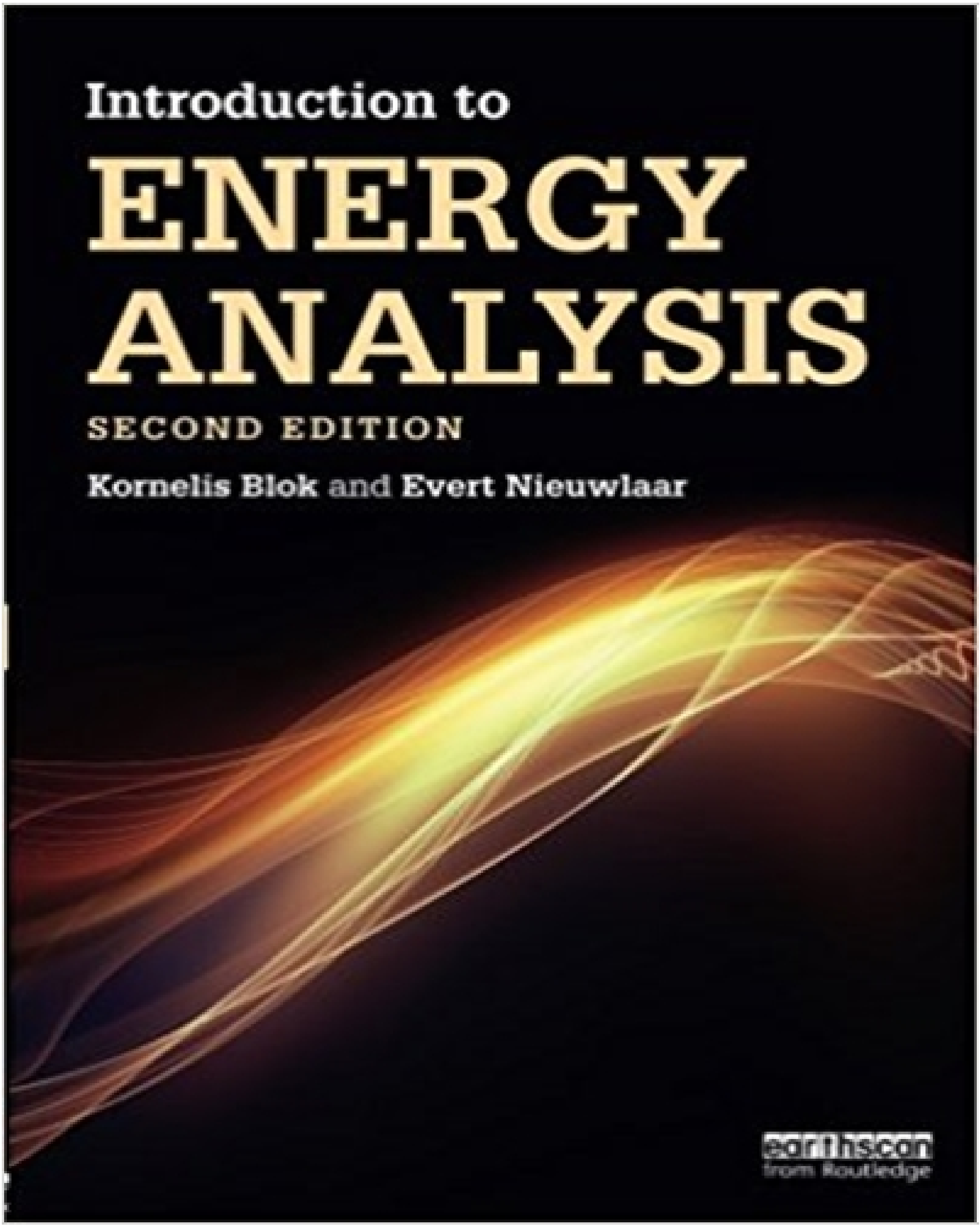
Solutions for Introduction to Energy Analysis 2nd Edition by Blok



