Lectures and Homework

4/8/2016 Lecture 6: Biofuels

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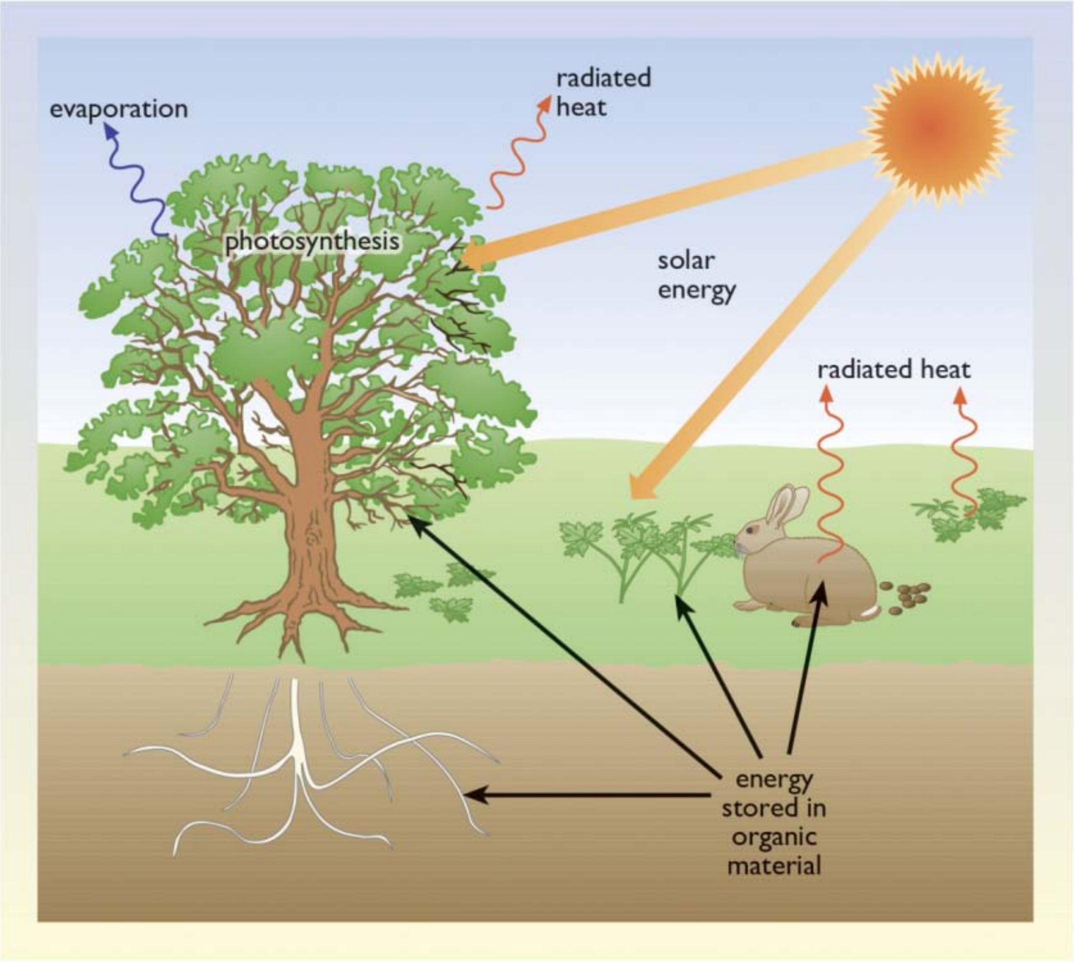
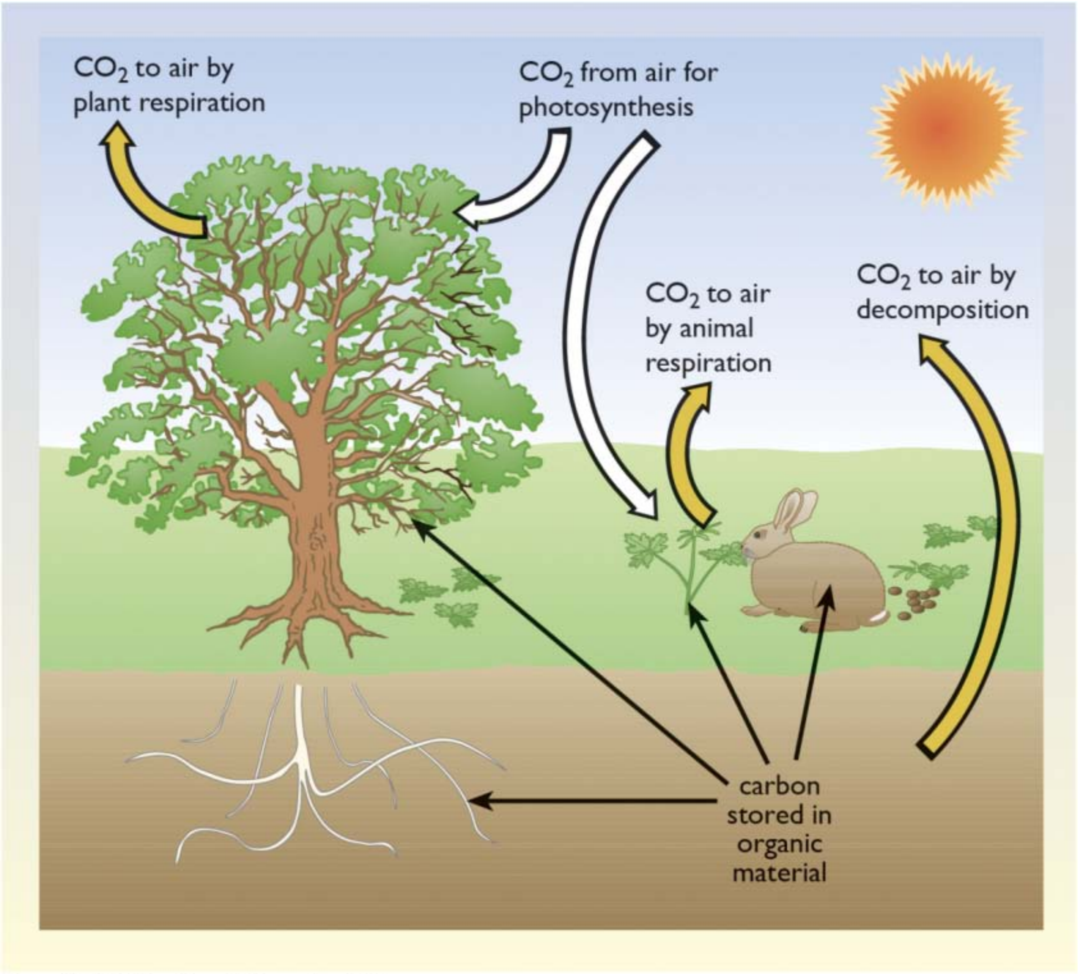
Personal energy audit coming up.

Homework #1: due April 13, 2016

Biofuels/energy




CO_2 to air by plant respiration
CO_2 from air for photosynthesis
CO_2 to air by animal respiration
CO_2 to air by decomposition
carbon stored in organic material

biomass

- Total mass of living matter 1800B tons
- Mass of land plants 1800B tons
- Mass in oceans 4B tons
- Population (2009) 4B tons
- Per capita terrestrial biomass 270 tons
- Net yearly prod. of biomass 130Btons

Biomass energy storage

- World energy
  - Rate of energy storage (biomass) 76 TWatts (2400EJ/yr)
  - Rate of Consumption (2009) 15.9 TWatts
  - Biomass consumption 1.6TWatts
  - Energy consumed as food 0.9 TWatts

Stesser and Lewis, 2009,4th IEA in Bioenergy

BIOMASS AS ENERGY STORAGE AND FUEL

PHOTOSYNTHESIS:

– $6CO_2 + 6H_2O$ + light energy = $C_6H_{12}O_6 + 6O_2$

utilizes 42% of sunlight at 700nm wavelength, only 27% in visible region, 400-600nm (44% of available sunlight)

Shorter wavelength: excess energy transferred as heat

Therefore, only .27x.44 = 12% efficient at converting sunlight

Other losses as well

STILL: 220Gtons/year of useable biomass

BIOMASS AS ENERGY STORAGE AND FUEL

PHOTOSYNTHESIS:

– $6CO_2 + 6H_2O$ + light energy = $C_6H_{12}O_6 + 6O_2$

COMBUSTION:

$CH_4 + 2O_2 = CO_2 + 2H_2O$

$12+(4x1) = 12 +(2x16) +2x (2x1 + 16)$

Burning 16 tons of methane releases 44 tons of CO_2

BOX 4.3 Conversion of solar energy

Consider one hectare (ha) of land, in an area such as southern England where the annual energy delivered by solar radiation is 1000 kWh m^{-2} y^{-1}.

