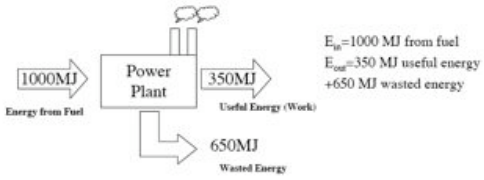
PSc 320

Class 5 Carbon Intensity

Pete Schwartz, Cal Poly Physics

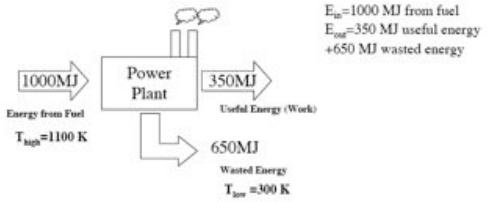
Energy Balance for a Power Plant



$\eta_I = W_{net}/Q_{in}$

η_I=350MJ/1000MJ = 0.35 = 35%

Efficiencies of the Power Plant

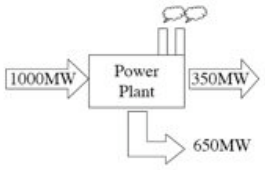


$\eta_I = W_{net}/Q_{high}$=350MJ/1000MJ = 0.35 = 35%

$\eta_c = 1 - T_{low}/T_{high} = 1 - 300K/1100K = 73\%$

$\eta_{II} = \eta_I / \eta_c = .35/.73 = 48\ \%$

Power Balance for a Power Plant



$P_{in} = P_{out}$

$P_{out} = P_{out\,1} + P_{out\,2}$

$P_{fuel} = P_{useful} + P_{waste}$

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

$\frac{CO_2}{\text{Energy Use}}$ $\frac{CO_2}{\text{Electrical Energy?}}$

Masses (AMU)	
Hydrogen:	1
Carbon:	12
Nitrogen:	14
Oxygen:	16
CO_2:	12 + 2x16 = 44

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

CO_2 or C?: You MUST Specify Units

Carbon Intensity of some Fuels:

Thermal Carbon Intensity of fuel

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

Carbon Intensity of Electricity = $\frac{CO_2}{\text{Electrical Energy}} = \frac{CO_2}{\eta\ \text{Heat energy}}$

$= \frac{\text{Thermal Carbon Intensity}}{\eta_{conversion}}$

Carbon Intensity of some Fuels:

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

Fuel	g(C)/MJ	Thermal $g(CO_2)/MJ_{th}$	Electrical $g(CO_2)/MJ_e$	Electrical $g(CO_2)/kWh_e$
Natural Gas:	15	51	85	310
Petroleum:	20	73		
Coal:	25	92	260	950
Wood:	~30	110		

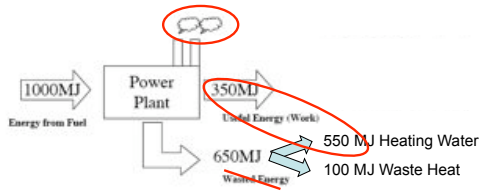
kWh = 3.6 MJ

Natural Gas can use Combined Cycle: η = 50% - 65%

Coal can only use Single Cycle Rankin: η = 30% - 45%

Cogeneration???

Energy Balance for a Power Plant



Heat Water with η = 85%
650 MJ (85%) = 550 MJ

$\eta_I = W_{net}/Q_{in}$

η_I=350MJ/1000MJ = 0.35 = 35%

η_{total} = (350 MJ + 550 MJ)/100 MJ = 90%

Cogeneration – Heat from one source provides two services

Combined Cycle ≠ Cogeneration?

CHP – Combined Heat and Power

CCHP – Combined Cooling Heat and Power

Heat is hard to ship long distances
Is distributed Generation (DG) Required?

Trigeneration? Coors Brewery:
Electricity, Heat for Brewing, Heat to Colorado School of Mines

Topping – Generating electricity first, and using the waste heat for something else (cooking, heating water or homes, AC)

Bottoming – Using the heat for something else, like melting steel and generating electricity from the heat as the steel cools.

