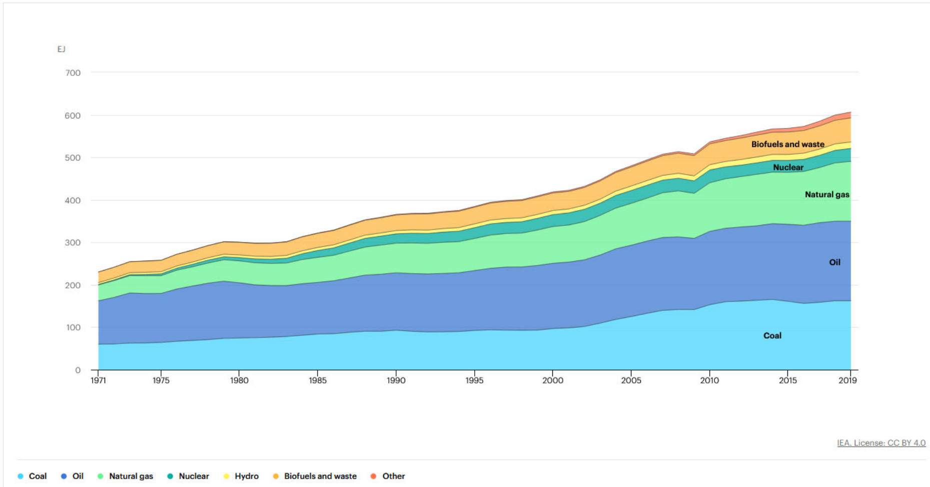
Why worry about complex fuels?

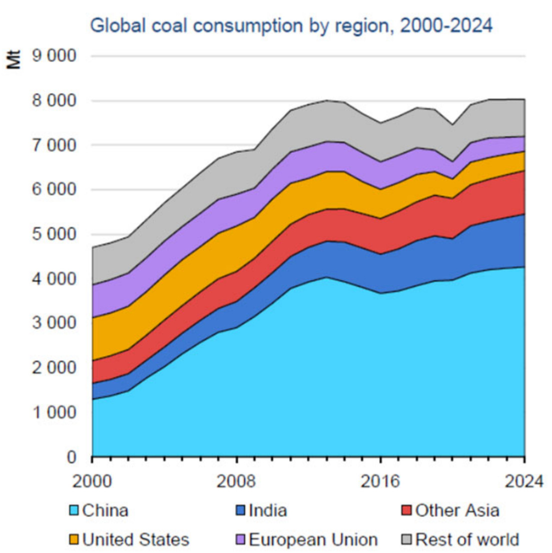


https://www.iea.org/data-and-statistics/charts/world-total-energy-supply-by-source-1971-2019

1

World Coal Consumption

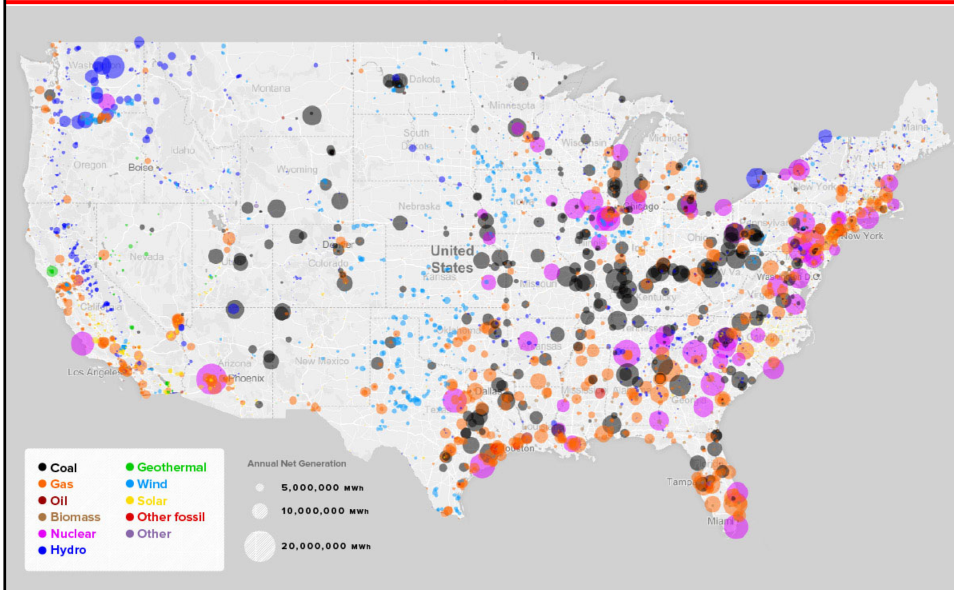
(megatons/yr)