Solutions

2.1 A piece of wood

a. kinetic energy and velocity
conservation of mechanical energy:

$$E_{kin} + E_{pot} = \text{constant}$$
$$\tfrac{1}{2} m v_1^2 + m g h_1 = \tfrac{1}{2} m v_2^2 + m g h_2$$
$$\tfrac{1}{2} m \left(v_2^2 - v_1^2 \right) = m g \left(h_1 - h_2 \right)$$

data:

m = 1 kg	g = 9.8 m/s^2
v_2 = ? m/s	v_1 = 0 m/s
h_2 = 0 m	h_1 = 30 m

since $v_1 = 0$ and $h_2 = 0$, we get for the kinetic energy and velocity at ground level:

$$\tfrac{1}{2} m v_2^2 = m g h_1 = 1 * 9.8 * 30 = 294 \text{ kg.m}^2/\text{s}^2 = \underline{294 \text{ J}}$$
$$v_2 = \sqrt{\frac{\not{m} g h_1}{\tfrac{1}{2} \not{m}}} = \sqrt{\frac{9.8 * 30}{0.5}} = 24.25... \approx \underline{24 \text{ m/s}}$$

b. Temperature increase
Assuming inelastic collision, kinetic energy is fully converted to thermal energy. Energy balance:

$$\tfrac{1}{2} m v_2^2 = m c (T_2 - T_1)$$
$$\Delta T = T_2 - T_1 = \frac{\tfrac{1}{2} m v_2^2}{m c}$$

the heat capacity (specific heat) is given: c=2.7 kJ·kg^{-1}·K^{-1} = 2700 J·kg^{-1}·K^{-1}:

$$\Delta T = \frac{\tfrac{1}{2} m v_2^2}{m c} = \frac{294}{1 * 2700} = \underline{0.109 \text{ K}}$$

c. heat release upon oxidation (combustion)
heat of combustion is given as 18 MJ/kg
Heat release: 1 kg * 18 MJ·kg^{-1} = 18 MJ = $\underline{18\ 10^6 \text{ J}}$

d. Lessons learned.
The heat of combustion is 5 orders of magnitude higher than the kinetic energy calculated. This exercise shows that very often differences in kinetic and gravitational energy can be neglected in energy balance calculations.

2.2 Forms of Energy

a. kinetic energy of a car

kinetic energy is $E_{kin} = \frac{1}{2} mv^2$, so we need mass and velocity

Car weight *m* = 1000 kg

v = 100 km/h = (100 km/h) * (10^3 m/km) * (1/3600 h/s) = 27.8 m/s

kinetic energy:

$$E_{kin} = \frac{1}{2} mv^2 = 0.5 * \underset{kg}{1000} * \left(\underset{m/s}{27.8} \right)^2 = 386 * 10^3 \ \mathrm{kg \cdot m^2 \cdot s^{-2}} = \underline{386 \ \mathrm{kJ}}$$

b. heat content bath tub

$Q = mc\Delta T = mc(T - T_{ref})$, so we need mass, specific heat and two temperatures

<u>Assumptions</u>:

reference temperature of 10 °C

bath water temperature 40 °C

specific heat water 4.18 kJ/(kg·K)

density water: 1 kg/liter

heat content:

$$Q = mc\Delta T = 100 * 4.18 * (40 - 10) = 12.54 * 10^3 \ \mathrm{kJ} = \underline{12.5 \ \mathrm{MJ}}$$

c. potential energy myself after climbing two flights of stairs

$E_{pot} = mgh$

$g = 9.8 \ \mathrm{m/s^2}$ so we need mass and height (difference)

assumptions:

My weight: 72 kg

each flight 3 m, 2 flights, so *h* = 6 m

Potential energy:

$$E_{pot} = mgh = \underset{kg}{72} * \underset{m/s^2}{9.8} * \underset{m}{6} = 4.23 \ 10^3 \ \mathrm{kg.m^2/s^2} = \underline{4.23 \ \mathrm{kJ}}$$

2.3 Power consumption household equipment

Annual energy consumption per device: $E \text{ kWh/yr} = (P \text{ kW}) * (Operation\ Time \text{ h/yr})$, so we need power (in kW) and (estimate of) operating time (in hours per year).

Some examples:
TV (data from www.milieucentraal.nl 2008):
Operating Time: 4 hours per day, stand-by/off 20 hours/day. (ca. 1500 hrs/yr)

type	power [W]	annual energy use [kWh/yr]
Plasma, 42 inch	140-300, average: 220	330
LCD, 32 inch	90-160, average 125	190

(This calculation is quite simple: standby losses were ignored).

