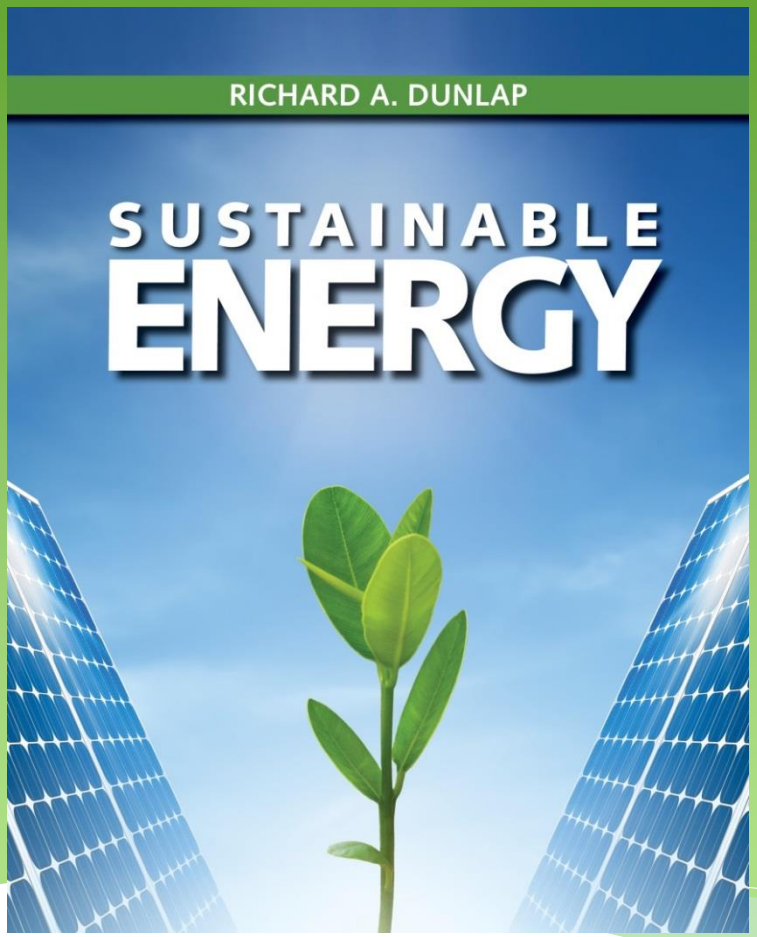
Sustainable Energy



Chapter 16

- Biomass Energy

CENGAGE Learning

Learning Objectives

- The properties of wood and its uses for energy.
- The production and use of ethanol and methanol.
- A comparison of the Brazilian and U.S. ethanol programs.
- Biodiesel production.
- Environmental consequences of biofuel utilization.
- The use of municipal waste for energy production.

Biofuels

Biofuels are hydrocarbon based materials which are extracted from recently grown organic matter.

Biofuels produce greenhouse gases (CO_2), as do fossil fuels, but are carbon neutral if new organic material is grown to replace that which is burned.

