Goal: Want to generate 1000 MW ($1x10^6$ kJ/s) of Electricity.

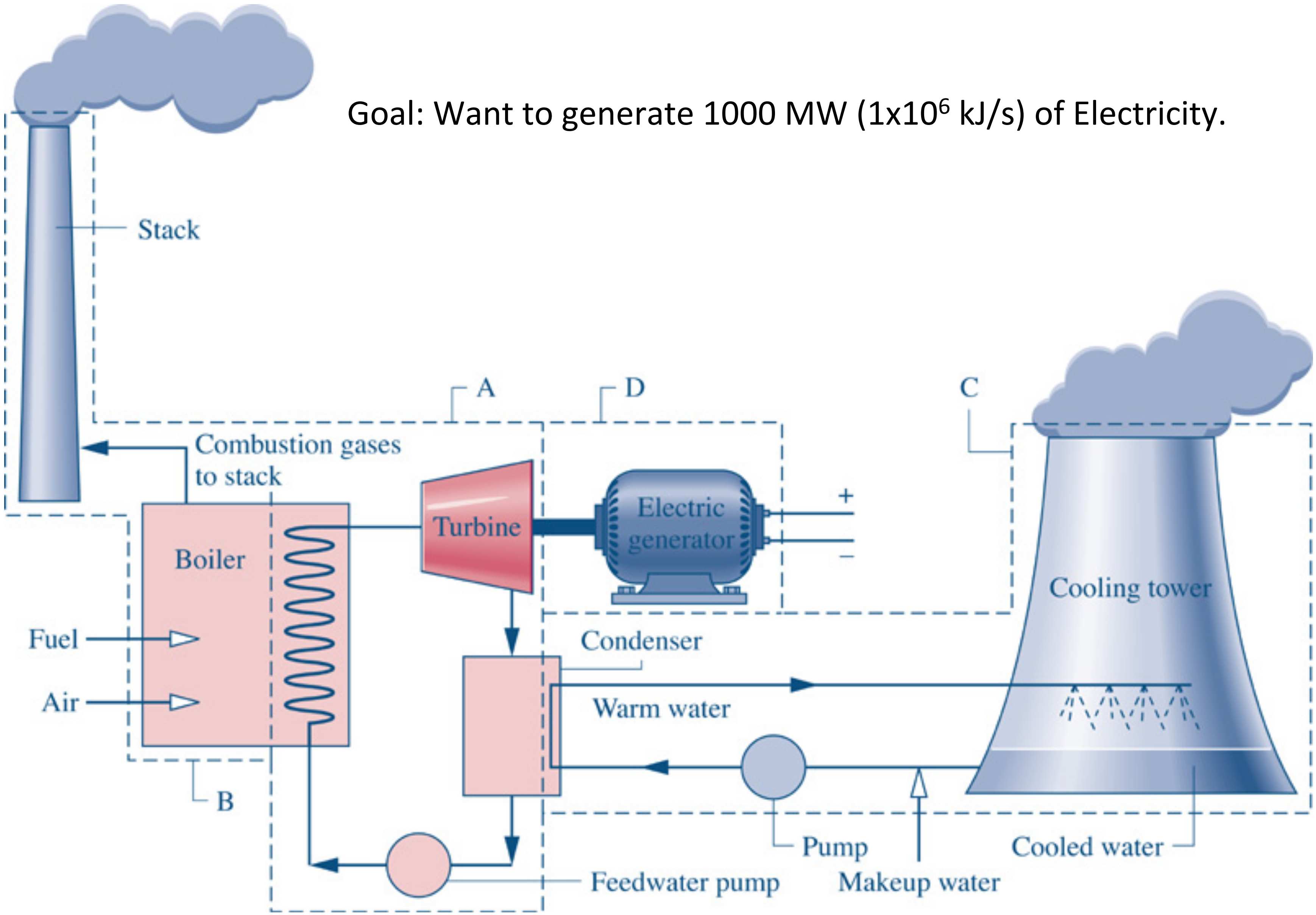
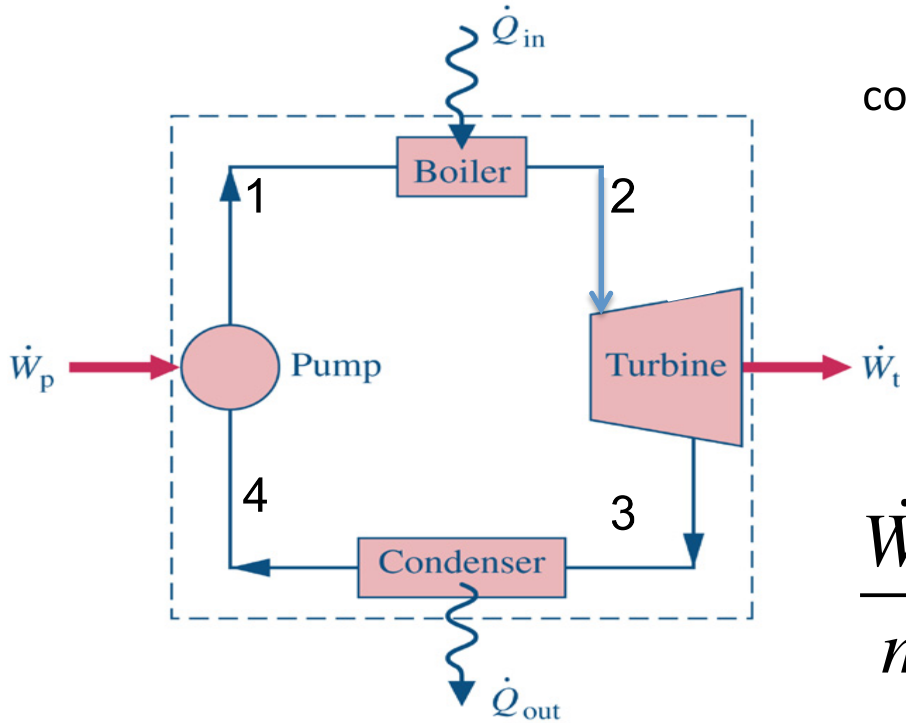