https://www.iea.org/reports/coal-2021

2

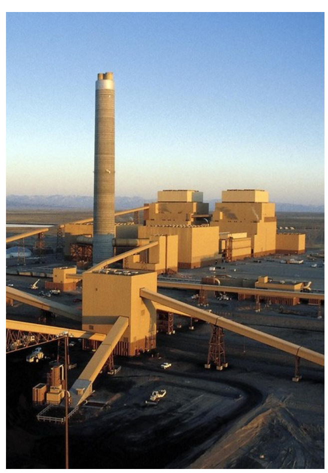
Power Plants in the US
(2019)



https://www.visualcapitalist.com/mapped-every-power-plant-in-the-united-states/

3

IPP Slides



4

Hypothetical Coal Molecule

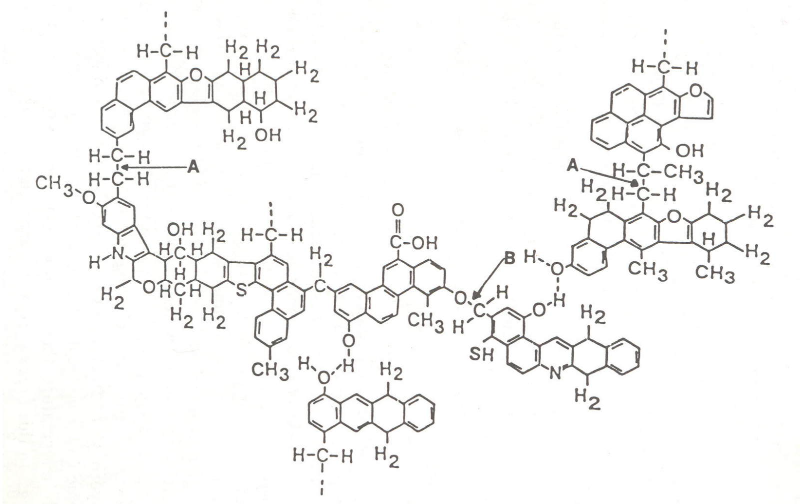


Figure 1. Summary of coal structure information in a hypothetical coal molecule.

From Solomon and coworkers (1985)