Types of biofuels

Biofuels that are covered in this chapter can be classified as

- Wood and wood products
- Ethanol
- Biodiesel
- Municipal solid waste

Relative proportions of energy sources worldwide

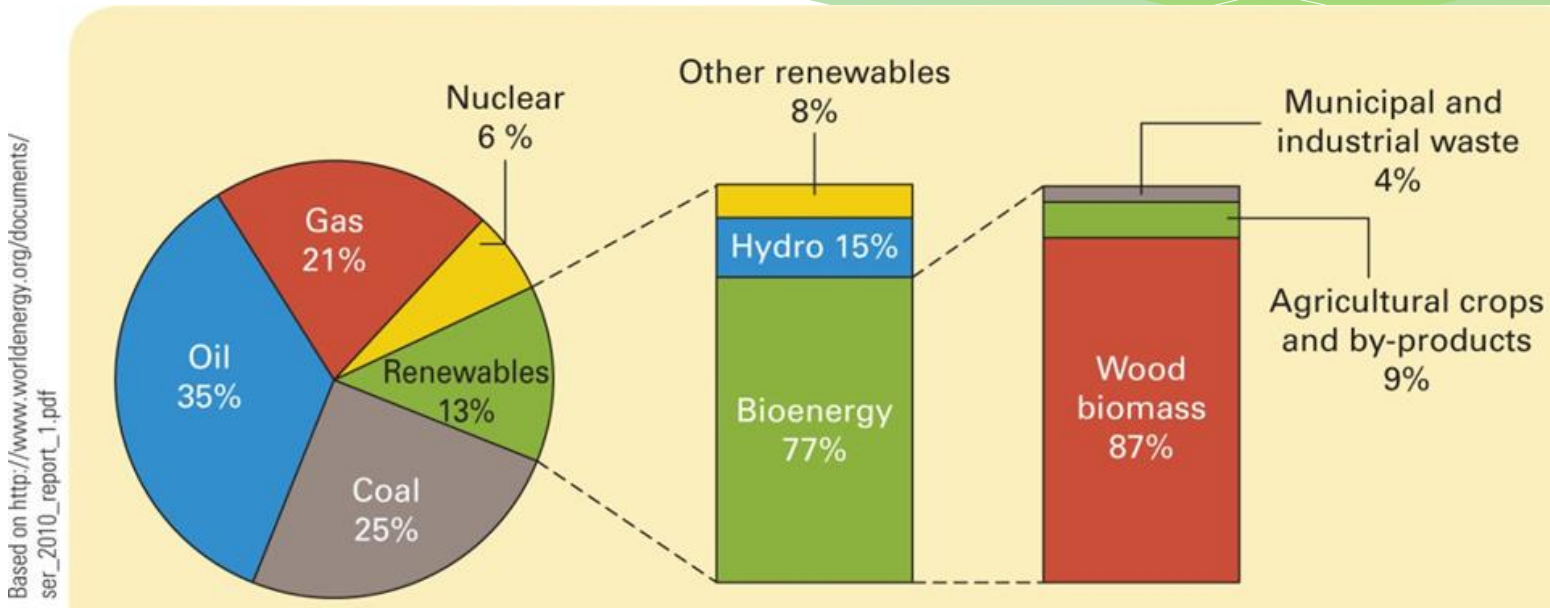


Figure 16.2: Proportion of renewable energy production worldwide (in 2007) and a breakdown of the various renewable sources.

Wood

Wood is the oldest source of energy used by humans.

Wood remained the major source of energy in industrialized nations until late 1800s when it was replaced by coal.

Types of wood fuel products

Wood is used as a fuel in three forms

- Firewood - wood as harvested
- Charcoal - relatively pure carbon produced by heating wood
- Black liquor - combustible oil-like liquid which is a by-product of the paper industry

Proportions of different wood products

Table 16.1: Energy content of wood used annually as an energy source (in 2002) in different regions of the world.

region	fuelwood		charcoal		black liquor		total	
	(10^{15} J)	(10^{12} Btu)	(10^{15} J)	(10^{12} Btu)	(10^{15} J)	(10^{12} Btu)	(10^{15} J)	(10^{12} Btu)
Africa	6088	5777	453	430	~0	~0	6541	6207
North/Central America	1673	1588	64	61	1599	1517	3335	3165
South America	1528	1450	211	200	601	570	2341	2221
Asia	9254	8782	145	138	414	393	9812	9311
Europe	806	765	23	22	592	562	1420	1348
Oceania	86	82	1	1	29	28	115	109
world total	**19,458**	**18,466**	**897**	**851**	**3234**	**3069**	**23,589**	**22,386**

Based on data from World Energy Council

Most wood that is used for energy production is used as firewood - Asia and Africa are the principal users

Ethanol

Properties of light alcohols

Table 16.2: Properties of the light alcohols of the composition $C_nH_{2n+1}OH$. Heat of combustion is the HHV (Chapter 1).

n	name	formula	molecular mass (g/mol)	density (g/cm^3)	boiling point (°C)	heat of combustion (MJ/L)
1	methanol	CH_3OH	32.04	0.792	64.7	17.9
2	ethanol	C_2H_5OH	46.07	0.789	78.4	23.5
3	propanol	C_3H_7OH	60.10	0.785	82.3	26.3
4	butanol	C_4H_9OH	74.12	0.810	117.7	29.7

Ethanol is a light alcohol and is one of the hydrated alkanes

Sources of ethanol

Ethanol is a by-product of the distillation of petroleum.

Ethanol can also be produced by the fermentation of sugar containing biological material (sometimes called bioethanol). This accounts for about 90% of all ethanol production.

Ethanol is convenient as a direct replacement for liquid fossil fuels (e.g. gasoline).