Vacuum cleaner:
Miele S380: power 1800 W (max.).
Operating time: 0.5 hours per week: 26 h/yr
Energy use: (1.8 kW) * (26 h/yr) = 46.8 kWh/yr
Milieucentraal: average (NL): 54 kWh/yr

Lamps
example: 1 lamp burning 3 hours/day, so operating time = 3 h/d * 365 d/yr = 1095 h/yr

lamp type	power [W]	annual energy use [kWh/yr]
Incandescent	75	82
fluorescent	15	16
LED	10	11

Average household (NL), annual energy use for lighting: 540 kWh. (source: Milieucentraal 2008)

Microwave
Example Bosch HMT96660 1000 W microwave, max. power use: 1.27 kW.
Assume 15 minutes/day max. power = (0.25 h/d) * (365 d/yr) = 91 h/yr
Energy use: (1.27 kW) * (91 h/yr) = 116 kWh/yr

desktop computer
(data from Milieucentraal 2008)
active use: 11 h/w, stand-by: 42 h/w

Use	Power (W)	operating time h/yr	electr. use kWh/yr
active	150	570	86
stand-by	42.9	2184	93.6

Note that stand-by use exceeds active use in this case.

2.4 HHV versus LHV

a. From textbook (table 2.4): for coal E_{HHV}/E_{LHV} = 1.03, so the amount of fuel giving 1 MJ_{LHV} on LHV basis, gives off 1.03 MJ_{HHV} on a HHV basis.

$$\eta_{LHV-based} = \frac{\text{electricity output}}{\text{fuel input, LHV based}} = 0.40 = \frac{0.40\ \text{MJ}_\text{e}}{1\ \text{MJ}_\text{LHV}}$$

same amount of coal used so denominator becomes 1.03 [MJ_{HHV}]

$$\eta_{HHV-based} = \frac{0.4\ [\text{MJ}_\text{e}]}{1.03\ [\text{MJ}_\text{HHV}]} = \underline{0.388}$$

b. From textbook (table 2.4): for natural gas E_{HHV}/E_{LHV} = 1.10, so the amount of fuel giving 1 MJ_{LHV} on LHV basis gives off 1.10 MJ_{HHV} on HHV basis, or 1 MJ_{HHV} of fuel is 1/1.10=0.91 MJ_{LHV}

$$\eta_{HHV-based} = 0.97 = \frac{0.97\ \text{MJ}_\text{th}}{1\ \text{MJ}_\text{HHV}}$$

same amount of natural gas used, so denominator becomes 0.91 MJ_{LHV}

$$\eta_{LHV-based} = \frac{0.97\ \text{MJ}_\text{th}}{0.91\ \text{MJ}_\text{LHV}} = \underline{1.065}$$

Since the LHV-efficiency is higher than 100%, (partial) condensation of water vapor must have taken place.

c. The Higher Heating Value gives a better indication of the (maximum) usable energy content of a fuel and thus a better indication of (maximum) possibilities of a fuel.

2.5 Combustion of wood

a. *LHV oven dry wood*

use formula 2.4b from box 2.1.

$$E_{LHV,wb} = E_{HHV,wb} - h \cdot E_{w,evap} \cdot m_{H_2O} \cdot (1-w) - E_{w,evap}.w$$

The chemical composition of wood is $(CH_2O)_n$.
Atomic weights (or molar masses, in kg/kmol):
H – 1
C – 12
O – 16

Using molar masses, 1 kg oven dry wood contains 2/(12+2+16) = 0.0667 kg
Hydrogen → h = 0.0667 [-]
w=0 for oven dry wood

$E_{LHV,\text{ oven dry}}$ = (20 MJ/kg) –(0.0667 kg/kg) * (2.44 MJ/kg) * (8.9 kg/kg)[1] = 18.6 MJ/kg.

b. *HHV and LHV air dry and harvested wood*

Use equations 2.4a and 2.4b
Harvested wood contains 50% water, and thus w =0.5
$E_{HHV,\text{ harvested wood}}$ = (20 MJ/kg) * (1-0.5) = 10.0 MJ/kg
$E_{LHV,\text{ harvested wood}}$ = (10 MJ/kg) – (0.0667 kg/kg) * (2.44 MJ/kg) * (8.9 kg/kg)*(1-0.5 kg/kg) – (2.44 MJ/kg) * 0.5 = 8.1 MJ/kg

w =0.2-0.35 for air dry wood, and thus
$E_{HHV,\text{ air dry}}$= 13 – 16 MJ/kg
$E_{LHV,\text{ air dry}}$ = 11.3 –14.5 MJ/kg

[1] The more exact molar masses of hydrogen and oxygen are 1.00797 and 16.01534 and the mass of water created per mass of hydrogen is therefore 8.9 and not 9.

