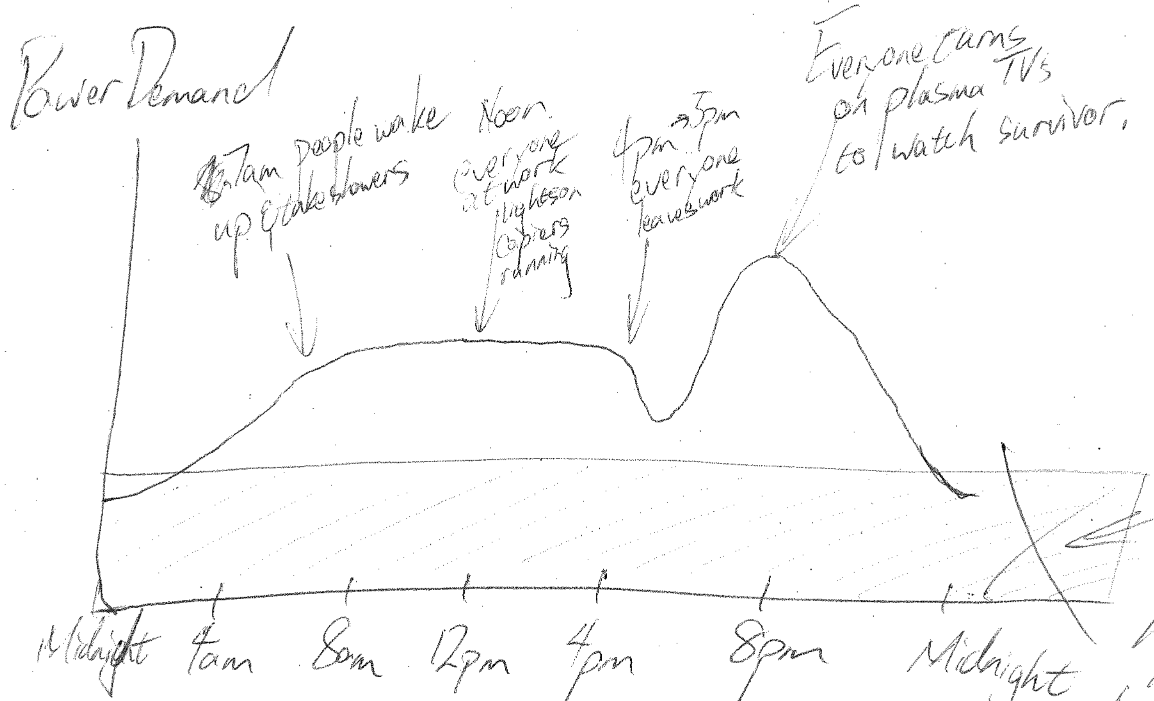
Brayton Cycles: Steam plant field trip, literature searches related to project

When you woke up this morning & flipped on your coffee pot, or hopped in the shower, did you think about the ramification of 10+ other people doing the exact same thing at the same time?



Baseload provided by big nuclear, hydroelectric, coal etc. using Rankine cycles that run 24/7 & are very expensive.

→ You can't afford to build a Rankine cycle to meet the peak load & only use it 50% of the time. ⟸ We still don't have good ways to store energy efficiently.

→ To meet this "peak" demand in this country we use almost entirely natural gas fueled peaking plants that operate using the Brayton cycle.

→ Brayton cycles can be open (air) or closed (helium, argon, etc.) usually they operate with air because it is free & abundant.

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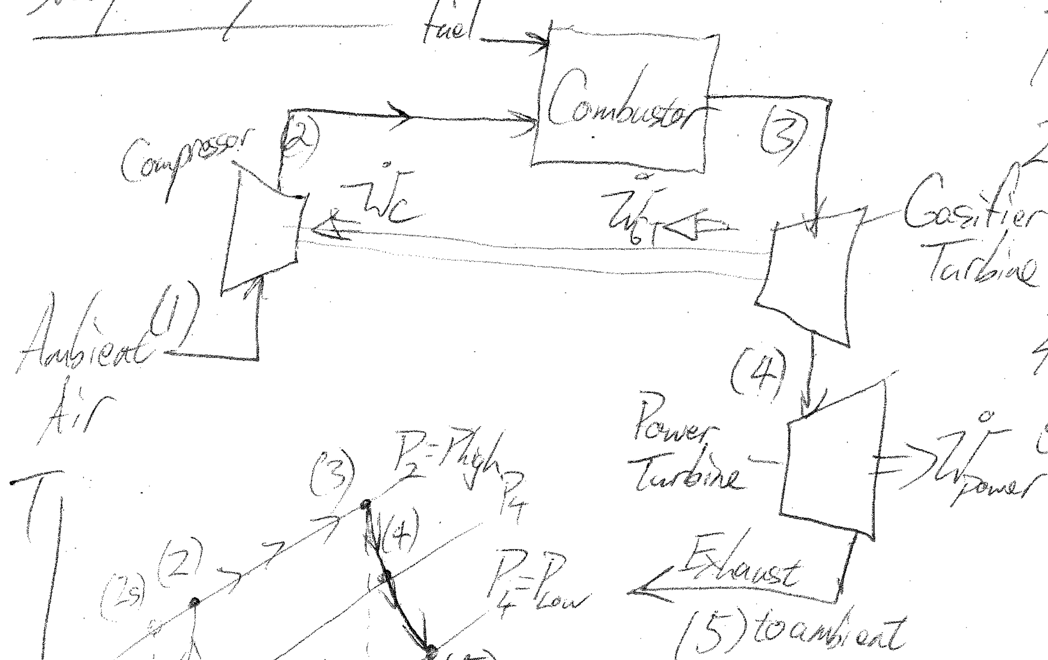
Brayton Cycle:



