Figure by MIT OCW.

Problem Set 1
IAP Part A: Sustainable Energy
10.391J/22.811J/ESD166J/11.371J/1.818J/3.564J/2.65J
Due Wednesday January 17, 2007

Practice Problems for Class:

1. **"Sustainable Transport"** - If we stacked all the cars and trucks in the world on top of each other, how far would the stack reach into space?

2. **"Sustainable hydro"** - How much water flow does the Niagara Falls hydroelectric plant require? The falls are about 170 feet high.

3. **"Do we have enough gas stations**" - How many gasoline stations are there in the United States?

Homework Problems:

1. The average American uses about 8 tonnes of oil equivalent per year. Suppose that 1/4 of this is used as electricity. How many kWh/year would this person use?

2. Many Americans drive 15,000 miles or more per year. Let's assume that this typical American uses a SUV or light truck that averages 11 miles per gallon. How many TOE does this correspond to? If the transportation sector is about 1/3 of total primary energy use, how would this rate of consumption compare with U.S. average?

3. Recently, *Sierra* magazine (Jan-Feb 2003 issue) published a short Ecological Footprint Quiz that was designed by The Redefining Progress Group, based in Oakland California, to help people determine their "ecological footprint" – or how much land is needed to support their individual lifestyle. Please use their format to estimate your personal ecological footprint in acres of land. Go to: http://www.earthday.net/footprint/info.asp to take the quiz. Print your quiz results page and submit with your homework.

4. Alternatively, the Carbon Fund Foundation has developed a "carbon footprint" quiz. Go to: http://www.carbonfund.org/site/pages/calculator to estimate your carbon footprint. Print out your quiz results page and submit with your homework.

5. Imagine a future lifestyle when you are at the height of your professional career. Re-estimate your eco-footprint based on how you would like to live in the future. Is it more or less than at present? By how much?

6. In addition to the on-line estimates you have just completed in Questions 3 and 4, a more detailed approach was developed by Ernst called the "Personal Energy Calculator" or PEC. The PEC calculation sheet and pages discussing the assumptions follow. Write two or three paragraphs evaluating the two footprint estimates you have made. Are they realistic? How would they compare to the PEC? What do they omit? How would you improve them?

Personal Energy Calculator

Developed by Dr. Walter Ernst in 2002 for the Youth Encounter on Sustainability (YES), Edited by Beth Conlin

Please enter consumption estimates for the following tasks. Use the provided conversion units to convert to kWh.

Task	**Consumption (Metric conversions below)**		**NEW Conversion Unit**	**Demand per person and year [kWh/y]**	
Household:					
Direct energy:					
residence - area heated		m2	x 25-170 kWh/m2y =		kWh/y
residence - area air conditioned		m2	x 5-15 kWh/m2y =		
residence – electricity		m2	x 18-28 kWh/m2y =		
Indirect energy:					
residence - total used area		m2	x 55-67 kWh/m2y =		
Total Household					kWh/y
Mobility					
Car					
Direct energy:					
fuel [Liter gasoline per year]		L/y	x 12 kWh/L =		
fuel [Liter diesel per year]		L/y	x 12.5 kWh/L =		
Indirect energy:					
km driven per year		km/y	x 1.2-1.4 kWh/km =		
car weight		kg	x 5.3 kWh/kgy =		
Public Transport					
Train		km/y	x .5-.9 kWh/km =		
Bus/Boat		km/y	x .15-.8 kWh/km =		
Aircraft [hours per year]		h/y	x 500-1000 kW/h =		
Total Mobility					kWh/y

Nutrition (consumed per year)					
Select one of the following:	(see guidance)		2000-4000 kWh/y =		
Non-Vegetarian			14845 kWh/y =		
Vegetarian			10603 kWh/y =		
Vegan			7634 kWh/y =		
Total Nutrition					kWh/y
Private Consumption					
Higher Education		US$/y	x 2.3 kWh/US$ =		
Furniture and Appliances (total value)		US$	x .14 kWh/US$y =		
Clothes, shoes purchased per year		US$/y	x .1 kWh/US$ =		
Computer and Internet Use		hrs/y	x .2 kW/hr =		
Total Private Consumption					kWh/y
Public Consumption	(see guidance)		1,000-10,000 kWh/y =		kWh/y
Grand Total					kWh/y
CO2 Emissions Estimate	(Grand Total)		x 0.22 kg CO2/kWh ˜		CO2/y
1 ft2 ˜ 0.1m2; 1 US gallon = 3.8 Liters; 1 mile = 1.6km; 1 US pound = 0.453kg					

Energy Calculator
Explanation of Calculations

July 5, 2006

The following explanations derive from final projects reports. The housing and vehicle calculations were primarily compiled by Katje Lange, and the rest were compiled by Beth Conlin. (MIT LFEE)

Background

The calculator is an activity that allows students and anyone interested in their ecological impact to calculate an estimate of their annual energy consumption and carbon dioxide production. It was developed at another institution several years ago but little documentation exists about the underlying calculations. Data is gathered about different activities of each individual, such as within the household. This is converted into an annual energy estimate using conversion factors. The task is to use the most recent available data to verify or update the current conversion factors.