5

Reacting Coal Molecule

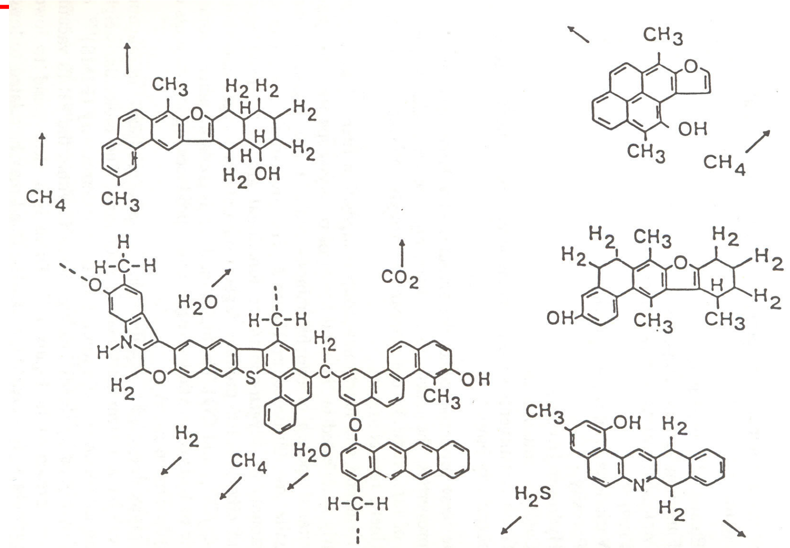
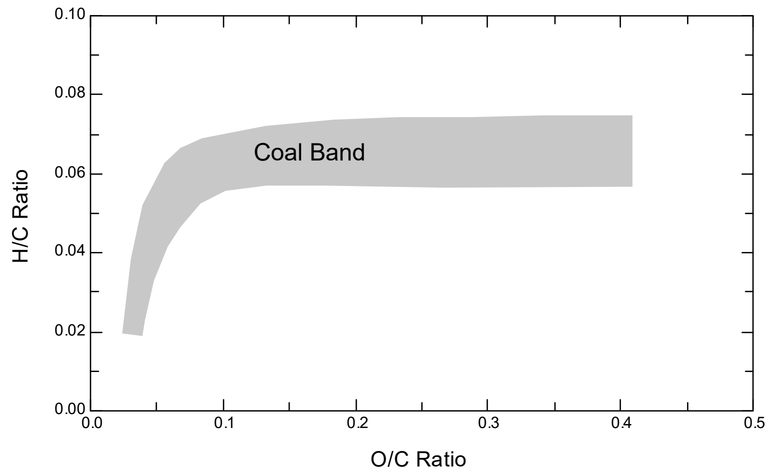


Figure 2. Cracking of hypothetical coal molecule during thermal decomposition.

6

Fuel Characterization

Where are….graphite…..oil…..peat…..biomass?



7

TABLE I *Classification of Coals by Rank*

Class	Group	Fixed carbon limits (%) (dry, mineral-matter-free basis) ⩾	Fixed carbon limits (%) <	Volatile matter limits (%) (dry, mineral-matter-free basis) >	Volatile matter limits (%) ⩾	Calorific value limits (Btu/lb) (moist mineral-matter-free basis) ⩾	Calorific value limits <	Agglomerating character
I. Anthracitic								
	1. Meta-anthracite	98	—	—	2	—	—	nonagglomerating
	2. Anthracite	92	98	2	8	—	—	
	3. Semianthracite	86	92	8	14	—	—	
II. Bituminous								
	1. Low volatile bituminous coal	78	86	14	22	—	—	commonly agglomerating
	2. Medium volatile bituminous coal	69	78	22	31	—	—	
	3. High volatile A bituminous coal	—	69	31	—	14,000	—	
	4. High volatile B bituminous coal	—	—	—	—	13,000	14,000	
	5. High volatile C bituminous coal	—	—	—	—	11,500	13,000	
						10,500	11,500	agglomerating
III. Subbituminous								
	1. Subbituminous A coal	—	—	—	—	10,500	11,500	nonagglomerating
	2. Subbituminous B coal	—	—	—	—	9,500	10,500	
	3. Subbituminous C coal	—	—	—	—	8,300	9,500	
IV. Lignitic								
	1. Lignite A	—	—	—	—	6,300	8,300	
	2. Lignite B	—	—	—	—	—	6,300	