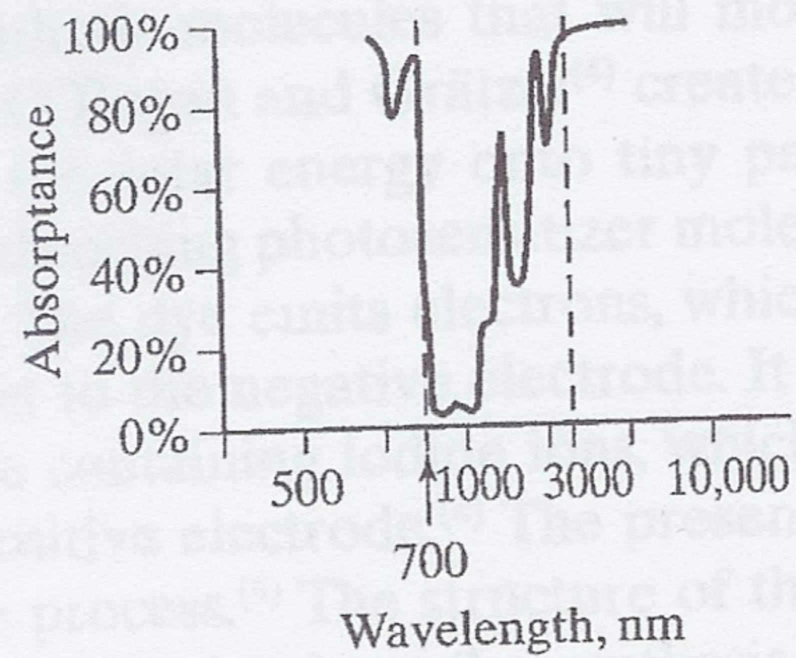
1000 kWh is 3.6 GJ and 1 ha is 10 000 m^2,
so the total annual energy is 36 000 GJ

After losses about an eighth of this reaches the crop at the right time. Say

12% of the annual energy reaches growing leaves	4320 GJ
50% of this is photosynthetically active radiation	2160 GJ
85% of which is captured by the growing leaves	1836 GJ
21% of which is converted into stored chemical energy	386 GJ
40% of which is consumed in respiration to sustain the plant or lost in photorespiration leaving	231 GJ

This is about 5.3% of the solar radiation reaching the growing plant, and only 0.64% of the original total annual energy.

Solar Irradiance: the water window
Absorption of sunlight through the atmosphere



Absorption of light in plants

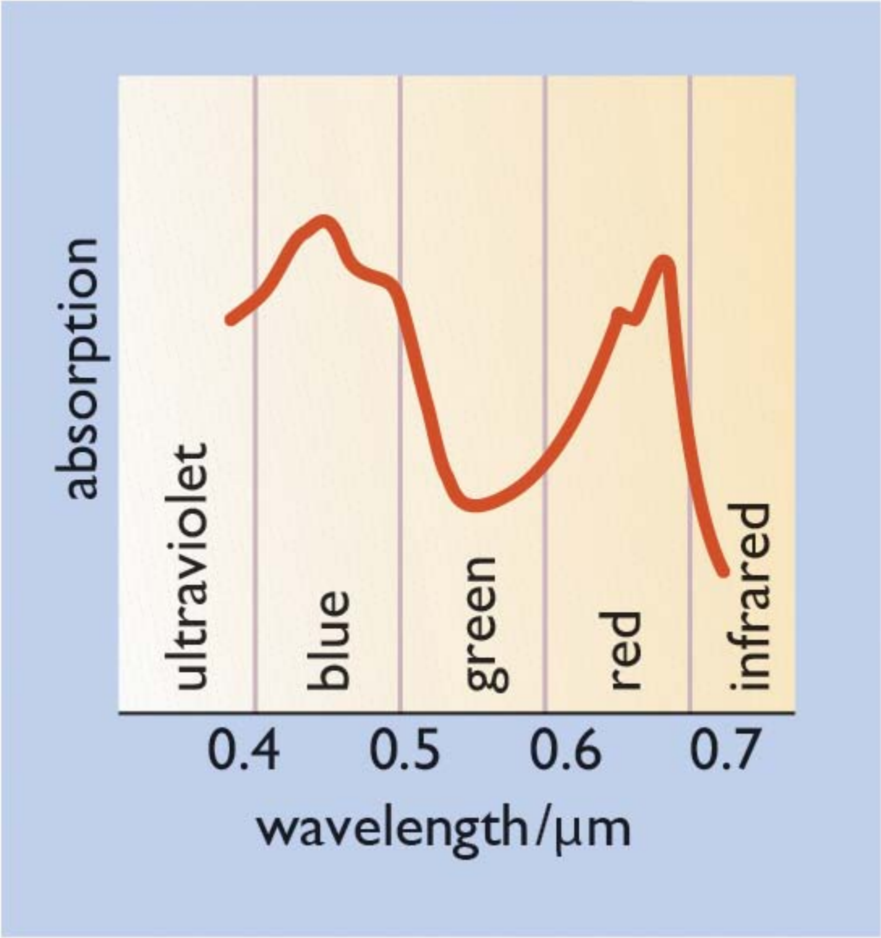


Table 4.1 Heat content (net calorific value, see Box 4.5) and CO_2 emissions

Fuel	Heat content/GJ t^{-1}	CO_2 released/kg GJ^{-1}
Coal	24	94
Fuel oil	41	79
Natural gas	48	57
Air-dry wood	~15	~80*

Note that the composition of coal, oil and wood and the moisture content can vary significantly, so the figures are typical values.

* If the wood is grown sustainably, so that trees are planted to replace those harvested and combustion is complete, its *life cycle* CO_2 emission should be close to zero.

Sources: DECC, 2011, AEA, 2011.

Table 4.2 Typical heat energy content (net calorific value, see Box 4.5) per unit of dry mass and volume of various forms of biomass and fossil fuel

Fuel	**Energy content**	
	GJ t^{-1}	**GJ m^{-3}**
Wood (green, 60% moisture)	6	7
Wood (air-dried, 20% moisture)	15	9
Wood (oven-dried, 0% moisture)	18	9
Charcoal	30	*
Paper (stacked newspapers)	17	9
Dung (dried)	16	4
Grass (fresh-cut)	4	3
Maize grain (air-dried)	19	14
Straw (as harvested, baled)	15	1.5
Sugar cane residues (bagasse)	17	10
Domestic refuse (as collected)	9	1.5
Commercial wastes (UK average)	16	*
Domestic heating oil	43	36
Coal (domestic heating, average)	28	50
Natural gas (at supply pressure)	48	0.04

* Indicates dependence on specific types of material.

Source: includes data from Biomass Energy Centre 2011a

Ethanol and Methanol

Ethanol can be made by fermentation from almost any crop containing sugars: corn, sugar cane, woody wastes, and so on. In Brazil, the ethanol process is an energy gainer[22] because of the burning of the **bagasse** (solid residue) from sugar cane to supply energy to make the ethanol, and the ratio of energy out as ethanol to fossil fuel used is between 5.9 and 8.2.[19] For the ethanol process to be economic with corn, the lignin must be used as a fuel. The process is

$$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2C_2H_5OH + 2CO_2$$

About 3% to 12% of the liquid becomes alcohol. This process would be more attractive economically if the feedstocks were cheaper.