Calculations

Household

	Old conversion factor	New conversion factor
Residence- area heated	50-300 kWh/m^2y	25-170 kWh/m^2y
Residence- area cooled	50-200 kWh/m^2y	5-15 kWh/m^2y
Residence- total used area	30-80 kWh/m^2y	50-110 kWh/m^2y
Residence- Electricity	N/A	40-75 kWh/m^2y

The conversion units for the direct energy uses were calculated from EIA (Energy Information Agency) data, the Residential Energy Consumption Survey (RECS) 2001 (1).
Note the large disagreement between the old and new conversion factor for air conditioning. The new factor is in strong agreement with general household energy consumption percentages. Roughly speaking, space heating consumes about 40% of the total energy used in a household, whereas air conditioning only takes up around 10%. The ratios of the conversion units are in line with this general distribution so I could conclude that the old factor was incorrect. The range of the conversion factors is large and I would like to give advice on how to choose a factor within this range in the presentation. People will have to choose the factor depending on how cold/warm the area they live in is, how well insulated the house is, and how much they think they use heating and cooling. For heating, it also strongly depends on which fuel is being used. As you can see in the appendix, the factors have wide ranges in different areas of the US so giving people an idea of these ranges and comparing them to where they live will help them make an informed choice.

Indirect energy is the energy needed in construction and maintenance of a building, averaged over its life time. First, I used data from Walter Ernst's 'Persoenlicher Energie Rechner'. In section C, he assigns points to buildings of different ages and construction types which range from 0.8 to 1.5. The points are multiplied by a factor of 70 kWh/m^2y so I obtain a range of roughly 50-110 kWh/m^2y. This will again depend on the age of the house, how well insulated it is and how expensively it was built. Using local building materials can lower the factor compared to importing materials from another continent. Also, if a house uses renewable energy for instance to heat its water, it will be assigned a lower overall factor. A second method is outlined in the appendix.

On top of the existing factors, I would like to introduce a line which takes account of the electricity use in a household. Again, using RECS 2001 data, this turned out to be not insignificant. I determined a conversion factor of 40-75 kWh/m^2.

Household - Heating (2)
note: HH denotes household

	area (sqft)	**energy per HH (million BTU)**	**energy per HH (10^3 kWh)**	**kWh/ sqft**	**kWh/m^2**
New England					
Natural Gas	1880	74.1	21.7	11.6	124.3
Kerosene	1487	47.4	13.9	9.3	100.6
Electricity	1122	14.8	4.3	3.9	41.6
Fuel oil	2268	80.5	23.6	10.4	112.0
LPG	1200	61.3	18.0	15.0	161.1
average	1988	71.5	20.9	10.5	113.4
North East					
Natural Gas	1822	67.3	19.7	10.8	116.5
Kerosene	1149	56.2	16.5	14.3	154.3
Electricity	1609	17.6	5.2	3.2	34.5
Fuel oil	2087	71.7	21.0	10.1	108.4
LPG	1642	63.2	18.5	11.3	121.4
average	1872	62.6	18.4	9.8	105.5
US					
Natural Gas	1836	55.4	16.2	8.8	95.2
Kerosene	1076	39.0	11.4	10.6	114.3
Electricity	1399	11.3	3.3	2.4	25.5
Fuel oil	2043	70.2	20.6	10.1	108.4
LPG	1570	50.3	14.7	9.4	101.1
average	1707	43.0	12.6	7.4	79.5

Household - Air Conditioning (3)

Only electrical air conditioning was considered in the RECS 2001. A distinction was made between central and room based air conditioning appliances.

	kWh/HH/y	area(sqft)/HH	kWh/sqft/y	kWh/m^2y
New England				
Total	805	1533	0.53	5.7
-Central	1595	2944	0.54	5.8
-Room	552	1081	0.51	5.5
North East				
Total	953	1505	0.63	6.8
-Central	1420	2306	0.62	6.6
-Room	642	971	0.66	7.1
US				
Total	2263	1724	1.31	14.1
-Central	2796	2032	1.38	14.8
-Room	950	967	0.98	10.6

Household - Electricity consumption per household, RECS 2001 data (4)

