Energy and the Built Environment
CRP 470.004 /570.004

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Lecture 5

Energy economics and life cycle assessment

Outline

- Review power plants/thermo
- Combustion review/calculation
- Economic and energy analysis
  - Simply payback
  - Discount factors
  - Net present value

Combustion (cont.)

What happens in combustion?

- Fuel + oxygen → $CO_2 + H_20$ + light + heat
- Combustion, in its simplest form, with methane

$$CH_4 + O_2 \rightarrow CO_2 + H_20$$

- This idealized reaction takes place in pure oxygen and the fuel doesn't have any impurities

All equations need to be balanced

- Conservation of mass: each side of the equation needs to have the same number of each element

- $CH_4 + O_2 \rightarrow CO_2 + H_20$ 1C, 4H, 2O → 1C, 2H, 3O

- $CH_4 + O_2 \rightarrow CO_2 + 2H_20$ 1C, 4H, 2O → 1C, 4H, 4O

- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_20$ 1C, 4H, 4O → 1C, 4H, 4O

How to convert # of particles to mass

- A mol contains 6.022x10^23 (Avagadro's #) particles
- Molar mass is the mass of a mol of particles
- For elements, it is the same number as the atomic weight, usually in units of g/mol

Table 6 Atomic weights of common elements in combustion

Element	Symbol	Atomic Number	Atomic Weight
Hydrogen	H	1	1.008
Carbon	C	6	12.01
Nitrogen	N	7	14.01
Oxygen	O	8	16.00
Sulfur	S	16	32.06

Some common fuels

		formula
Natural Gas	Mostly CH_4; may include C_2H_6, C_3H_8, and C_4H_{10} prior to refining.	CH_4
Propane		C_3H_8
Butane		C_4H_{10}
LPG	Liquefied petroleum gas (LPG) is a mix of C_3H_8 and C_4H_{10}.	
Gasoline	Mostly C_8H_{18}, but with a mixture ranging from C_7H_{16} to $C_{12}H_{26}$.	
Wood/Cellulose		$C_6H_{12}O_6$

What is the molar mass of CO_2?

- Molar mass of C: 12 g/mol
- Molar mass of O: 16 g/mol
- Molar mass of CO_2 :
- 1 x 12g/mol + 2 x 16 g/mol = 44 g/mol

What is the molar mass of $C_6H_{12}O_6$?

- C: 12 g/mol
- H: 1 g/mol
- O: 16 g/mol
- $C_6H_{12}O_6$ molar mass:
- 6 x 12g/mol + 12 x 1 g/mol + 6 x 16g/mol
- = 180 g/mol

How many mols in a ton of wood?

- Wood has a molar mass of 180 g/mol

$$1000kgC_6H_{12}O_6 x \frac{mol}{180g} x \frac{1000g}{1kg} = 5556mol$$

How many mols of CO_2 per mol of wood ($C_6H_{12}O_6$) when combusted?

First write the stochiometric equation for combustion, and balance the equation.

1. Balance the equation (both sides of the equation have the same number of each element)

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

First the carbon:

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

Then the hydrogen:

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

Last, the oxygen (because you can change the oxygen without altering other elements):

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

Find the mol ratio between wood and CO_2

1. Mol ratio is 6 mols of CO_2 per 1 mol of wood
2. Use the mol ratio to convert the total mols of wood in a ton (5556 mol) to the total mols of CO2 that would be produced

$$5556 mol C_6H_{12}O_6 x \frac{6 mol CO_2}{mol C_6H_{12}O_6} = 33336 mol CO_2$$

3. Use the molar mass of CO2 to convert the mols of CO2 to mass of CO2

$$33336 mol CO_2 x \frac{44 g}{mol CO_2} x \frac{ton}{1e6 g} = 1.5 tons CO_2$$

kg CO_2 per kg of wood combusted

- 1 kg of our simplified wood combusted in pure oxygen produces 1.5 kg of CO_2 o
- Also, we know wood has an energy density of 4.4 kWh/kg, so we find that:

$$\frac{1.5 kgCO_2}{1 kgwood} x \frac{kgwood}{4.4 kWh} = 0.340 \frac{kgCO_2}{kWh}$$

Combustion in air (78% N_2, 21% O_2)

- If combustion occurs without complete oxidation instead, we get:

$$CH_4 + O_2 + N_2 \rightarrow \text{mostly } (CO_2 + 2H_20 + N_2) + \text{traces } (CO + HC + NO...)$$

- This can occur when:
  - temperature too low,
  - insufficient O,
  - combustion too rapid,
  - poor mixing of fuel and air, etc. ...