Methanol is produced through a process involving both heating and chemical changes. First a feedstock is treated with steam and heat to become synthesis gas, then this is reacted to produce methanol. World demand for methanol is 23 GL/yr.[20] At present, the methanol is mostly produced from natural gas, but methanol is known as wood alcohol, and any carboniferous substance (biomass, coal, and so forth) will produce methanol. The process for making synthesis gas from biomass is

$$\text{dried biomass} + O_2 \longrightarrow CO + H_2 + \text{heat},$$

$$\text{heat} + \text{biomass} + \text{steam} \longrightarrow CO + H_2.$$

The gas is cleaned and scrubbed, the hydrogen-to-carbon monoxide ratio is adjusted to 2 to 1, and the processes making methanol out of synthesis gas are

$$2H_2 + CO \longrightarrow CH_3OH + \text{heat}$$

and

$$3H_2 + CO_2 \longrightarrow CH_3OH + H_2O.$$

Brazil is considering growing **cassava** (also know as manioc; *Manihot esculeuta*) in addition to huge quantities of sugar cane to supply ethanol. Assuming production of 6 tonnes of cassava per hectare (which is realistic), a 30 km delivery radius could supply 2 Mt of feed per day to a plant that would then produce 15,000 bbl of ethanol per day.[23] It has been estimated that the Brazilian ethanol program could ultimately supply 250,000 to 1,000,000 jobs, mainly in agriculture.[24]

The energy question is more open in the United States because the higher cost of labor invites the substitution of energy for labor.[25] Production of ethanol from wastes has worked in the United States. The notorious Al Capone distilled bootleg liquor from Chicago garbage during Prohibition.[26] One analysis shows that distillation of ethanol from corn (or other grains) can produce disparate results. At best, it can produce a *gain* equivalent to 1 liter of gasoline per liter produced if coal, biomass, or solar energy is used in the distillation process; the ethanol is added to gasoline; and the distiller's grain (leftover mash) is used as animal feed. At worst, it can produce a *loss* of as much as a quarter of a liter of gasoline per liter produced when oil or gas is used in distillation; the ethanol is used straight; and the distiller's grain is not used.[27]

The processes as used currently in the United States to produce ethanol (and methanol) require about as much energy to produce as is produced

Figure 4.4

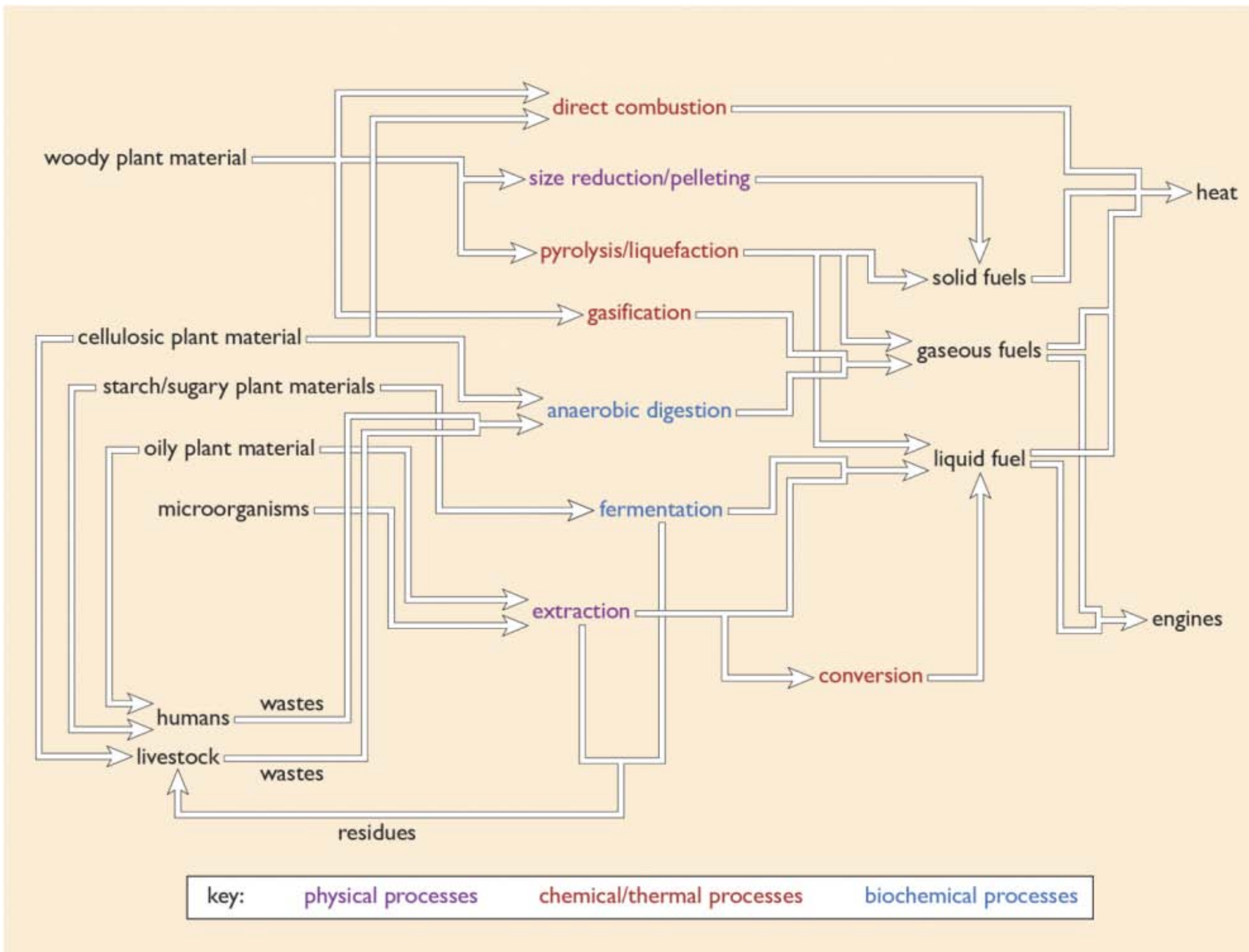

direct combustion
woody plant material
size reduction/pelleting
heat
pyrolysis/liquefaction
solid fuels
gasification
cellulosic plant material
gaseous fuels
starch/sugary plant materials
anaerobic digestion
oily plant material
liquid fuel
microorganisms
fermentation
extraction
engines
conversion
wastes
humans
livestock
wastes
residues
key:
physical processes
chemical/thermal processes
biochemical processes

Figure 4.5

Courtesy of Coppice Resources Limited

Cellulosic biomass

(a) (b) (c)

a. Bracken
b. .miscanthus
c. Gunnera
d. Kelp
e. E. water hyacinth

(d) (e)

(a) mikeuk/iStockphoto.com; (b) Dr Rob Stepney/Science Photo Library; (c) Photo by Tom Oates, used under a Creative Commons Attribution-Share Alike 3.0 Unported licence; (d) imageZebra/iStockphoto.com; (e) River North Photography/iStockphoto.com

Starch/sugar crops

(a) (b) (c)

(a) Duncan Walker/iStockphoto.com; (b) santosha/iStockphoto.com; (c) LUGO/iStockphoto.com

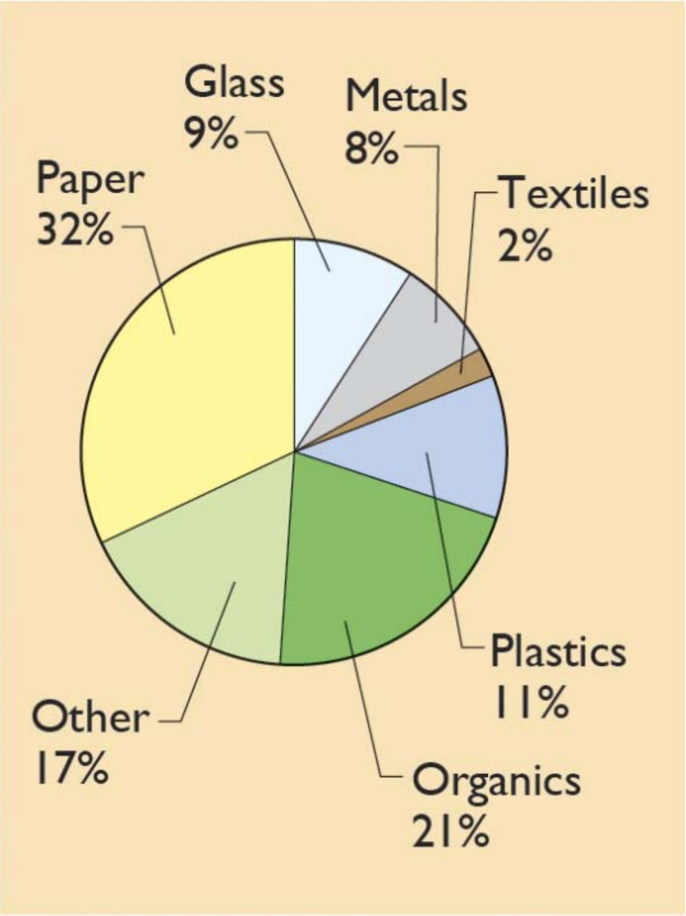
a. Sugar cane
b. B. maize
c. C. sugar beet