New England
water heating: 2,149 kWh
2.3 household members
other appliances: 1152+4480 kWh =3,383kWh/member
per household: 7781 kWh
area of household (sqft): 1988 =42.13 kWh/m^2

= 18.3 kWh/m^2 per person

North East
water heating: 2,342 kWh
2.5 household members
other appliances: 1230+4480 kWh =3,221 kWh/member
per household: 8052kWh
area of household (sqft): 1872 =46.30 kWh/m^2

= 18.5 kWh/m^2 per person

US
water heating: 2,552 kWh
2.4 household members
other appliances: 1462+5435 kWh =3,937 kWh/member
per household: 9449 kWh
area of household (sqft): 1707 =59.58 kWh/m^2 per household

= 24.8 kWh/m^2 per person

Midwest
water heating: 2515 kWh
2.4 HH members
other: 1438+5727 kWh =4,033 kWh/member
per household: 9680 kWh
area of household (sqft): 1997 = 52.18 kWh/m^2

= 21.7 kWh/m^2 per person

South
water heating: 2661kWh
2.5 HH members
other: 1746+6232 kWh =4,256 kWh/member
per household: 10639 kWh
area of household (sqft): 1624 =70.52 kWh/m^2

= 28.2 kWh/m^2 per person

West
water heating: 2386 kWh
2.4 HH members
other: 1213+4626 kWh =3,427 kWh/member
per household: 8225 kWh
area of household (sqft): 1391 =63.65 kWh/m^2

= 26.5 kWh/m^2 per person

Range: 3200-4300 kWh/member/year
40-75 kWh/m^2 per household
18-28 kWh/ m^2 per person

(Other appliances are given as refrigerators+other&lighting)

Indirect energy:
According to the Census Bureau, (12), the average floor area of a new built one family house is 2349 sqft in the US or 2543 sqft in the North East. The Census Bureau gives the price per sqft as approximately $81.2 in the US or $97.3 in the North East. Using these cost estimates as an input for the Economic Input-Output Life Cycle Assessment (EIO-LCA) model (11) I obtain an estimated energy expenditure of 0.010 TJ per m^2 in the US or 0.012 TJ per m^2 in the North East. I estimate the

average life time of a building to be 50 years. The conversion factor would then be 55-67 kWh/m^2y. This lies well in the range of the conversion factor obtained using Walter Ernst's data.

Mobility

	Old Conversion Unit	New Conversion Unit
Car		
fuel (gasoline/y)	11 kWh/L	12 kWh/L
fuel (diesel/y)	11 kWh/L	12.5 kWh/L
km driven/y	0.05-0.15 kWh/km	1.2-1.4 kWh/km
car weight	5 kWh/kgy	5.3 kWh/kgy
Public Transport		
Train	0.1-0.5 kWh/km	0.5-0.9 kWh/km
Bus/Boat	0.03-0.5 kWh/km	0.15-0.80 kWh/km
Aircraft	400-1200 kWh/H	500-1000 kWh/H

Notice that the new factor for rail travel is significantly larger than the one previously used. It would be interesting to see if trains in Europe are run more efficiently than in the US. The factor used in air travel can still be determined more precisely but it will always enclose a large range of values. To choose the right factor, one needs to consider the relative efficiencies of short, mid and long range flights. Also, a fully booked new commercial airplane will use fuel more efficiently than an old private jet.

Mobility - Fuel:
Energy content per liter of fuel (5)
Gasoline contains 32-35 MJ/L= 8.9-9.7 kWh/L
Diesel contains more energy per liter: 36.4 MJ/L = 10.2 kWh/L

In 2002, refineries used 6391 trillion Btu of total energy. 2002 EIA data (6)
The estimated monthly petroleum products output is 500 million barrels.
Conclude 2 kWh/L in production of all petroleum products.
Estimate 0.5 kWh/L for transportation to the end user.

Get an approximate conversion of 12 kWh/L for gasoline and 12.5 kWh/L for diesel.

Mobility - Car Weight:
To calculate an estimate of the energy expenditure per kg of car weight, the following data was used:
The average price of a new car is $28,000 (in 2003) (10).
The average life time of a light vehicle is 9.0 years and the average curb weight for light vehicles is 3090 lbs (Transportation Energy Data Book, (7)).
Using the average sales price as an input, the Economic Input-Output Life Cycle Assessment (EIO-LCA) model (11) gives the total energy consumption in the manufacturing industries as 0.242 TJ. Thus I obtain a value of 47.9 kWh/kg or 5.3 kWh/kgy averaged over the life time.