CO_2 emissions factors for different fuels

Carbon Dioxide (CO_2) Factors:	Kg CO_2 per vol or mass		Kg CO_2 Per KWh
For homes and businesses			
Propane	5.8	gallon	0.215
Butane	6.7	gallon	0.222
Home Heating and Diesel Fuel	10.2	gallon	0.250
Kerosene	9.8	gallon	0.247
Coal (All types)	2,100.8	short ton	0.325
Natural Gas	54.4	thousand cubic feet	0.181
Gasoline	8.9	gallon	0.243

Source: EPA

More complicated combustion

- At higher temperatures, N reacts with O:

  air(N_2 +O_2) + heat $\rightarrow$ NO_x (thermal)

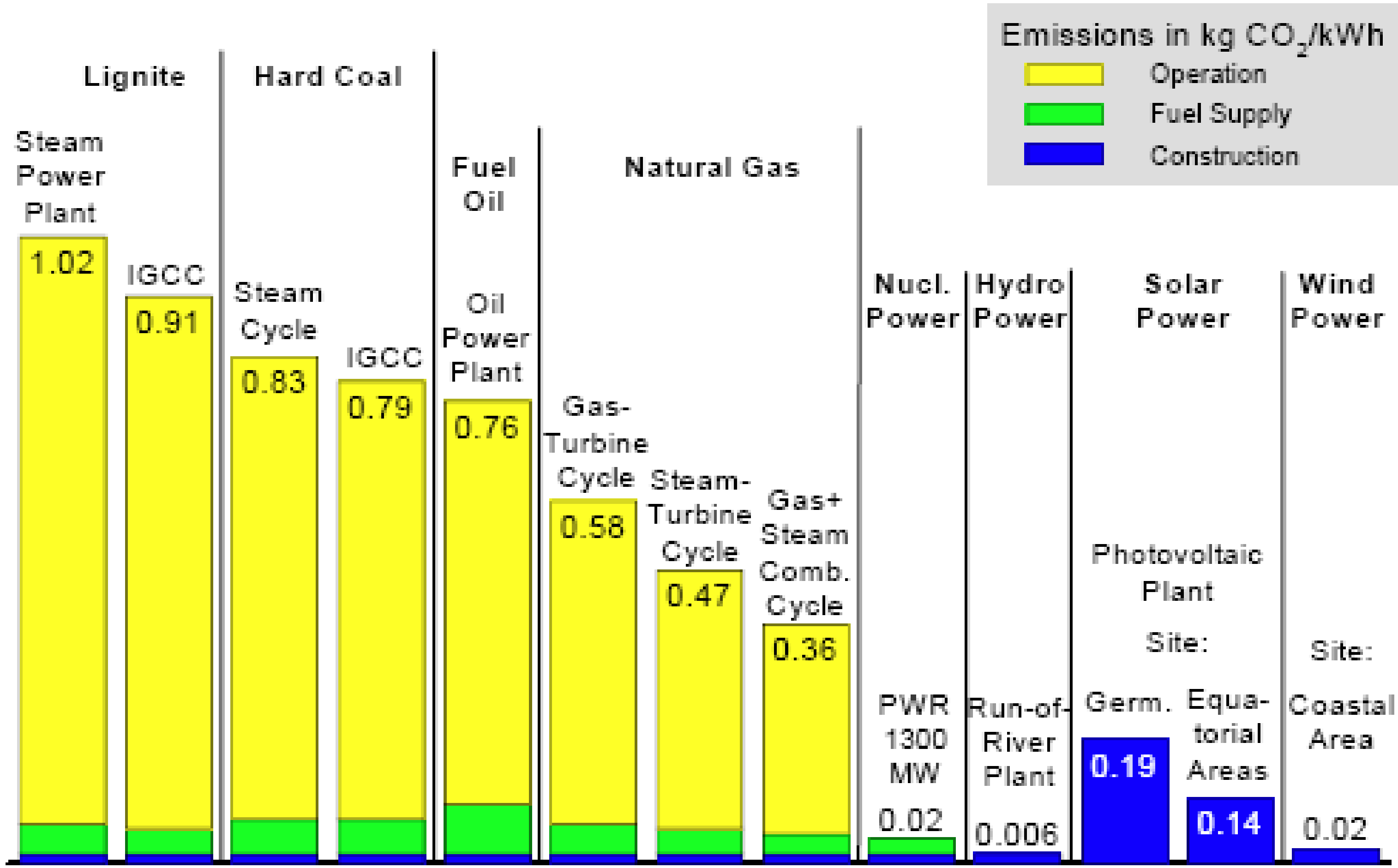
- Fuels often have impurities, such as N, S, metals and ash (non-combustibles)