Chemistry of ethanol

Glucose is produced by photosynthesis

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2 \quad (16.1)$$

Ethanol is produced from glucose by fermentation

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{heat} \quad (16.2)$$

Energy can be extracted from ethanol by combustion

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + \text{heat} \quad (16.3)$$

Note that $6CO_2$ are used to produce glucose. $2CO_2$ are released during fermentation and $4CO_2$ are released during combustion, giving net zero carbon emissions.

Steps in the production of ethanol

- Fermentation
- Distillation
- Dehydration

Fermentation

Simple sugars and starches can be used to produce ethanol by fermentation.

More complex processes are needed to produce ethanol from cellulose.

These processes are not yet economical.

Distillation

Fermentation products contain water and this must be removed to produce a combustible fuel.

Traditional distillation methods produce a mixture of about 96% ethanol and 4% water.

The presence of 4% water makes the ethanol immiscible in gasoline and limits its use as a transportation fuel.

Dehydration

Excess water may be removed from ethanol using molecular sieves.

Uses of ethanol

Ethanol commonly blended with gasoline in different proportions

- E10 refers to 10% ethanol 90% gasoline
- E85 refers to 85% ethanol 15% gasoline
- E100 refers to 100% ethanol

An unmodified gasoline internal combustion engine will run on up to 10% ethanol without problems.

Use of E10 in North America

Much of the gasoline sold commercially in North America is actually E10.

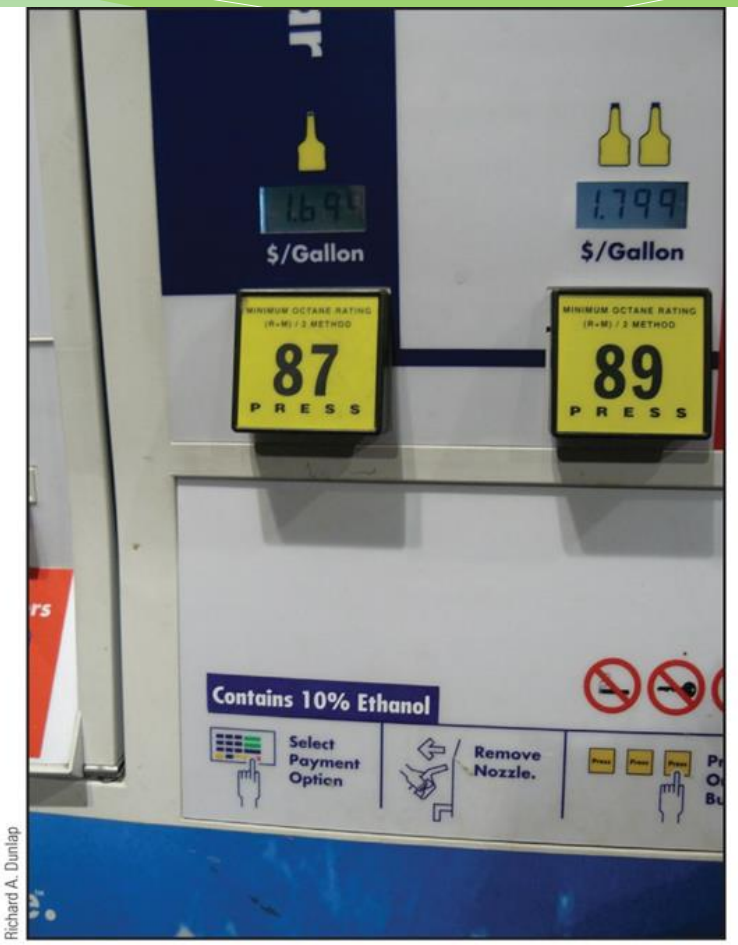


Figure 16.3: Gasoline pump in Maine indicating 10% ethanol content (E10).

Flex fuel vehicles

Modifications to the fuel delivery system will allow a gasoline engine to run on ethanol mixtures up to E85.

Flex fuel vehicles are common in North America but E85 is available at only about 1% of gasoline stations.

Figure 16.4: Nameplate on vehicle designed to run on gasoline with up to 85% ethanol (E85).

Energy content of ethanol

Ethanol energy content is 23.5 MJ/L compared with gasoline at 34.8 MJ/L.

Running a gasoline vehicle of ethanol or ethanol blends will increase the fuel consumption and reduce the driving range.