Fig08_01

How much fuel is required to run a 1000 MW power plant?
What are the C02 and other emissions?



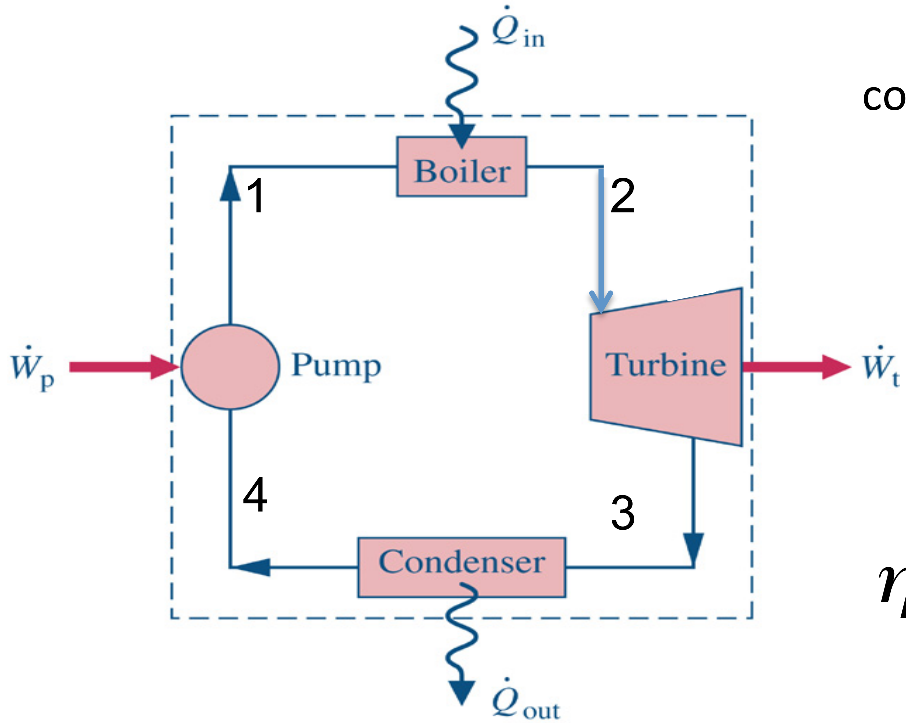
Consider a system similar to what the components that we've just analyzed in class.

Assume ideal conditions initially

Look up state properties

$$\frac{\dot{W}_P}{\dot{m}} = v(P_1 - P_4) \text{ Work Added}$$

	P (bar)	T (deg. C)	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/(kgK)	x
1	40	86.91	.0010338	355.84	363.93	1.1565	Liq
2	40	478	.083603	3060.16	3394.63	7.0219	SH
3	.6	85.94	2.51352	2319.22	2469.97	7.0211	.92
4	.6	85.94	.0010331	359.79	359.86	1.1453	0



Consider a system similar to what the components that we've just analyzed in class.

How to address actual conditions?

A) Measure/observe any two independent state properties and look up the rest.