What we really get:

- Fuel (C, H, N, S, ash) + air (N_2 +O_2) $\rightarrow$

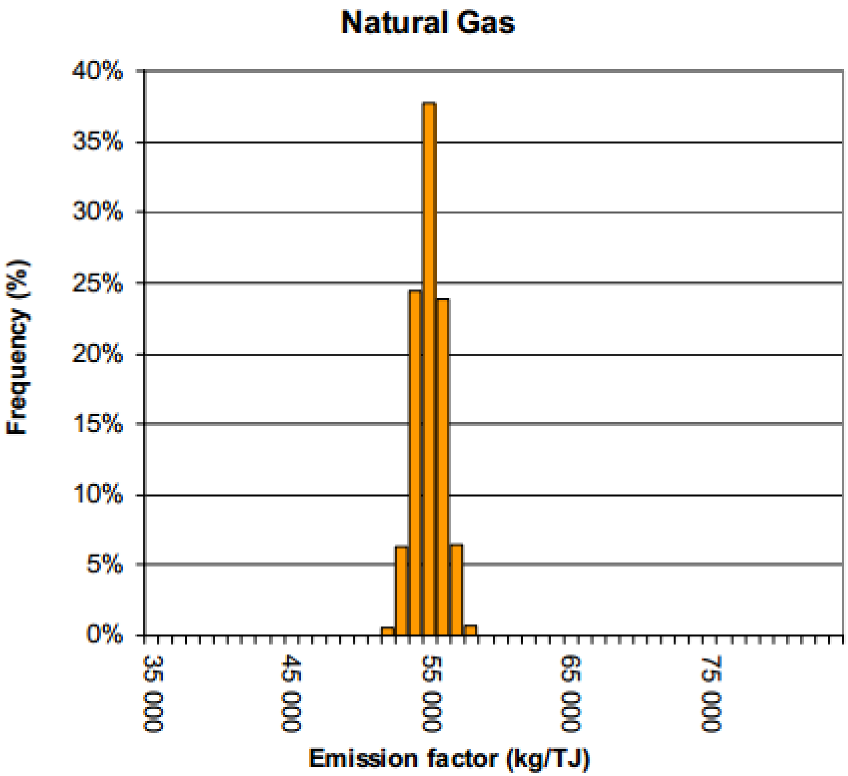
  (CO_2, H_2O, CO, NO_x, SO_x, VOCS, particulates) + ash
  - Volatile Organic Compounds: VOCs