Ethanol production by country

Table 16.3: Ethanol production (for 2009).

country	ethanol production 10^6 L	ethanol production 10^6 gal
United States	40,121	10,600
Brazil	24,898	6578
European Union	3936	1040
China	2051	542
Thailand	1646	435
Canada	1098	290
Columbia	314	83
India	348	92
Australia	216	57
Other	1749	247
world total	**73,940**	**19,535**

United States is the major producer

Growth of ethanol production

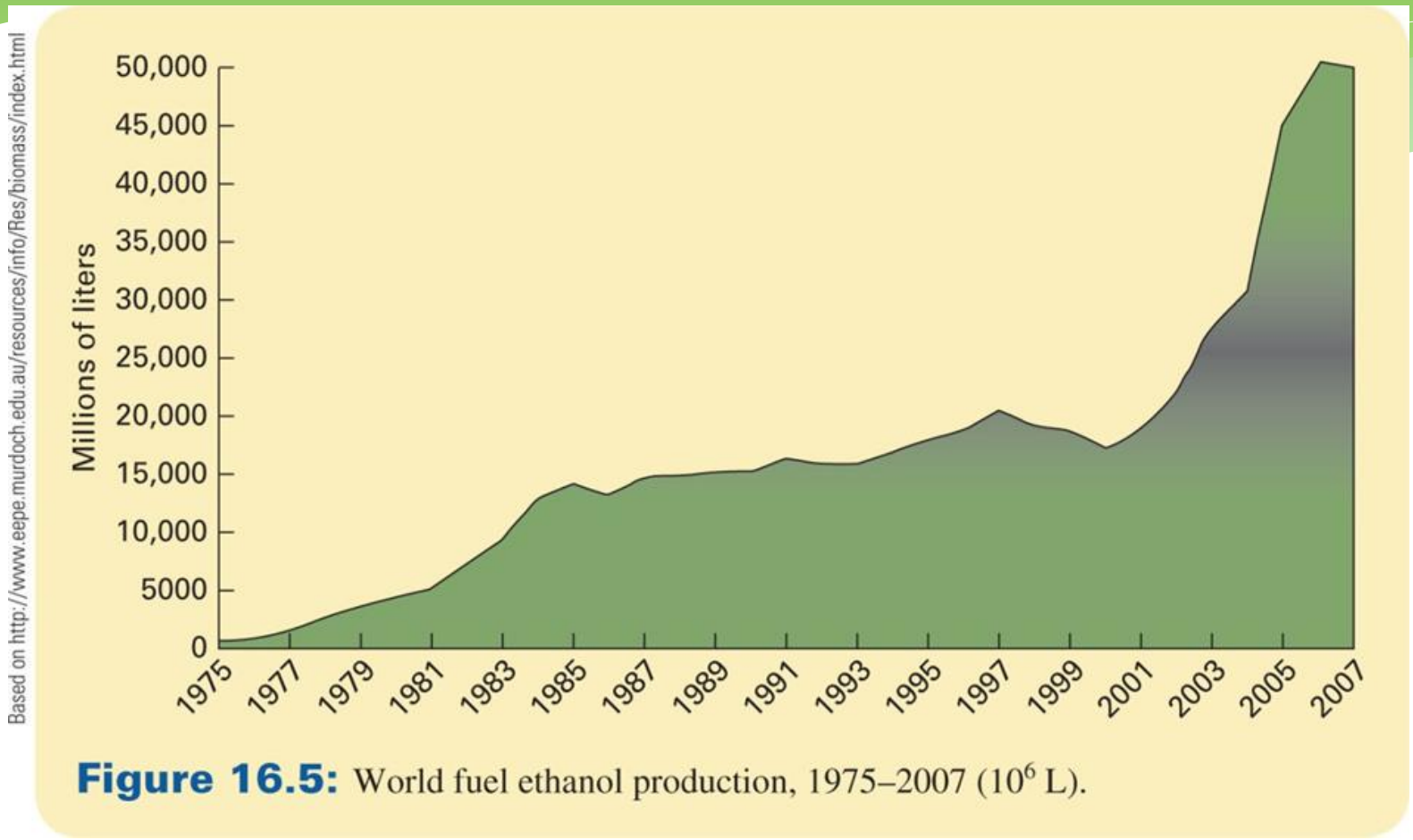


Figure 16.5: World fuel ethanol production, 1975–2007 (10^6 L).