Mobility - km Travelled:

Stammer and Stodolsky (14) offer energy investments of various types of roadway construction on a per mile basis. This data was converted to per kilometre figures for both rural and urban scenarios, and weighted for percentage of roadway affected by each particular type of construction. Detailed calculations are available in the spreadsheet "kWh-km Data.xls."

Mobility - Public transport:
I used the Transportation Energy Data Book (edition 24). (7)

For the different types of trains, such as commuter rail or intercity travel, a range of energy intensities is given: 2714-4830 Btu/passenger mile
This converts to 0.50-0.90 kWh/km.

Mobility - Aircraft:
The Rocky Mountain Institute (8) gives the energy intensities per passenger mile as
domestic 4053 Btu/pass mile
international 4123 Btu/pass mile
general 5628 Btu/pass mile

The Bureau of Transportation Statistics (9) gives the energy intensities per passenger mile as:
domestic 3476 Btu/pass mile
international 3894 Btu/pass mile

I assumed that the average travel speed of a commercial airplane is 500-600 mph.
This gives as a rough estimate a range of 500-1000 kWh/h.

Buses have differing energy intensities according to their service routes. Transit routes have much higher energy intensities than intercity travel. The Transportation Energy Data Book (edition 24) (7) gives the following data:
Transit 4127 Btu/pass mile = 0.76 kWh/km per passenger
Intercity 932 Btu/pass mile = 0.17 kWh/km per passenger
(Note that no 2002 data was available for intercity bus travel so the most recent data was used, from 2000)
Thus we can assign a range of energy intensities of 0.15-0.80 kWh/km per passenger.

Nutrition:
The nature of this calculation changed from an input of food weight into a calculation with a conversion factor. The new method has the user pick a standard number based on the general characteristics of their diet.

Pimentel and Pimentel calculated an estimate of the fossil energy used as part of various diets. These figure were provided in kcal per day. Final conversion factors were calculated as below.

	Fossil Energy (kcal/day)	Fossil Energy (kWh/d)	Fossil Energy (kWh/y)
Vegetarian	18000	20.9	7634.3
Lacto-Ovo Vegetarian	25000	29.1	10603.3
Nonvegetarian	35000	40.7	14844.6

This method improves upon the previous method. It allows a quick calculation of a generally small percentage of impact, so more time can be concentrated on accurate estimation of the great impact line items.

Private Consumption:

Private Consumption	Old Conversion Unit	New Conversion Unit
Higher Education	.25 kWh/US$	2.3 kWh/US$
Furniture and Appliances (total value)	.15 kWh/US$y	.14 kWh/US$y
Clothes, shoes purchased per year	2 kWh/US$	.1 kWh/US$
Computer and Internet Use	n/a	.2 kW/hr

Private Consumption – Private Education

This estimates for American private education were derived from energy use per student data and tuition information. A report provided internally from Peter Cooper from the Association of Higher Education Facilities Officers detailed million btu use per dollar spent and dollars spent on energy per student in associate and baccalaureate offering institutions. From this, we derived mbtu per student. The College Board "Trends in College Pricing 2005" (15) provided tuition for associate and baccalaureate programs. We divided energy use by tuition, and derived a conversion factor of kilowatt hours per tuition dollar.

Detailed calculations are available in the spreadsheet "college worksheet.xls."

Private Consumption – Furniture and Appliances

These figures were calculated by combining data from the U.S. Department of Energy (16) for energy consumption by industry, and U.S. Census Bureau (17) for retail sales by industry.

Total btu of energy used per industry (in this case the Textile Mills, Textile Product Mills, Apparel, and Leather and Allied Products) were converted to kilowatt hours (a standard conversion), divided by retail sales in dollar units.

Note that this does not include the energy used for transport or retail outlets, but this information for this specific sector was unavailable.

Private Consumption – Clothes, shoes purchased per year

These figures were calculated by combining data from the U.S. Department of Energy (16) for energy consumption by industry, and U.S. Census Bureau (17) for retail sales by industry.

Total btu of energy used per industry (in this case the Textile Mills, Textile Product Mills, Apparel, and Leather and Allied Products) were converted to kilowatt hours (a standard conversion), divided by retail sales in dollar units.

Note that this does not include the energy used for transport or retail outlets, but this information for this specific sector was unavailable.

Detailed record of the calculations are available in the spreadsheet "Private Consumption - Consumer Goods.xls."

Private Consumption – Computer Use

The Harvard Green Campus Initiative (18) lists 125 watts as the amount of energy a computer uses when active or idle. An extremely conservative estimate for the supporting an continuously running servers and other computer networks puts the total computer energy use at 200 watts, or .2 kilowatts as a conversion factor.

Public Consumption:

Public consumption figures are still currently based on Walter Ernst's original calculations.

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