Processes

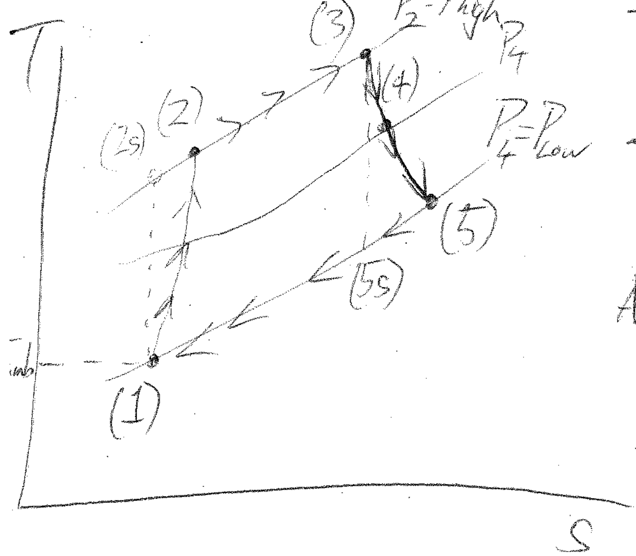
1→2 Compression

2→3 Heat addition via combustion

3→4 Gasifier turbine expansion

4→5 Power turbine expansion

5→1 Air exchanges heat with surroundings until equilibriated



We haven't studied combustion yet for now:

Assume 1) energy per mass of fuel provided by combustion is given by the heat of combustion: HC.

2) Combustion products can be treated as air

Definitions for Gas Power Cycles: PR = Pressure Ratio $= \frac{P_2}{P_1}$

BWR = Backwork ratio $= \frac{\mathring{W}_{comp}}{\mathring{W}_{GT} + \mathring{W}_{PT}}$ AF = Air→fuel Ratio $= \frac{\text{mass flow of air}}{\text{mass flow of fuel}}$

Wait a minute.. how come we have extra power left over?

Cycle swept out an area. $\mathring{W} = \int P d\forall \Rightarrow \frac{\mathring{W}}{\mathring{m}} = \int_{P_1}^{P_2} v dP$ v is much larger @ the turbine So less ΔP is required to do the same.

Which ~~[illegible]~~ takes less work to compress? liquid or vapor

Vapor takes a lot of work to compress, so Typical Brayton Cycle efficiencies ≈ ~~10~~ → ~~30~~ 35%

vs Rankine Cycle ≈ 20 → 40%

Advantages of Gas Turbine Engine / Brayton Cycle?

$\Rightarrow$ Huge power to weight ratio: typical car engine $\approx$ 750 lbm puts out 150 Hp

Car $\frac{\text{Power}}{\text{Weight}} = \frac{750\,lbm}{150\,hp} = 0.2\,hp/lbm$ A typical gas turbin engine used in a helicopter:

helicopter GTE $\frac{\text{Power}}{\text{Weight}} = \frac{\cancel{400} \; 140\,lbm}{400\,Hp} = 3\,hp/lbm = 15\times$ Power to weight versus car ICE!!

$\rightarrow$ This is why GTE's are used on fighter jets, airplanes, & peaking plants. Low mass = Low cost. No huge heat exchangers made of highly conductive material

$\rightarrow$ They are <u>not</u> used because of $\eta_{Thermal}$ which is actually worse than most

Why such a high power to weight ratio?

1) No HEX's (condenser or boiler) which are usually the largest components

2) Higher linear speeds are possible versus ICE's
   - $\rightarrow$ Not intermittent but continuous operation
   - $\rightarrow$ Velocities of turbine tips approaches Mach 1
   - $\rightarrow$ ICE's cant come close, acceleration & deceleration would kill it.
   - $\rightarrow$ You can therefore process far more air.

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$$\dot{m}_f HC \rightarrow,\ \dot{m}_{air} h_2 \rightarrow \boxed{\text{Combustor}} \rightarrow (\dot{m}_i + \dot{m}_f) h_3$$

<u>Energy Balance</u>: $\dot{E}_{in} = \dot{E}_{out}$

$$\dot{m}_f HC + \dot{m}_{air} h_2 = (\dot{m}_{air} + \dot{m}_f) h_3 \Rightarrow$$

$$\Rightarrow h_2 + \frac{\dot{m}_f}{\dot{m}} HC = \left(1 + \frac{\dot{m}_f}{\dot{m}}\right) h_3 \rightarrow h_2 + \frac{HC}{AF} = \left(1 + \frac{1}{AF}\right) h_3$$

<u>Energy Storage</u>: Chemical: hydrogen, diesel, . . .

Thermal: Molten salt, steam, water, ice

Mechanical: Spring, ΔPE, ΔKE

Electrical: SuperConducting magnet coil, batteries

Nuclear: antimatter, enriched fuels, uranium, etc.