Comparison of U.S. and Brazil ethanol use

Table 16.4: A comparison of ethanol production and use in the United States and Brazil [mi = miles].

property	united States	brazil
major crop	corn	sugarcane
total ethanol production (2007)[10^6 L]	24,600	19,000
[10^6 gal]	6500	5020
total arable land [10^6 km^2]	2.70	3.55
[10^6 mi^2]	1.04	1.37
land used for ethanol production [10^5 km^2]	1.0	0.36
[10^3 mi^2]	38.6	13.9
percent arable land used for ethanol production	3.7%	1.0%
productivity [L/km^2]	380,000–400,000	680,000–800,000
[gal/mi^2]	260,000–274,000	571,000–547,000
energy balance	~1.4	~9.2
ethanol fueling stations	1700	33,000
percent fueling stations selling ethanol	1.0	100
ratio of fuel ethanol to gasoline used	0.04	1.0

Important differences between U.S. and Brazil

Fraction of fuel:

- U.S. ethanol is minor component of transportation fuel
- Brazil ethanol is the major component of transportation fuel

Energy balance:

- U.S. 1.4 MJ ethanol energy output per 1 MJ energy input
- Brazil 9.2 MJ ethanol energy output for 1 MJ energy input

Importance of climate and agriculture

- Brazil has longer average growing season
- U.S. mostly corn, Brazil mostly sugar cane
- Sugar cane has a higher glucose content but does not grow in most of the U.S.
- Brazil has developed a more efficient ethanol production infrastructure
- U.S. agriculture largely mechanized and uses fossil fuels
- Brazil agriculture much less mechanized

Biodiesel

Biodiesel is a direct replacement for petroleum derived diesel fuel

Biodiesel produced from waste or low grade vegetable oil and/or animal fat

Blended with petroleum diesel

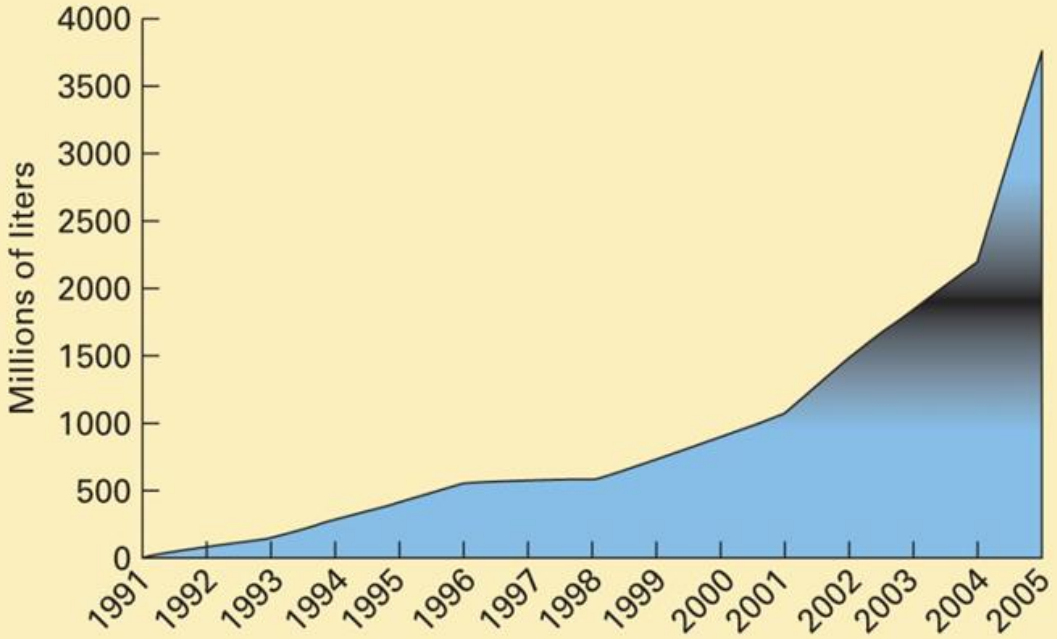
- B5 is 5% biodiesel, 95% petroleum diesel
- B99 is 99% biodiesel, 1% petroleum diesel

Biodiesel productivity from different plant sources

Table 16.5: Typical annual productivity of biodiesel from different plant materials per unit farming area.

plant	annual biodiesel production 10^3 L/km^2	annual biodiesel production 10^3 gal/mi^2
algae	1700	1160
palm oil	475	324
coconut	215	147
rapeseed	95	65
soy	55–91	37–62
peanut	84	57
sunflower	77	53

Growth of biodiesel production



Based on http://www.eepe.murdoch.edu.au/resources/info/Res/biomass/index.html

Figure 16.8: Growth of biodiesel production worldwide, 1991–2005 (10^6 L).