Microalgae Bioreactor

Straw fired Power Plant

Avedore 2 (Denmark) combined heat and power plan/570 MWattt

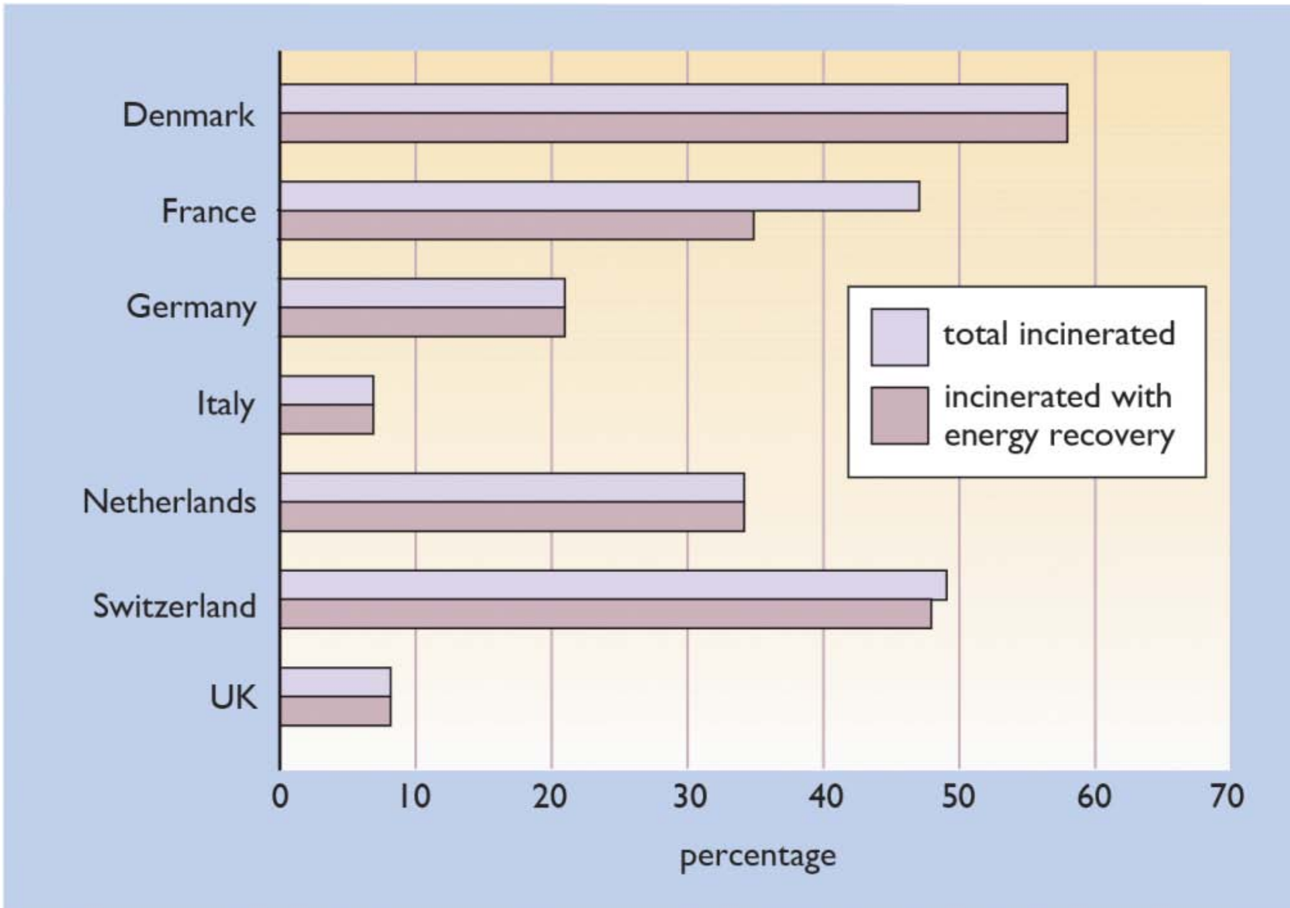
Composition of municipal solid waste in UK



SE London / combined heat and power/ 1994

Courtesy of SELCHP

MSW plants in Europe



Wood Pellets

(a)

Courtesy of Puffin Pellets

(b)

Some problems with biomass fuel

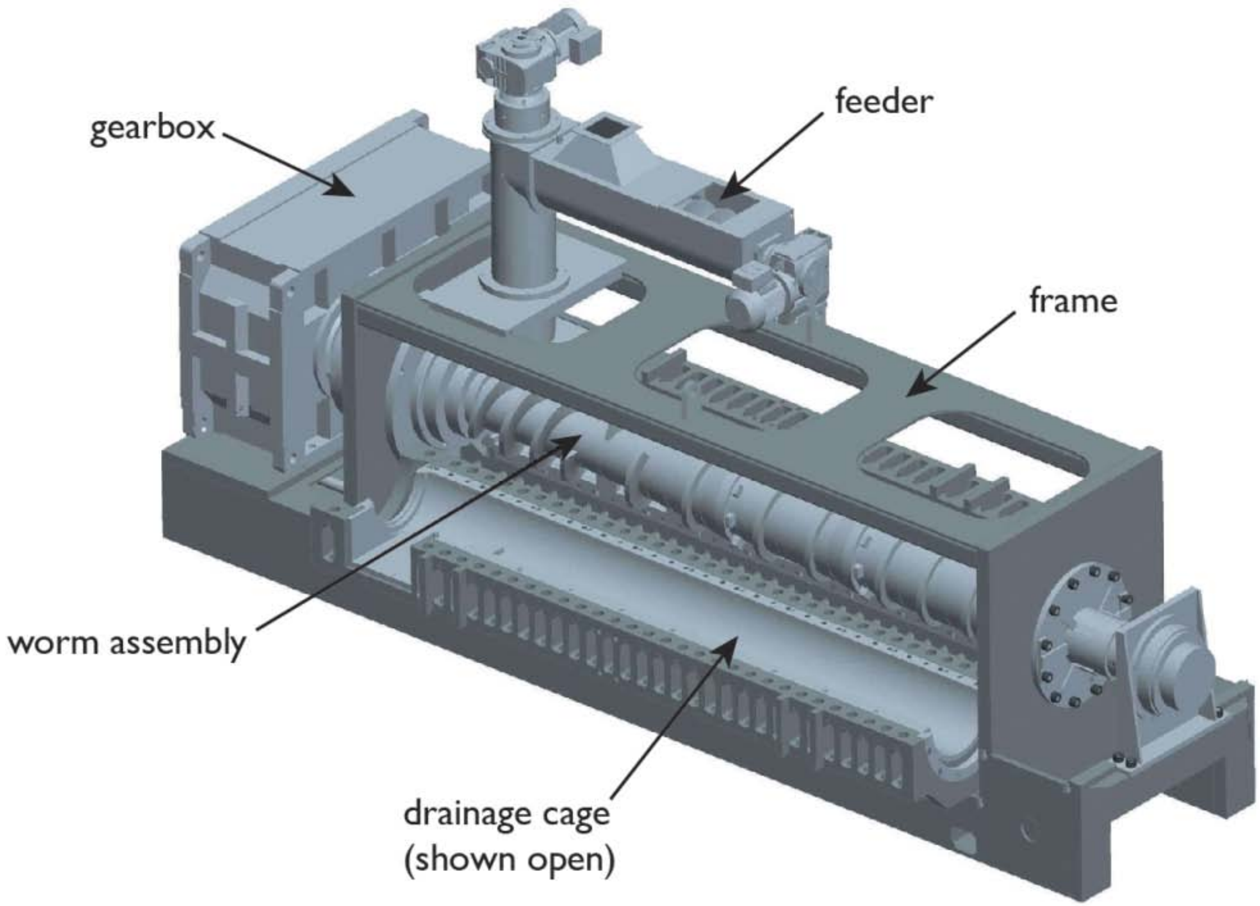
1.transport/low mass density requires larger volumes
2.high water content/ drying (energy)
3.High water content/decay