B) Use reasonable efficiency estimates for each device

$$\eta_P = \frac{\dot{W}_{\text{P-Ideal}}}{\dot{W}_{\text{P-Actual}}} \qquad \eta_T = \frac{\dot{W}_{T\text{-Actual}}}{\dot{W}_{\text{T-Ideal}}}$$

$$\eta_T = 0.90$$

$$\eta_P = 0.95$$

	P (bar)	T (deg. C)	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/(kgK)	x
1	40	87.5			364.15		
2	40	478	.083603	3060.16	3394.63	7.0219	SH
3	.6	85.94	2.6228	2404.41	2562.44	7.27653	.96
4	.6	85.94	.0010331	359.79	359.86	1.1453	0

How much fuel is required to run a 1000 MW power plant?
What are the C02 and other emissions?

1.) Given state variables, determine Ideal and Actual performances

Performance ?

$$\eta = \frac{\dot{W}_{Net}}{\dot{Q}_{\mathrm{In}}} = \frac{\dot{Q}_{\mathrm{In}} - \dot{Q}_{out}}{\dot{Q}_{\mathrm{In}}} \qquad \eta_{Ideal} = \frac{(3394.63 - 2469.97) - (363.93 - 359.86)}{(3394.63 - 363.93)} = \frac{920.6}{3030.7} = 30.38\%$$

$$\eta = \frac{\dot{W}_{Net}}{\dot{Q}_{\mathrm{In}}} = \frac{\dot{Q}_{\mathrm{In}} - \dot{Q}_{out}}{\dot{Q}_{\mathrm{In}}} \qquad \eta_{Actual} = \frac{(3394.63 - 2562.44) - (364.15 - 359.86)}{(3394.63 - 364.15)} = \frac{827.9}{3030.5} = 27.32\%$$

$$\eta_{Max} = 1 - \frac{T_C}{T_H} = 1 - \frac{87.5 + 273.15}{478 + 273.15} = 1 - .48 = 52\%$$

How much fuel is required to run a 1000 MW power plant?
What are the C02 and other emissions?

1.) Given state variables, determine Ideal and Actual performances
2.) Determine the mass flow rate for 1000 MW generation

$$\eta = \frac{\dot{W}_{Net}}{\dot{Q}_{\text{In}}} = \frac{\dot{Q}_{\text{In}} - \dot{Q}_{out}}{\dot{Q}_{\text{In}}} \qquad \eta_{Actual} = \frac{(3394.63 - 2562.44) - (364.15 - 359.86)}{(3394.63 - 364.15)} = \frac{827.9}{3030.5} = 27.32\%$$

$$\dot{W}_{Net-Actual} = (3394.63 - 2562.44) - (364.15 - 359.86)\frac{kJ}{kg} = 827.9\frac{kJ}{kg}$$

$$\dot{W}_{1000\,MW} = \dot{m}\frac{kg}{s} w\frac{kJ}{kg} = \dot{m}\frac{kg}{s} 827.9\frac{kJ}{kg}$$

$$\frac{\dot{W}_{1000\,MW}\dfrac{kJ}{s}}{w\dfrac{kJ}{kg}} = \dot{m}\frac{kg}{s} = \frac{1x10^6\dfrac{kJ}{s}}{827.9\dfrac{kJ}{kg}} = 1{,}208\frac{kg}{s}$$

How much fuel is required to run a 1000 MW power plant?
What are the C02 and other emissions?

1.) Given state variables, determine Ideal and Actual performances
2.) Determine the mass flow rate for 1000 MW generation
3.) Determine Boiler fuel requirements

$$\eta = \frac{\dot{W}_{Net}}{\dot{Q}_{\text{In}}} = \frac{\dot{Q}_{\text{In}} - \dot{Q}_{out}}{\dot{Q}_{\text{In}}} \qquad \eta_{Actual} = \frac{(3394.63 - 2562.44) - (364.15 - 359.86)}{(3394.63 - 364.15)} = \frac{827.9}{3030.5} = 27.32\%$$

$$\dot{Q}_{\text{In-Total}} = \dot{m}\frac{kg}{s}\dot{Q}_{\text{In}}\frac{kJ}{kg} = 1{,}208\frac{kg}{s}\,3030.5\frac{kJ}{kg} = 3.661x10^{6}\frac{kJ}{s}Energy$$

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What about Boiler efficiency? Say 85% efficient implies:

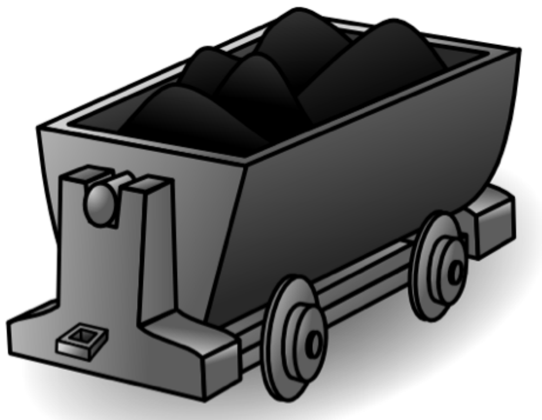
$$\dot{Q}_{\text{In-Fuel}} = \frac{\dot{Q}_{\text{In-Total}}}{Efficiency} = \frac{3.661x10^{6}}{.85} kJ/s = 4.306x10^{6}\, kJ/s \;\; Fuel\, Energy$$

How much fuel is required to run a 1000 MW power plant?
What are the C02 and other emissions?