Europe (Germany in particular) has been most active in biodiesel production

Net environmental impact of biofuels

Greenhouse gas emissions and total environmental impact of biofuels has been analyzed.

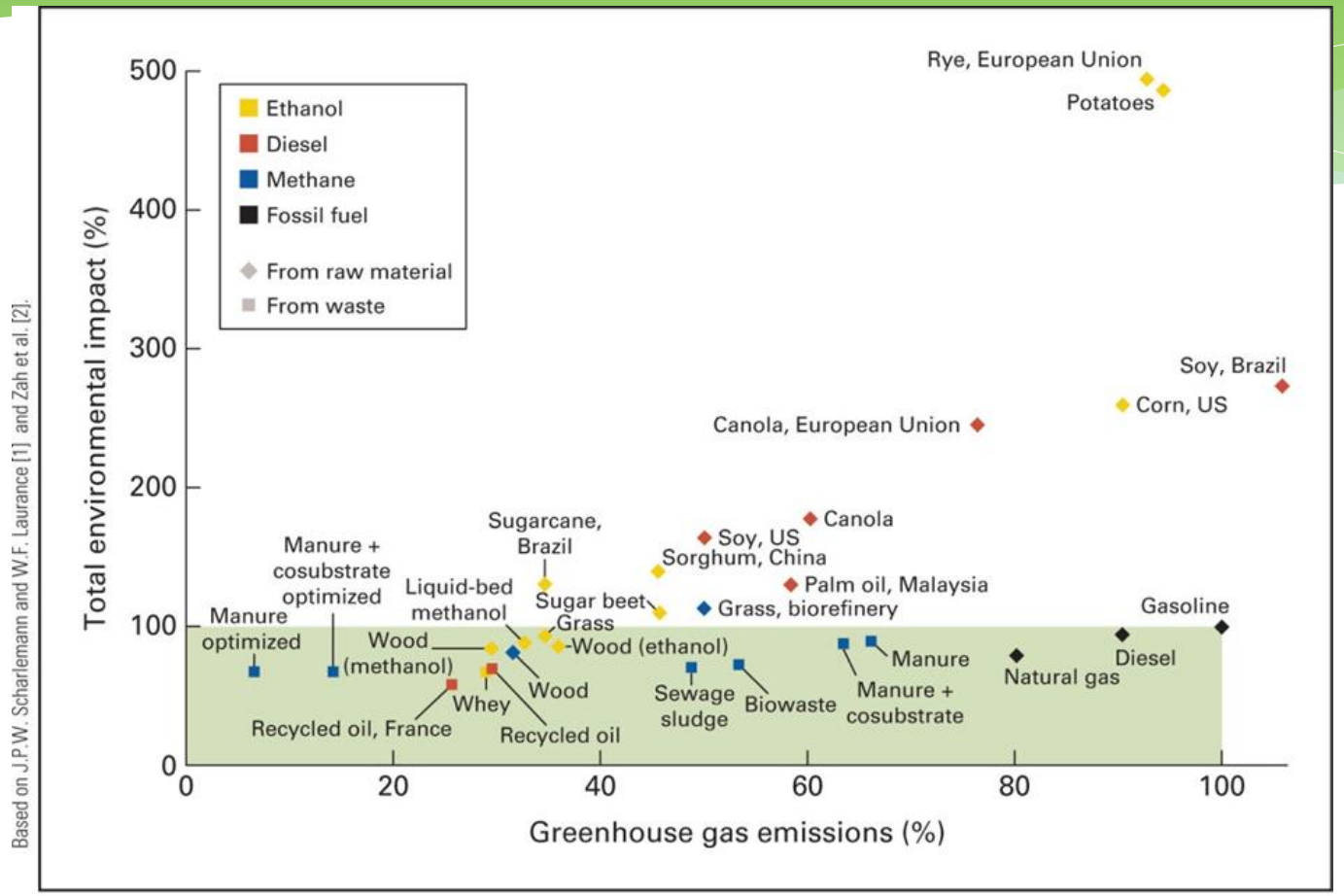
Most alternative fuels emit less CO_2 per unit energy than gasoline.

Many, however, have greater total environmental impact.

These include

- ethanol from sugarcane (Brazil) - worse than gasoline
- ethanol from corn (U.S.) - much worse than gasoline

GHG emissions and environmental impact normalized to gasoline



Greenhouse gas emissions and total environmental impact factors for some biofuels.

Municipal solid waste

Much of municipal solid waste (MSW) is combustible and can be used to generate energy.