OIL EXTRACTION FROM PLANTS
Rapeseed, soya, palms

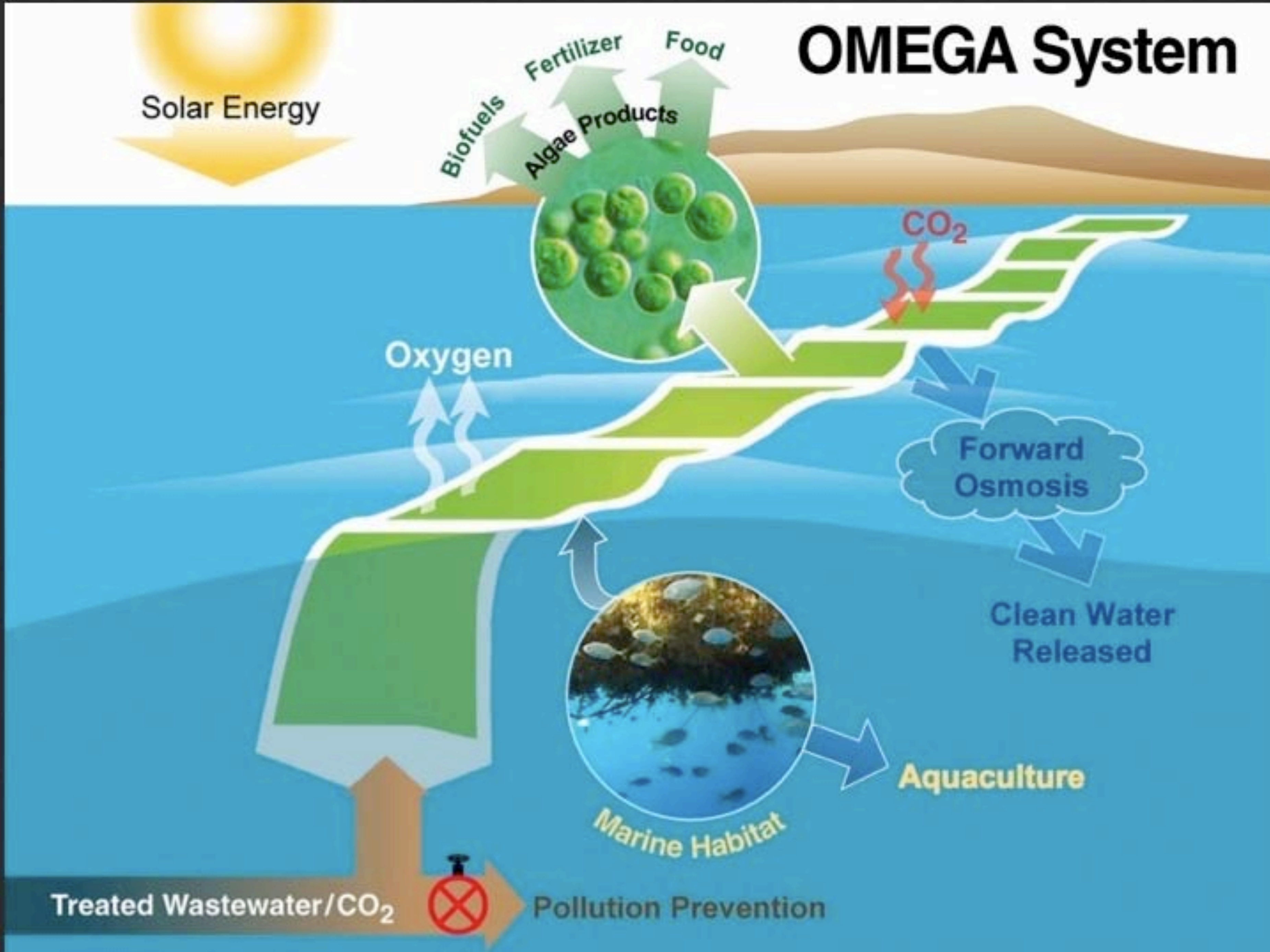
Seed cleaning
Separation from tissue
Mechanical extraction
solvent extraction

ALGAE

Figure 4.15



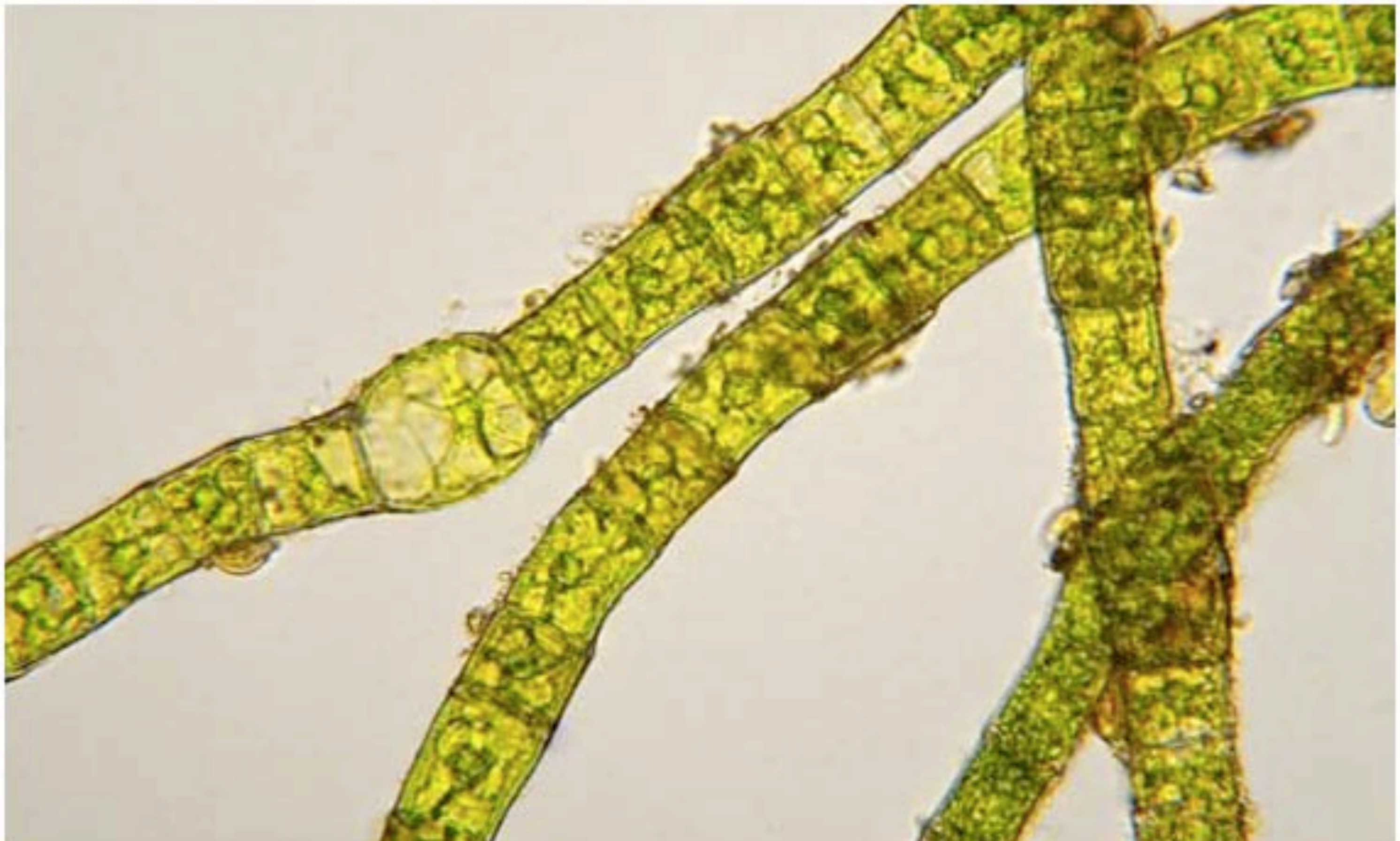
De Smet Rosedowns Ltd


OMEGA System
Solar Energy
Biofuels
Fertilizer
Food
Algae Products
CO_2
Oxygen
Forward Osmosis
Clean Water Released
Marine Habitat
Aquaculture
Treated Wastewater/CO_2
Pollution Prevention

Grow Your Own Energy

A NASA-backed experiment harvests algae for oil, releases fresh water.