8

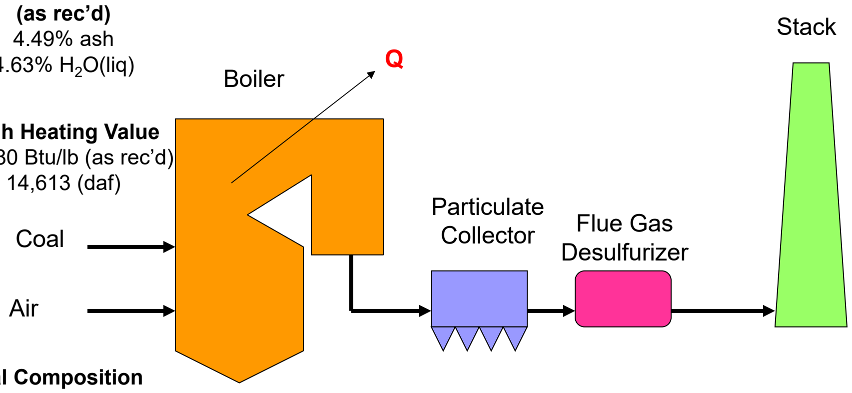
Terminology

- High heating value
  - Calculated using H_2O (liq) as product
- Low heating value
  - Calculated using H_2O (gas) as product
- Heating value = $-\Delta H_c$
  - i.e., heating value is positive, but heat of reaction is negative
  - Table B.1 lists the high heating value
    - Actually ΔH_c corresponding to the high heating value

Coal Combustion

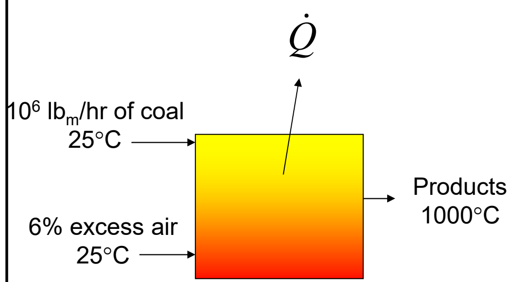
Coal Composition (as rec'd)
4.49% ash
4.63% H_2O(liq)

High Heating Value
13,280 Btu/lb (as rec'd)
14,613 (daf)



Coal Composition (wt% daf)
80.69% C
5.76% H
11.58% O
1.57% N
0.37% S

Heat Balance



Strategy

- Get $n_{air,stoich}$ from elemental composition of coal
- Find $n_{O2,in}$ and $n_{N2,in}$
- Find $n_{i,out}$ for all gas species
- Find $m_{i,out}$ for all solids
- $\boxed{\text{If path method used:}}$

What is the energy balance equation?

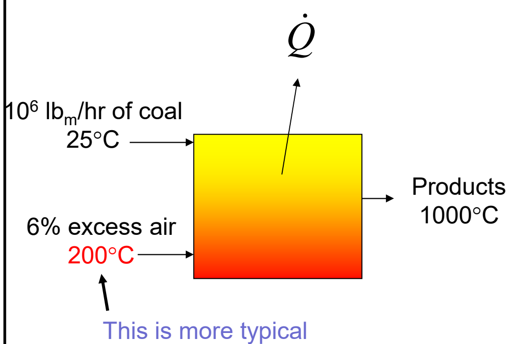
$$\dot{Q} = \Delta\dot{H} = \underbrace{\dot{m}_{coal}\Delta H_{comb,25^\circ C} + \left(\dot{m}_{moist} + \dot{m}_{H_2O,comb}\right)\Delta H_{vap,25^\circ C}}_{\text{Messy!}} + \sum\left(n_i \int_{25^\circ C}^{1000} C_{p,i}\,dT\right)_{products}$$

11

See Spreadsheet Example

12

Heat Balance with Preheated Air



What is the energy balance equation?

$$\dot{Q} = \Delta \dot{H} = \left(\sum \dot{n}_i \hat{H}_i\right)_{gas,out} + \left(\sum \dot{m}_i \hat{H}_i\right)_{solid\,\&\,liquids,out} - \left(\sum \dot{n}_i \hat{H}_i\right)_{in} - \left(\sum \dot{m}_i \hat{H}_i\right)_{solid\,\&\,liquids,in}$$

Need heat of formation of coal!

Strategy

- Get $n_{air,stoich}$ from elemental composition of coal
- Find $n_{O2,in}$ and $n_{N2,in}$
- Find $n_{i,out}$ for all gas species
- Find $m_{i,out}$ for all solids
- Use ΔH_f^o method

Recommended!