Two approaches to obtaining energy from MSW

- Burn the combustible component of MSW directly to produce heat to make steam and rive a turbine
- Use methane produced by MSW decomposition to burn to make steam

Amount of MSW

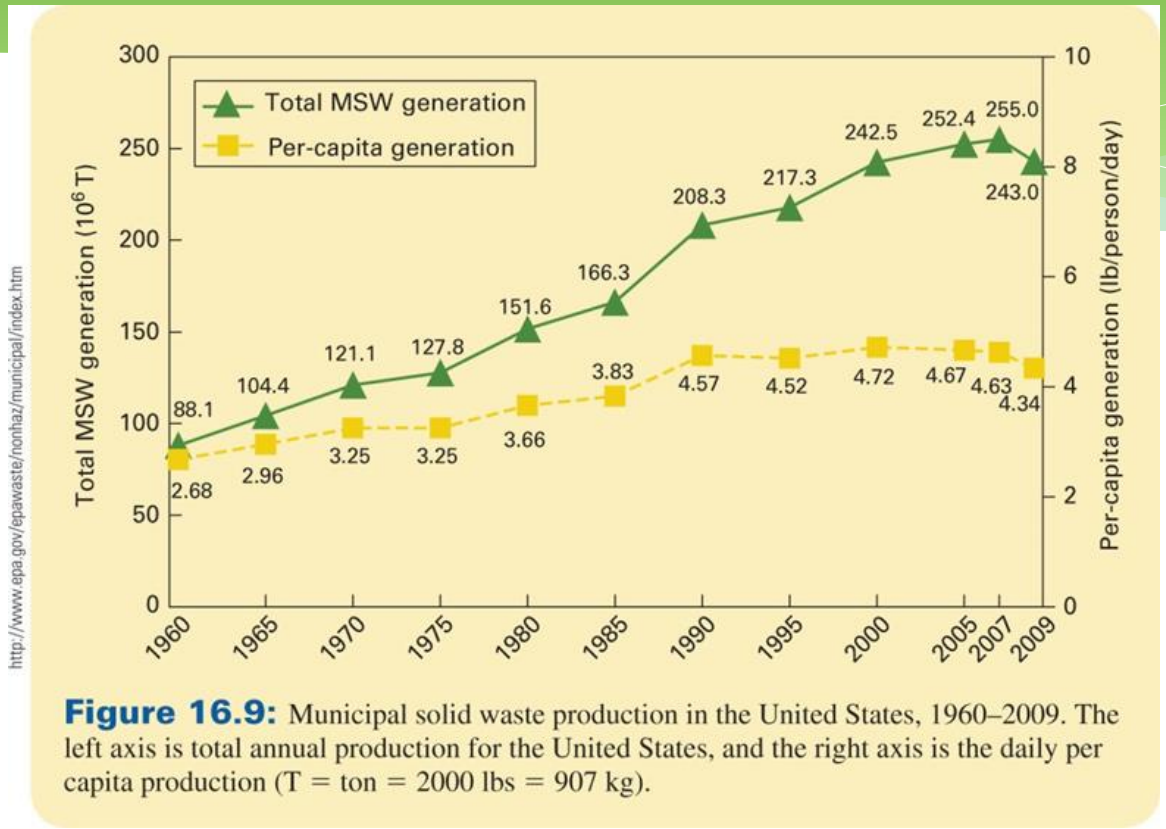


Figure 16.9: Municipal solid waste production in the United States, 1960–2009. The left axis is total annual production for the United States, and the right axis is the daily per capita production (T = ton = 2000 lbs = 907 kg).

MSW production has increased in the U.S. - Currently about twice the mass per capita of most industrialized countries

Fraction of total energy from MSW

In the U.S. an average of 2 kg MSW per capita per day is produced.

The average energy content of MSW is about 10 MJ/kg, so 2 kg MSW corresponds to about 20 MJ per capita per day or 7.3 GJ per capita per year.

This is about 2% of total per capita primary energy use.

Even if all MSW energy is utilized it represents a small fraction of total energy need.

Advantages of MSW energy production

Burning MSW produces energy (and also CO_2).

Putting MSW in a landfill produces no energy but can produce methane via decomposition.

Methane is a more effective GHG than CO_2..

The overall environmental impact of different MSW disposal methods is complex problem.

Changes in MSW disposal methods (U.S.)