By Jonathan Trent | Posted Monday, Sept. 3, 2012, at 7:15 AM



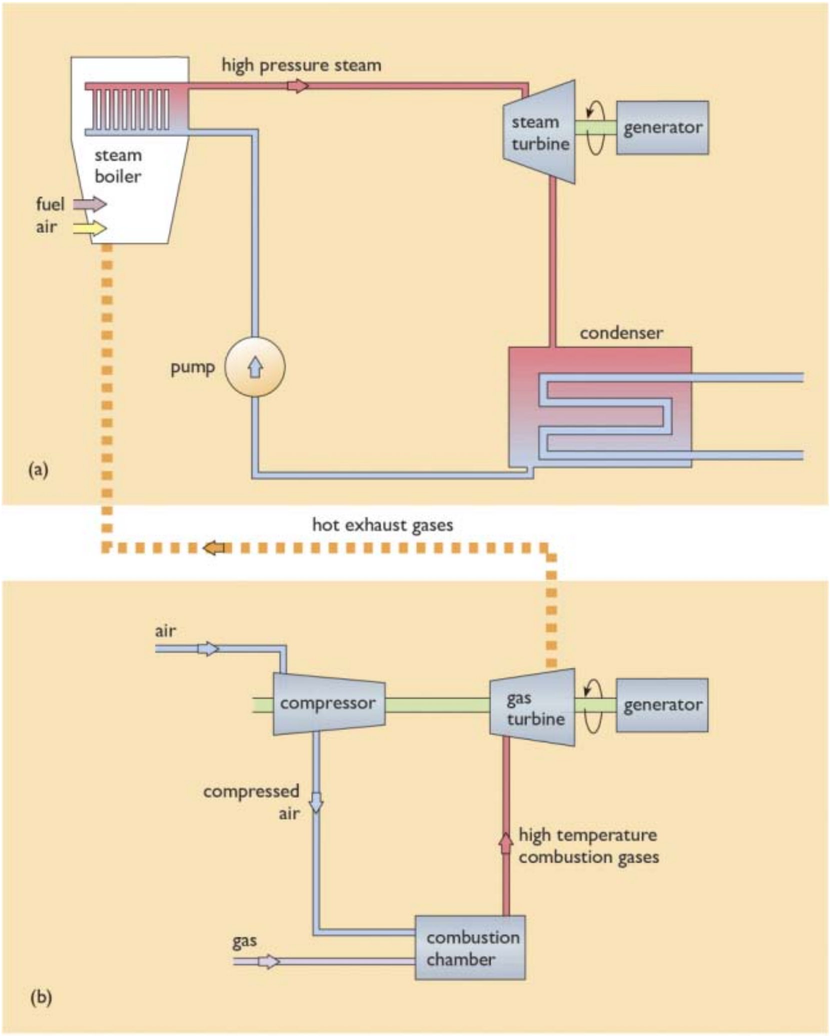
All algae produce natural oils. We may just need to harness the right ones for an energy source.
iStockphoto/Thinkstock.

Algae Growing tubes

Bio bags: A prototype algae plant for making biofuels.

Jonathan Trent, 2012

Generating Systems



Bidigestion System

Michael Chesshire

Anaerobic Digestion

Courtesy of the Ashden Awards for Sustainable Energy, www.ashdenawards.org/biogas

TABLE 23.3

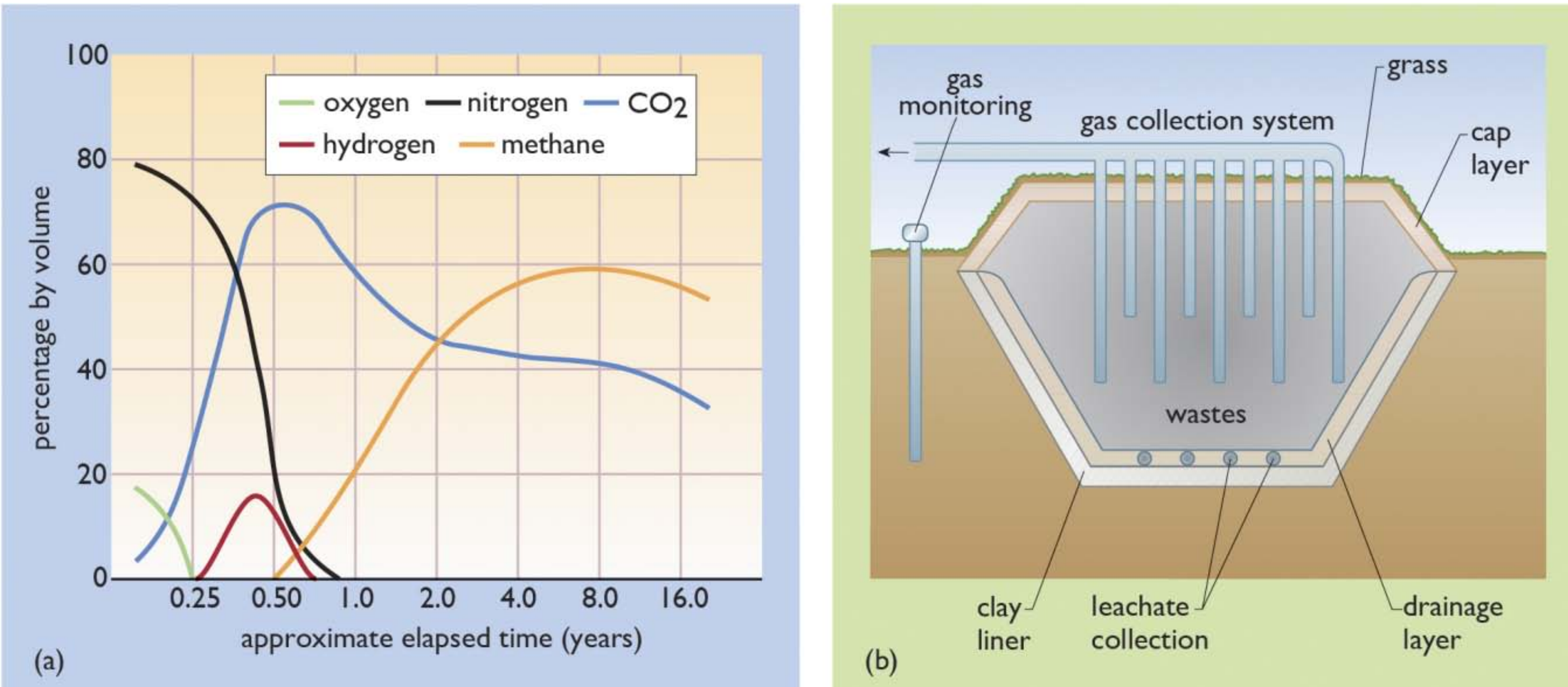
Net biomass energy resources

	Potential			Current use
	Biomass total (Mt)	Total available (Mt)	Amount (Mt)	Thermal energy (TWh_t)
Wood (total)	651	261		
Mill residues (forest)	135	118	58–75	207–214
Logging residues	164	45	3.3	12
Thinnings	43	43	2.2	9
Residential fuel wood	27	27	27	59
Mortality, excess over harvest	282	27	—	—
Forage	682	118	—	—
Animal wastes	159	45	1	0.3 (biogas)
Grains	321	9–20	1	2.4 (liquid)
Bagasse	3.6	3.6	3.6	12
Food-processing waste	14	14	—	—
Industrial wastes	90	21	7.1	15
Municipal solid wastes	124	60	—	—
Municipal sewage	12	9	—	5.7 (biogas)[a]
Aquatic plants	18	3–12	—	—
Crop residues	430	73	—	—