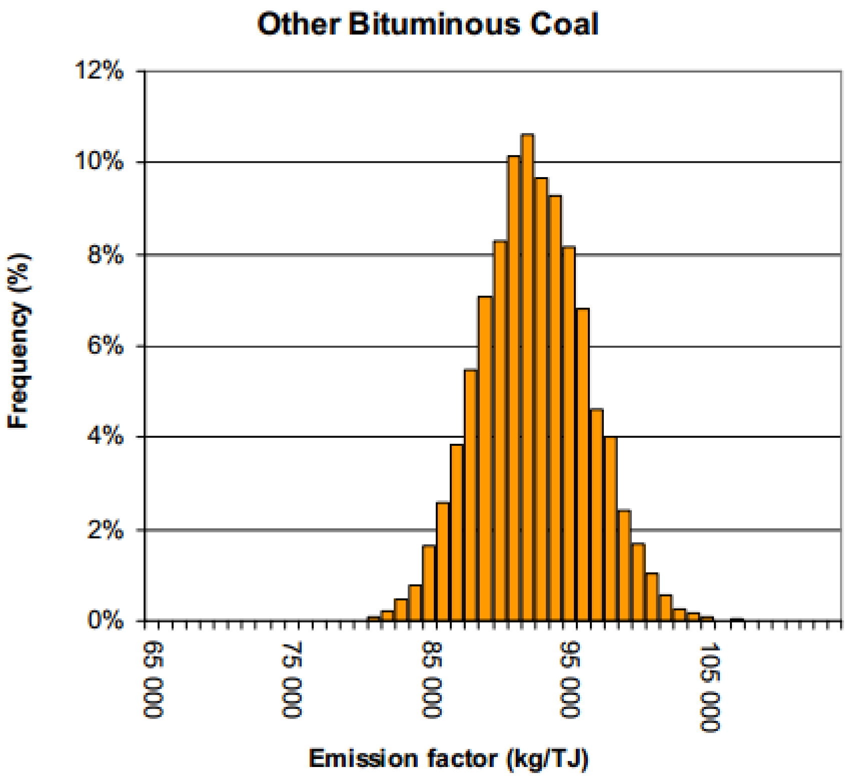
Carbon Dioxyde Emissions per kWh



according to Siemens / Voss / VDI-GET 1999

Uncertainties….





Variations in fuel purity and combustion environment

Source: IPCC Guidelines for GHG inventories, 2006

How can we assess energy choices?

1. Economic impacts
2. Environmental impacts
3. Social impacts

- The triple bottom line

Economic Impacts

Economic Impacts

- How much does a project or technology cost today?
  - CFL bulb vs Incandescent
  - Natural gas plant vs wind turbine
- How much does a project or technology cost in the long run?

Economic evaluation tools

- Simply payback
- Lifetime cost
- Lifetime cost of energy
- Lifetime cost of emissions

Economic comparison: light bulbs

	 Incandescent	 CFL	 LED
Brand	Phillips	Phillips	Cree
Price ($)	$ 0.41	$ 2.25	$ 8.00
Intensity (lumen)	860	810	815
Efficiency (lm/w)	14.3	62.3	74.1
Power (W)	60	13	11
Lifetime (hr)	1,000	10,000	25,000

Source: Product specs, Home Depot, 2015

How can we compare costs? Apples to apples?

- Total costs = capital cost + variable costs
- Put all of the costs on a $/year basis. Assume that you use the bulb 5 hours/night.

Economic comparison: light bulbs

	 Incandescent	 CFL	 LED
Brand	Phillips	Phillips	Cree
Price ($)	$ 0.41	$ 2.25	$ 8.00
Lifetime (yr)	0.68	6.85	17.12
Capital cost ($/yr)	0.59	0.33	0.47
Electricity costs ($/yr)	13.14	2.85	2.41
Total costs ($/yr)	13.88	3.26	2.99

Source: Product specs, Home Depot, 2015

Simple Payback Period

- Simple payback is the time to recover an investment, through savings, without discounting.
- When you are planning to upgrade an existing technology with a more efficient one, this would tell you how long until you have earned back your investment.

$$\text{Simple Payback (yr)} = \frac{\text{Capital Cost (\$)}}{\text{Annual Energy Savings } \left(\frac{\text{kWh}}{\text{yr}}\right) \text{ x Energy Price } \left(\frac{\$}{\text{kWh}}\right)}$$