2.6 Water heating

a. If you assume that the cold water has a temperature of 10 °C, then the amount of energy needed is:
E_{fuel}= (100 litre) * (1 kg/litre) * (4.18 kJ/(kg.K)) *(70-10 [°C])/0.80 = 31.4 MJ

b. The amount of electricity needed is :
$E_{electric}$= (100 litre) * (1 kg/litre) * (4.18 [kJ/kgK]) *(70-10 [°C])/1.00 = 25.1 MJ

This is less energy compared with heating with natural-gas. However the electricity has to be made as well.

c. Primary energy

Use eq. 2.7:

$$E_p = F + \frac{E}{\eta_e}$$

For heating with natural gas: E_p=E_{fuel}=31.4 MJ
Electric power production typically with an efficiency of 40%.
The amount of primary energy needed is thus E_p= 25.1/0.40= 62.8 MJ

Not considering the energy requirement for providing the fuels, the primary energy for electric heating is twice the primary energy use for natural gas heating.

2.7 Conversion efficiency of energy conversion sectors

a. Efficiency electricity plants
For total electricity production we use the row 'Electricity Plants' (beneath 'Statistical Differences'). The fuel inputs and electricity outputs are:

Energy inputs	**EU28 2012 [PJ]**
Coal	6522
Crude oil	99
Petroleum	388
Gas	1949
Nuclear	9505
Hydro	1206
Geothermal	208
Solar/Wind	1047
Biofuels	770
Total Energy Input	**21694**
Electricity production	**9269**
efficiency (= el.prod/total energy input)	**0.427**

Efficiency per fuel type:
Electricity outputs from bottom of table; 1 TWh = 3.6 PJ
Electricity output: use line 'Electricity Plants' beneath 'Electr. Generated – TWh'

	EU28 [PJ)		
	fuel [PJ]	electr [PJ]	efficiency
Coal	6522	2487	0.381
Crude oil	99	34	0.345
Petroleum	388	141	0.364
Gas	1949	1003	0.515
Nuclear	9505	3136	0.330
Hydro	1206	1206	1.000
Geothermal	208	21	0.100
Solar/Wind	1047	1007	0.962
Biofuels	770	232	0.301

Remarks (some rounding differences):
Nuclear: consistent with 33% efficiency in IEA statistics
Hydro: consistent with IEA convention: hydroelectric output = primary input
Geothermal: consistent with IEA convention: 10% efficiency assumption for geothermal power plants
Solar wind: almost consistent with IEA convention: Solar PV/Wind electricity = primary input (maybe some solar thermal electricity?)

b. efficiency CHP
We only calculate totals, so we do not distinguish according to fuel
Total fuel input (from row 'CHP Plants',:

electricity+heat-total=2484+1761-(-2738)): 6982 [PJ]
Electricity output: 2484 [PJ] $\rightarrow \eta_e = 2484/6982 = 0.356$
Heat output: 1761 [PJ] $\rightarrow \eta_{th} = 1761/6982 = 0.252$
Total efficiency: 0.356 + 0.252 = <u>0.608</u>

c. Oil Refineries
Input = 27138 [PJ] Crude oil
Output = 26902 [PJ] Petroleum
Efficiency: $\eta = 26902/27138 = \underline{0.991}$
Actually the efficiency of refineries is lower. It is often found in Energy Statistics that refinery output is higher than refinery input. Since the first law is not (expected to be) violated, there must be energy flows that have not been accounted for (e.g., energy inputs from chemical industry on the same sites as the refineries).

2.8 Primary energy use of nuclear/hydro power plants

a. effect IEA conventions in converting nuclear/hydro to primary energy

Share Nuclear/Hydro in TPES (data from Appendix 2a and 2b):

	EU28 2012			USA 2012		
	(PJ)	%		(PJ)	%	
TPES [PJ]	68814	100		89623	100	
- Nuclear	9632	14		8741	9.8	
- Hydro	1206	1.8		1003	1.1	

Share of nuclear / hydro in electricity supply (data from appendix 2 bottom lines, TWh converted to PJ):

	EU28 2012			USA 2012		
	(PJ)	%		(PJ)	%	
Total E prod. [PJ]	9269	100		14209	100	
- Nuclear	3175	34		2884	20	
- Hydro	1206	13		1003	7	

Compared to hydro, Nuclear has about 3 times higher share in electricity production but an about 8 times higher contribution to the TPES, caused by the fact that a conversion efficiency of 0.33 has been used for nuclear, whereas the conversion factor for hydro is 1.0.

b. effect of using GEA conventions

In the GEA conventions an efficiency of 35% is used for electricity from non combustible sources which include nuclear and hydro. The primary energy for nuclear and hydro now become:

nuclear: 3175 / 0.35 = 9071 PJ

hydro: 1206 / 0.35 = 3446 PJ

The new value for TPES can now be obtained by subtracting the original values for the primary energy for nuclear/hydro and adding the new values:

TPES(new) = 68814 – 9632 – 1206 + 9071 + 3446 = 70439 PJ.