13

Calculation of ΔH_f^0 for Coal

- Given:
  - Elemental composition
  - Heating Value (Btu/lb_m) … Change to kJ/kg
  - Basis: 1.00 kg of dry, ash-free coal (daf)
- Calculate:
  - Mass of each element (C, H, O, N, S)
  - Moles of each element
  - O_2 requirement to burn each element

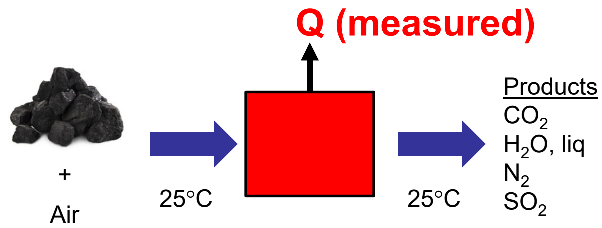
    $C + O_2 \Rightarrow CO_2$
    $H + \frac{1}{4} O_2 \Rightarrow \frac{1}{2} H_2O$ (liq)*
    $S + O_2 \Rightarrow SO_2$

    O in coal decreases O_2 requirement from air
    N in coal goes to N_2
  - Moles of each product (CO_2, H_2O, SO_2, O_2, N_2)

*H_2O product is liquid if the high heating value is specified!

14

Calculation of ΔH_f^0 for Coal



Calculation of ΔH_f^0 for Coal

- Energy Balance

$$Q = H_{products} - H_{reactants} = -Heating\ Value$$

$$H_{products} = \sum (n_i \hat{H}_i)_{products}$$

$$H_{reactants} = \sum (n_i \hat{H}_i)_{reactants}$$

unknown

$$\hat{H}_{coal} = \Delta H_{f,coal}^0 + \int_{25°C}^{T} C_{p,coal} dT$$

- For heat of formation calculation, reactants and products are at 25°C!
  - Only need $\Delta H_{f,products}$, not C_p's

Calculation of ΔH_f^0 for Coal
(cont.)

- Since we are computing everything at 25°C,

$$\hat{H}_i = \Delta H_{f,i}{}^0 + \cancel{\int_{25°C}^{25°C} C_{p,coal} dT}$$

$$H_{products} = \sum (n_i \Delta H_{f,i}^0)_{products}$$

$$H_{reactants} = \sum (n_i \Delta H_{f,i}^0)_{reactants}$$

- And since the gaseous reactant is air, $\Delta H_{f,air}^0$=0
- Therefore:

$$-Heating\ Value = \sum (n_i \Delta H_{f,i}^0)_{prod} - \boldsymbol{m_{coal} \Delta H_{f,i}^0}$$

17

Answer to Special Problem 29.1

$$\Delta H_{f,coal}^0 = -3134 \frac{kJ}{kg\ of\ daf\ coal}$$

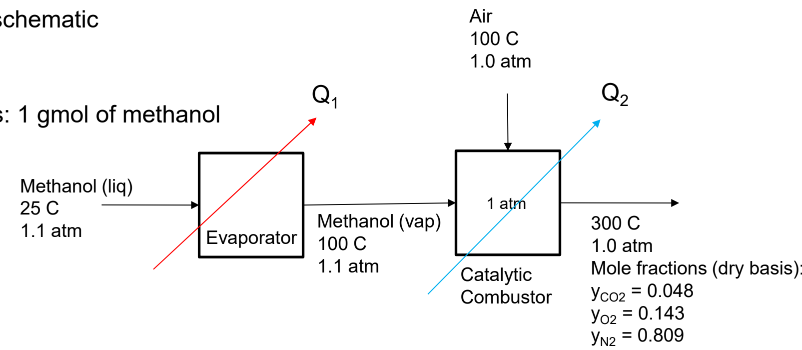
You will need to know how to get a heat of formation for coal when you do the case study!

18

Homework: Problem 29.2

Draw schematic

Basis: 1 gmol of methanol



(a) Find % excess air and dew point temperature of the product gas
(b) Find Q_1 and Q_2

Strategy:
(a) 1 mol methanol means 1 mol CO_2 produced, so find n_{dry}
(b) Find n_{O2} and n_{N2} in outlet stream from y_i's and n_{dry}
(c) n_{N2} is same in inlet air, so find n_{O2} and hence % excess air
(d) Find Q's from energy balances