1.) Given state variables, determine Ideal and Actual performances
2.) Determine the mass flow rate for 1000 MW generation
3.) Determine Boiler fuel requirements
4.) How much Fuel will be required?

Assume Coal (the dominant fuel source) is used with a heating value of 5,500 kJ/kg coal.

$$\dot{m}_{Coal} = \dot{Q}_{\text{In-Fuel}} = \frac{4.306x10^6\, {}^{kJ}\!/_{s}\ Fuel\,Energy}{5,500\,\dfrac{kJ}{kg}} = 783\, {}^{kg}\!/_{s}\ Fuel = 67.65x10^6\,\frac{kg}{day}$$



A coal train car has a carry capacity of Approximately 100,000 kg/car

$$train\ cars = \dot{Q}_{\text{In-Fuel}} = \frac{\dot{m}_{Coal\ per\ day}}{m_{Coal\ per\ car}} = \frac{67.65x10^6\ \frac{kg}{day}}{100{,}000\ \frac{kg}{car}} = 677\ \frac{train\ cars}{day}$$

In 1999 the average train could pull 70 coal cars. Consequently, about 10 train deliveries per day are required to run the power plant!

How much fuel is required to run a 1000 MW power plant?
What are the C02 and other emissions?

1.) Given state variables, determine Ideal and Actual performances
2.) Determine the mass flow rate for 1000 MW generation
3.) Determine Boiler fuel requirements
4.) Determine chemical balance

$$Fuel \approx C_{12}H_{26} \qquad Air \approx O_2 + (3.76 \frac{moles\, N_2}{mole\, O_2}) N_2$$

5.) Realistic chemical makeup of coal might be
(on a mass chemical analysis)

$$Fuel \approx 85.3\% C, 14.1\% H, 0.5\% S, and\, 0.1\% N_2$$

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6.) Consider 100 kg fuel and 125% theoretical air (realistic)

$$Fuel \approx \frac{85.3kg}{12.011 \frac{kg}{kgmol}} C, \frac{14.1kg}{2 \frac{kg}{kgmol}} H_2, \frac{0.5kg}{32.06 \frac{kg}{kgmol}} S, and \frac{0.1kg}{28.016 \frac{kg}{kgmol}} N_2$$

$$Molar\, Basis: 7.102C + 6.994H_2 + 0.0156S + 0.0036N_2 + 1.25(X)O_2 + 1.25(3.76)(X)N_2 =$$
$$\_\_\_\_\_ CO_2 + \_\_\_\_\_ H_2O + \_\_\_\_\_\_\_ SO_2 + \_\_\_\_\_\_\_ N_2$$

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Theoretical O_2 Requirements:

= 7.102+6.994/2 + 0.0156)=10.614 moles="X"

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Determine the mass of CO_2 emitted:

$$(7.102\,moles)(12.011 + 2 * 16)\frac{kg}{kgmol} = 312.57\frac{kg}{100\,kg\ fuel}$$

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Determine the mass of Sulfurous Acid H_2SO_3 emitted: (acid rain)

$$Molar\,Basis:$$
$$H_2O + SO_2 = H_2SO_3 \qquad SO_2 \text{ is the limiting factor}$$

$$(0.0156 moles)(2.016 + 32.06 + 3*16)\frac{kg}{kgmol} = 1.2804\frac{kg}{100\,kg\;fuel}$$

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For our 1000 MW Power Plant using 67.65x10^6 kg fuel/day

$$\dot{m}_{Coal} = \dot{Q}_{\text{In-Fuel}} = \frac{4.306x10^6\,{kJ}/{s}\ Fuel\,Energy}{5{,}500\,\frac{kJ}{kg}} = 783\,{kg}/{s}\ \ Fuel = 67.65x10^6\frac{kg}{day}$$

$$\left(1.2804\frac{kg}{100\,kg\ fuel}H_2SO_3\right)\left(67.65x10^4\frac{100kg\ fuel}{day}\right) = 866.19x10^3\,kg\,H_2SO_3 \text{ released daily}$$

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Or, about 3 Blue Whales per day!