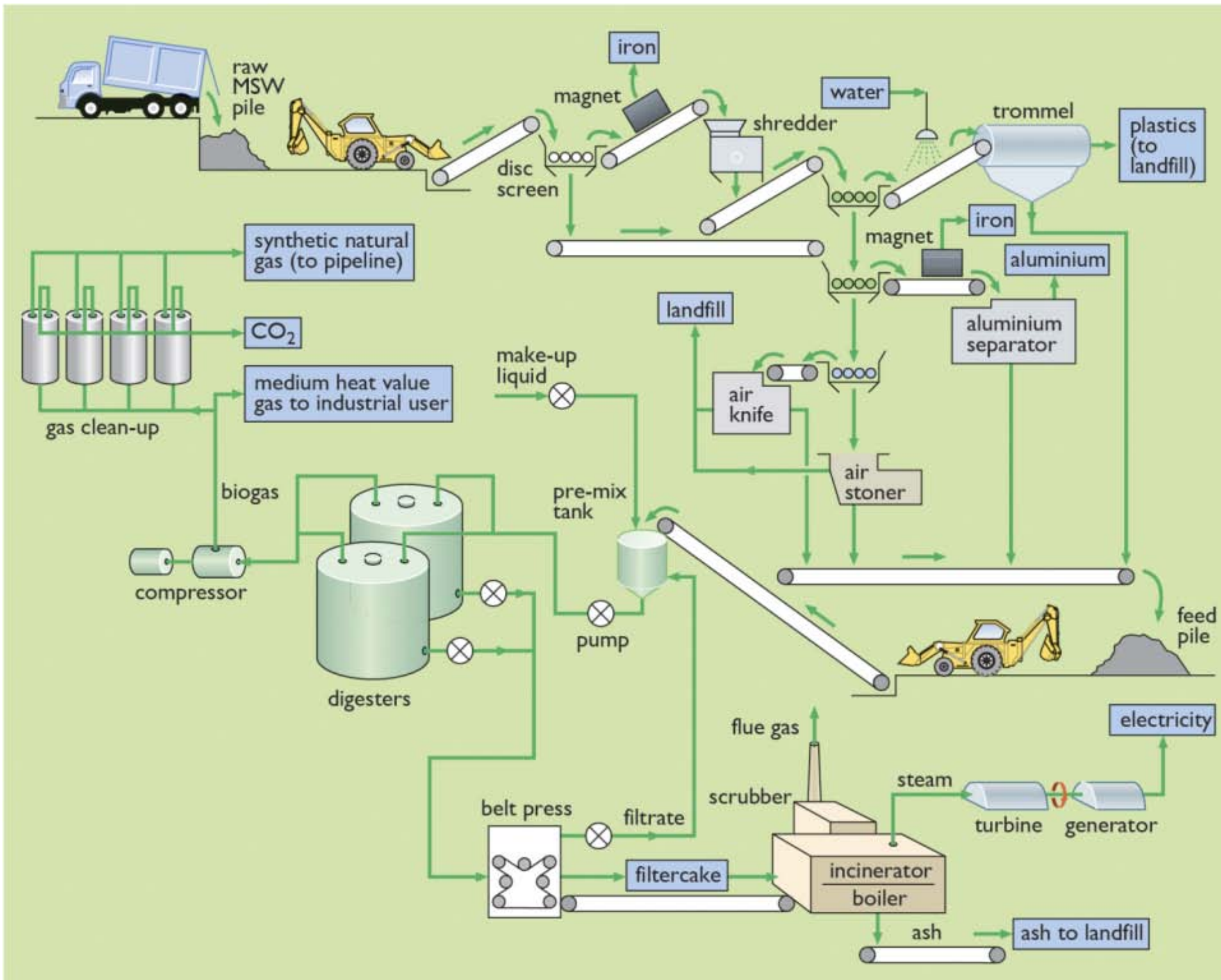
Source: Reprinted with permission from Review Panel on Biomass Energy, "Biomass Energy," *Solar Energy* **30**, 1 (1983), copyright 1983, Pergamon Journals, Ltd.

[a]Energy is used in sewage digestion so is not net energy.

Gas composition in a landfill

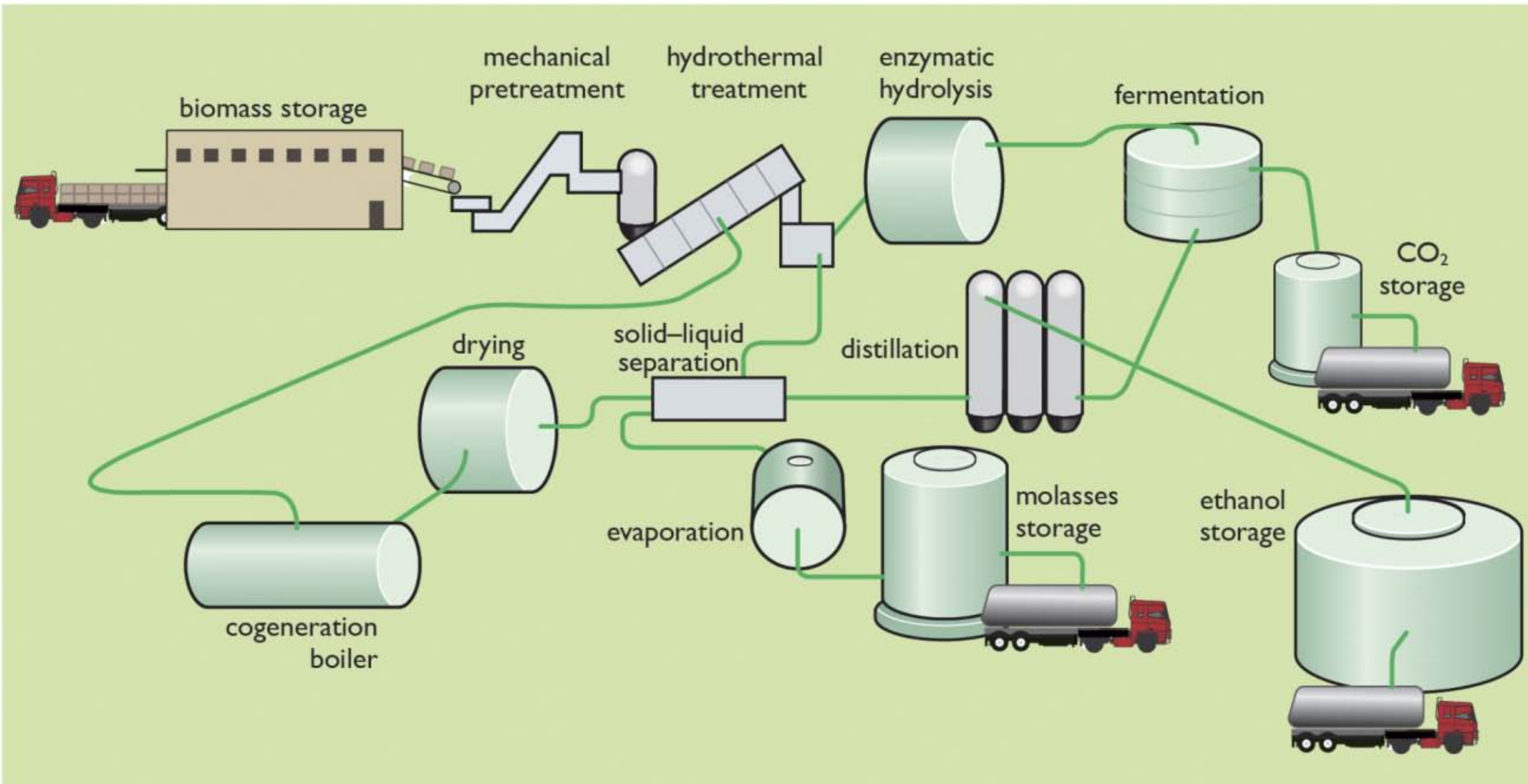


Integrated Waste Materials Plant



ETSU Project Summary Unit 192: Biofuels/MSW Digestion (1990) Crown copyright, reproduced by permission of the controller, HMSO