The difference is 70439 – 68814 = 1679 PJ (2.4%)

2.9 Share in total final consumption

Eq. 2.7: $E_p = F + \frac{E}{\eta_e}$

Using table Appendix 2a (Energy Balance EU28, 2012) this formula becomes:

$$E_p = [Total - El] + \frac{El}{\eta_e}$$

η_e = 0.427 (calculated in exercise 2.7)

	Total (PJ)	F (P{J)	E (PJ)	prim (PJ)	%
all	47698	37628	10070	61211	100%
industry	11034	7411	3623	15896	26%
transport	12849	12619	231	13159	21%
agriculture	1042	882	161	1258	2%
service	6217	3174	3042	10299	17%
residential	12105	9122	2983	16108	26%

2.10 Energy Balance Nomansland

Final table:

Energy Balance Nomansland (in PJ)	Coal	Gas	Electricity	Total
production	0	1672	0	1672
Imports	1230	0	0	1230
Exports	0	0	0	0
Stock changes	0	0	0	0
TPES	1230	1672	0	2902
Electricity Plants	-1000	-800	800	-1000
Other energy conversion	-100	-200	-70	-370
TFC	130	672	730	1532
Industry	115	250	220	585
Transport	0	22	10	32
Other sectors	15	400	500	915

Step 1: Calculate TFC=sum sector consumptions

Energy Balance Nomansland (in PJ)	Coal	Gas	Electricity	Total
production	0		0	
Imports		0	0	
Exports	0	0	0	0
Stock changes	0	0	0	0
TPES				
Electricity Plants				
Other energy conversion	-100	-200	-70	-370
TFC	**130**	**672**	**730**	**1532**
Industry	115	250	220	585
Transport	0	22	10	32
Other sectors	15	400	500	915

Step2: calculate electricity production (=TFC - other energy conversion)

Energy Balance Nomansland (in PJ)	Coal	Gas	Electricity	Total
production	0		0	
Imports		0	0	
Exports	0	0	0	0
Stock changes	0	0	0	0
TPES				
Electricity Plants			**800**	
Other energy conversion	-100	-200	-70	-370
TFC	130	672	730	1532
Industry	115	250	220	585
Transport	0	22	10	32
Other sectors	15	400	500	915

<u>Note</u>: in energy conversion sectors outputs have a positive sign, inputs have a negative sign.

Step 3: calculate Coal/gas input electricity plants (watch the minus sign!!)

El from coal (fraction)	0.5	eff. Coal	0.4
El from gas (fraction)	0.5	eff. Gas	0.5

Energy Balance Nomansland (in PJ)

	Coal	Gas	Electricity	Total
production	0		0	
Imports		0	0	
Exports	0	0	0	0
Stock changes	0	0	0	0
TPES				
Electricity Plants	**-1000**	**-800**	800	**-1000**
Other energy conversion	-100	-200	-70	-370
TFC	130	672	730	1532
Industry	115	250	220	585
Transport	0	22	10	32
Other sectors	15	400	500	915

Step 4: Calculate TPES (=TFC-conversions)

Energy Balance Nomansland (in PJ)

	Coal	Gas	Electricity	Total
production	0		0	
Imports		0	0	
Exports	0	0	0	0
Stock changes	0	0	0	0
TPES	**1230**	**1672**	**0**	**2902**
Electricity Plants	-1000	-800	800	-1000
Other energy conversion	-100	-200	-70	-370
TFC	130	672	730	1532
Industry	115	250	220	585
Transport	0	22	10	32
Other sectors	15	400	500	915

Step 5: Set imported coal and gas production

Energy Balance Nomansland (in PJ)

	Coal	Gas	Electricity	Total
production	0	**1672**	0	**1672**
Imports	**1230**	0	0	**1230**
Exports	0	0	0	0
Stock changes	0	0	0	0
TPES	1230	1672	0	2902
Electricity Plants	-1000	-800	800	-1000
Other energy conversion	-100	-200	-70	-370
TFC	130	672	730	1532
Industry	115	250	220	585
Transport	0	22	10	32

Other sectors	15	400	500	915