Simple Payback Period: CFL vs Incandescent

$$\text{Simple Payback (yr)} = \frac{\text{Capital Cost (\$)}}{\text{Annual Energy Savings } (\frac{\text{kWh}}{\text{yr}}) \text{ x Energy Price } (\frac{\$}{\text{kWh}})}$$

- The capital cost for the CFL is $2.25
- The CFL uses 13 Watts instead of 60 W, which is an energy saving of 47 W. If the light is operated for the 5 hours/day then the annual energy savings = .047kW x 5 hr/day x 365 days/yr = 86 kWh/yr
- Energy price is 0.12$/kWh
- Simple payback (yrs)

  = $2.25/ (86 kWh/yr *$.012/kWh)

  = 0.22yrs (80 days)

Interest rates and discount rates

- The Time-Value of Money: "A bird in hand is worth two in the bush"
- It is more important to have a dollar today than in the future due to lost opportunities, our ability to lend money and collect interest.
- Inflation also changes money's 'value' over time. Usually discount rates reflect both interest rates and inflation:

discount rate (r) = interest rate + inflation

- Discount rates are prices, specifically the relative price, used to compare future and present goods and services in benefit-cost analyses.

Nominal Discount Rates. A forecast of nominal or market interest rates for 2005 based on the economic assumptions from the 2006 Budget are presented below. These nominal rates are to be used for discounting nominal flows, which are often encountered in lease-purchase analysis.

Nominal Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	30-Year
3.7	4.1	4.4	4.6	5.2

Real Discount Rates. A forecast of real interest rates from which the inflation premium has been removed and based on the economic assumptions from the 2006 Budget is presented below. These real rates are to be used for discounting real (constant-dollar) flows, as is often required in cost-effectiveness analysis.

Real Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	30-Year
1.7	2.0	2.3	2.5	3.1

http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html

Future Value

- Future Value: If we put an amount of money, P, in the bank at an interest rate of r, the future value in 1 time period will be:

$$\mathbf{F_1} = P(1+r)$$

- The future value in 2 time periods will be:

$$\mathbf{F_2} = F_1(1+r) = P(1+r)^2$$

- The value in n time periods will be:

$$\mathbf{F} = P(1+r)^n$$

Present Value

- Using the equation for compounding interest, we can rearrange to determine what the present value would be of a future dollar amount:

$$P = \frac{F}{(1+r)^n}$$

Example

- I have access to a lending rate of 5%. If I put $100 in the bank for 5 years, how much money would I have?

$$\mathrm{F} = P(1+r)^n = \$100(1.05)^5 = \$128$$

- If someone offers to give me $100 in 5 years, how much would that money be worth today?

$$\mathrm{P} = \frac{\mathrm{F}}{(1+\mathrm{r})^{\mathrm{n}}} = \frac{\$100}{(1.05)^5} = \$78$$

Net Present Value

- The Net Present Value (NPV) places all future costs and benefits of a technology or service at the present time. It is the discounted series of costs and benefits:

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Uniform Series Amounts

- To compare costs in a uniform series of payments (e.g., monthly or annual) we assume a payment U is made at each interval against a borrowed amount P

$$U = P\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right] = P\left[\frac{r}{1-(1+r)^{-n}}\right]$$

Uniform Series Amounts

- This can be rearranged to determine the present value of a series of uniform, future payments:

$$P = U\left[\frac{1-(1+r)^{-n}}{r}\right]$$

Summary

Name	Converts	Equation
Present value	F to P	$\frac{1}{(1+i)^n}$
Uniform series present value	U to P	$\frac{1-(1+i)^{-n}}{i}$
Single payment compound amount	P to F	$(1+i)^n$
Compound amount	U to F	$\frac{(1+i)^n-1}{i}$
Capital recovery	P to U	$\frac{i}{1-(1+i)^{-n}}$
Sinking fund	F to U	$\frac{i}{(1+i)^{-n}-1}$

(Table 13.2 on page 554 of Introduction to Engineering and the Environment, Edward S. Rubin, McGraw-Hill, 2001)