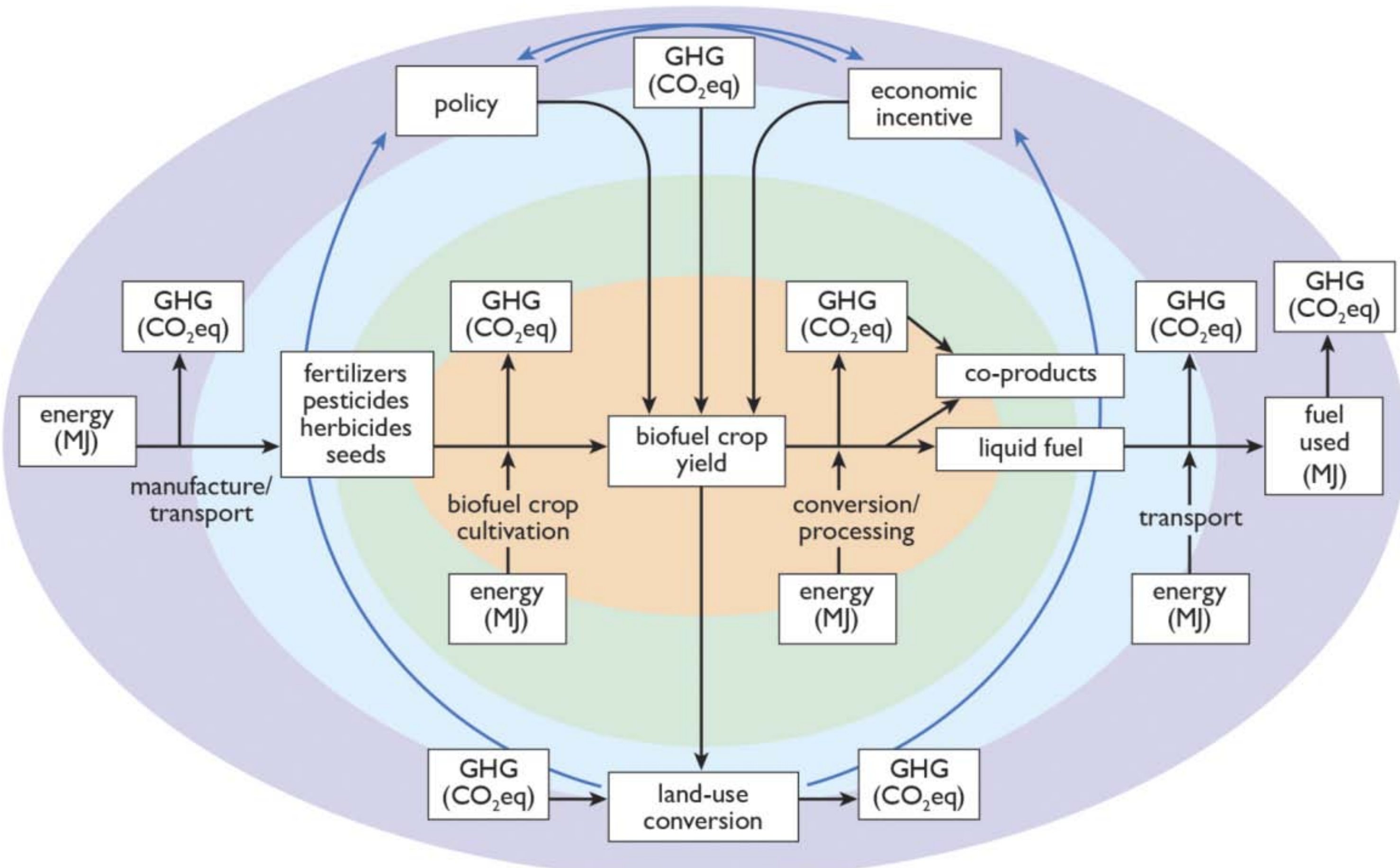
Ethanol production from straw



Adapted from www.inbicon.com

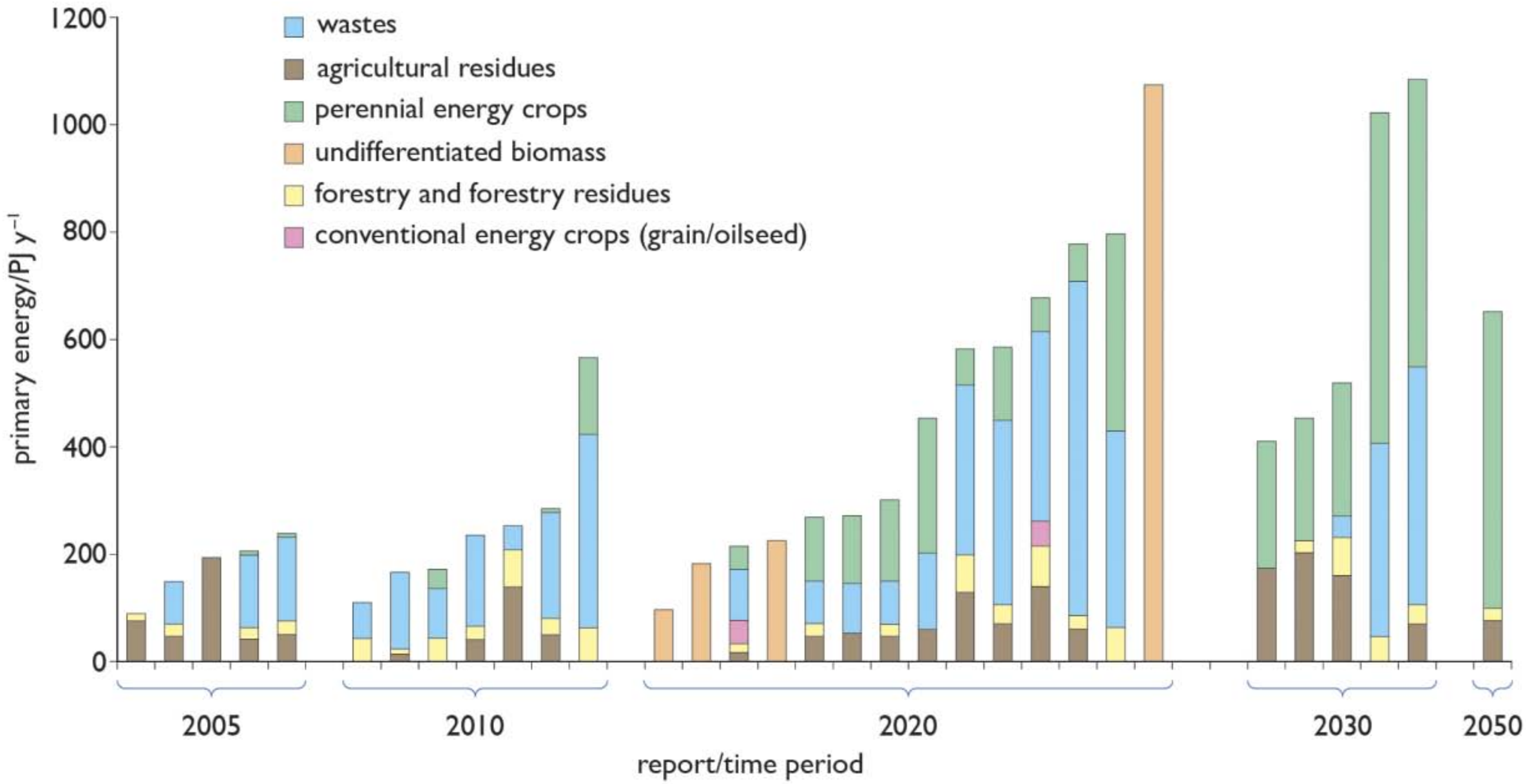
(a) (b)

Figure 4.24



Davies, S. C. et al. (2007) 'Life-cycle analysis and the ecology of biofuels', Trends in Plant Science, Vol 14. Elsevier Science

Figure 4.25



Slade, R. Bauen, A. and Gross, R. (2010) The UK bioenergy resource base to 2050: estimates, assumptions and uncertainties, UK Energy Research Centre.

Table 4.5 Net life cycle gaseous emissions from electricity generation systems in the UK

	Emissions[1]/t GW h^{-1}		
	CO_2	SO_2	NO_x
Combustion, steam turbine			
Poultry litter	10	2.42	3.90
Straw	13	0.88	1.55
Forestry residues	29	0.11	1.95
MSW (EfW)	364	2.54	3.30
Anaerobic digestion, gas engine			
Sewage gas	4	1.13	2.01
Animal slurry	31	1.12	2.38
Landfill gas	49	0.34	2.60
Gasification, BIGCC[2]			
Energy crops	14	0.06	0.43
Forestry residues	24	0.06	0.57
Fossil fuels			
Natural gas: CCGT[2]	446	0.0	0.5
Coal: with minimal pollution abatement	955	11.8	4.3
Coal: Flue Gas Desulfurization and low NO_x [3] burner	987	1.5	2.9

Note that 1 g kWh^{-1} is the same as 1 t GWh^{-1}

Biomass Integrated Gasification Combined Cycle. Wood is gasified and the gas used to feed a gas turbine to generate electricity, with the hot exhaust gas used to raise steam to power a further, steam turbine.

Flue gas desulfurization is a process for removal of sulfur compounds after combustion, and special forms of burners can be used that minimize emissions of oxides of nitrogen.

ource: Adapted from ETSU, 1999