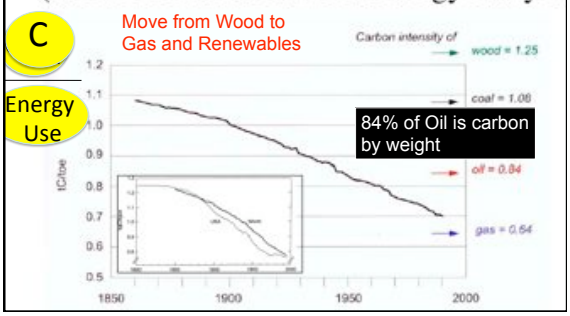
tC / toe — Ton of Carbon / Energy from burning ton of crude

Kammen, UC Berkeley

The "Decarbonization" Curve
(the most famous curve in energy analysis)

$\frac{C}{\text{Energy Use}}$

Move from Wood to Gas and Renewables



84% of Oil is carbon by weight

The Consumption Happiness Law:

☺ ∝ $ ∝ Energy Use ∝ CO_2

$\frac{CO_2}{☺} = \frac{CO_2}{\text{Energy Use}} \frac{\text{Energy Use}}{\$} \frac{\$}{☺}$

$\frac{CO_2}{\$} = \frac{CO_2}{\text{Energy Use}} \frac{\text{Energy Use}}{\$}$

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Minimize Carbon Intensity of Economy:

$\frac{CO_2}{\$} = \frac{CO_2}{\text{Energy Use}} \frac{\text{Energy Use}}{\$}$

$\frac{CO_2}{\text{Energy Use}}$	$\frac{\text{Energy Use}}{\$}$
carbon intensity energy production	energy intensity of our economy
Fuel => energy	Use Energy

$$\frac{Kg(CO_2)}{\$} = \frac{Kg(CO_2)}{MJ}\frac{MJ}{\$}$$

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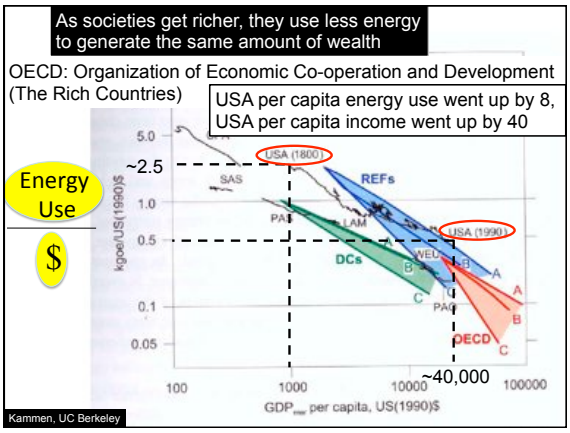
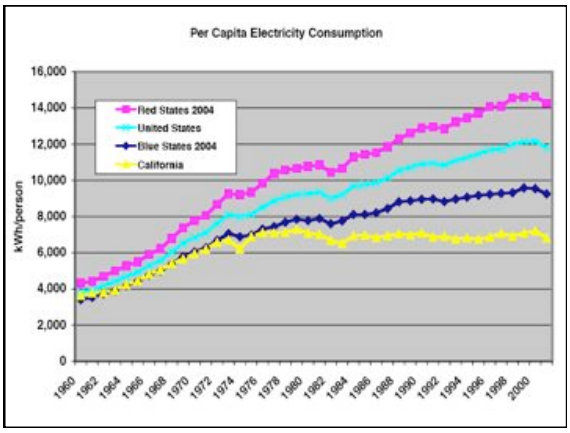

As societies get richer, they use less energy to generate the same amount of wealth
OECD: Organization of Economic Co-operation and Development (The Rich Countries)
USA per capita energy use went up by 8, USA per capita income went up by 40
Energy Use
$
~2.5
~40,000
USA (1800)
USA (1990)
REFs
DCs
OECD
SAS
LAM
MAF
PAS
PAO
WEU
kgoe/US(1990)$
GDP per capita, US(1990)$
Kammen, UC Berkeley


Per Capita Electricity Consumption
Red States 2004
United States
Blue States 2004
California
kWh/person