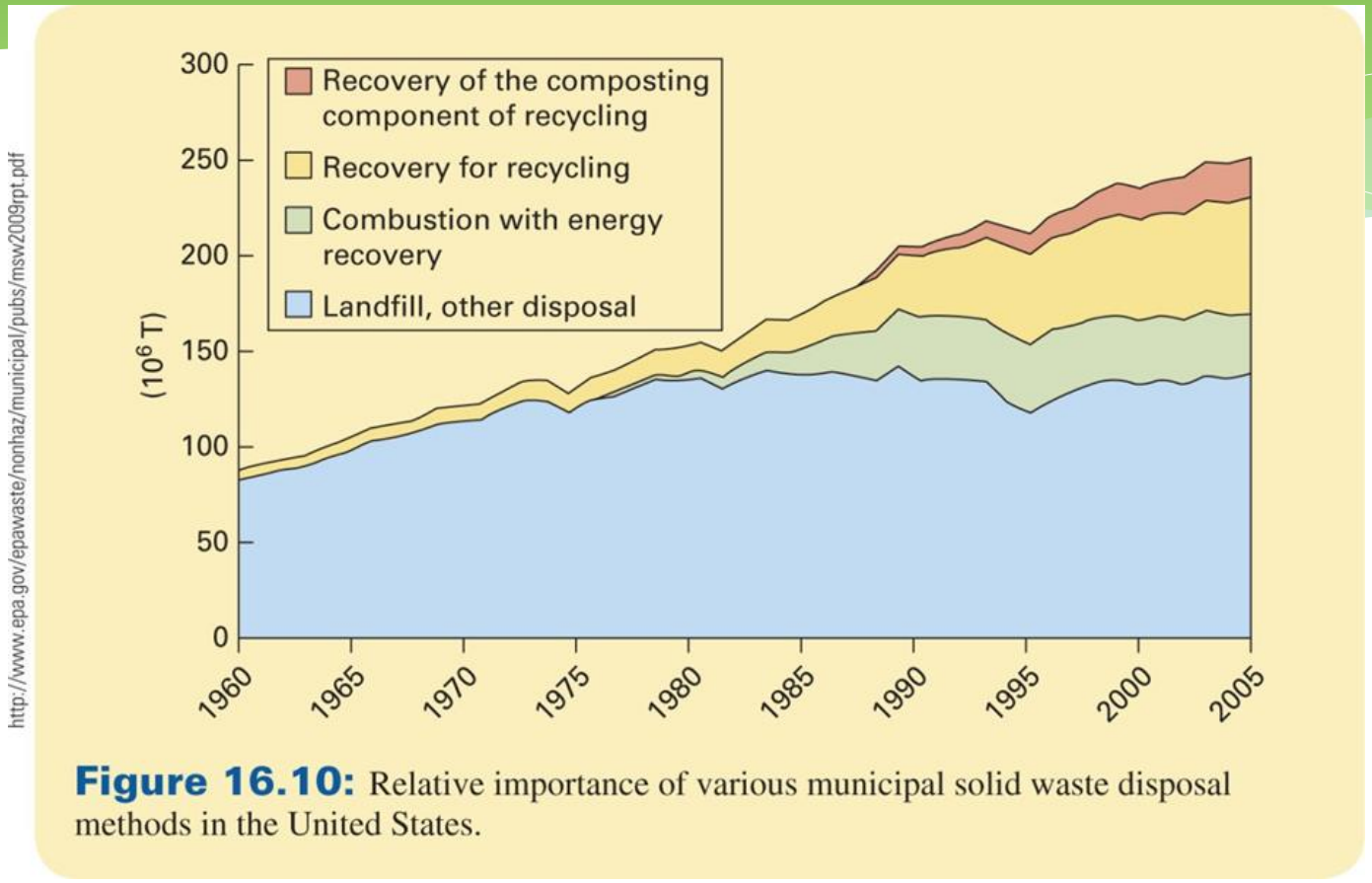


Figure 16.10: Relative importance of various municipal solid waste disposal methods in the United States.

Use of MSW as a fuel has increased since 1980

Summary

- Biofuels can be carbon neutral if organic material is grown to replace that which is burned
- Wood is a major source of heat in many less industrialized countries but is a minor source of energy in North America and Europe
- Use of ethanol as a fuel has increased in recent years
- Climate and agricultural practices are important in effective ethanol production
- Biodiesel most commonly used in Europe
- Biodiesel production has increased rapidly
- Net environmental impact of biofuels is not entirely clear
- MSW use as a fuel is a minor component of energy needs
- Use as a fuel may be environmentally preferable to alternate disposal methods