Queen Mary University of London

EMS717U/EMS717P

Renewable Energy Sources

Energy from biomass/biofuel

Content

- **Types of biomass**
- **Photosynthesis**
- **Biomass resources**
- **Conversion routes**
- **Environmental, economic and social impacts**

DENM035/DEN438

Self-study assignment

Sections 4.4 – 4.11 of Bioenergy Chapter
from *Renewable Energy* by Boyle, G.

Give particular attention to:
- Municipal waste incineration
- Biomass processing routes

! These topics are examinable !

What is biomass energy

Biomass:- term used to describe all organic material that stems from plants and includes algae, trees, crops and some animal wastes

Can define four main groups:

1.Woody crops, wood residue, short rotation crops

Traditional wood biomass

Short rotation coppice, UK

Woody crop harvesting, USA

Willow, UK

What is Biomass Energy

Biomass:- term used to describe all organic material that stems from plants and includes algae, trees, crops and some animal wastes

<u>Can define four main groups:</u>

1. Woody crops
2. Grasses/herbaceous plants

Corn mountain, USA

Native American switchgrass

Sugar crane crop, Brazil

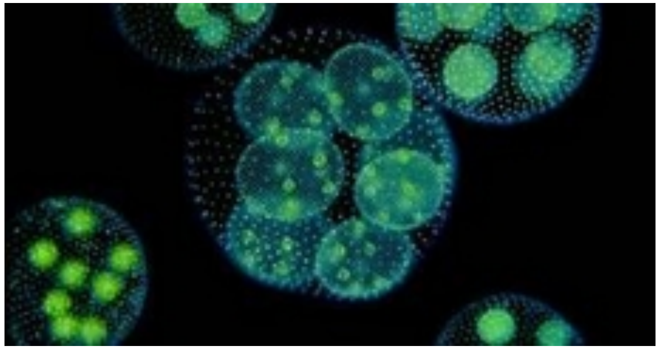
Miscanthus crop, England

What is Biomass Energy

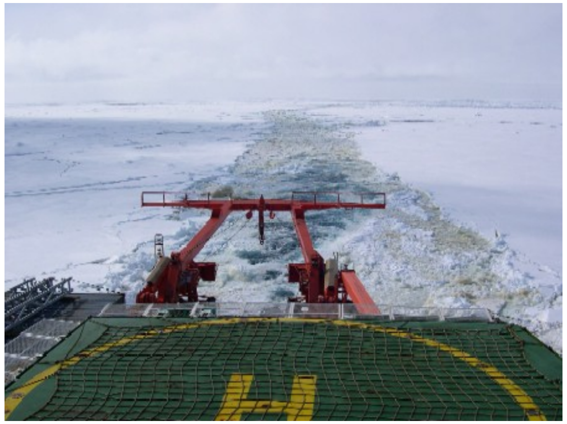
Biomass:- term used to describe all organic material that stems from plants and includes algae, trees, crops and some animal wastes

Can define four main groups:

1. Woody crops
2. Grasses/herbaceous plants
3. Aquatic plants, algae



Algae for bio-oil production



Ice algae growth, S. Ocean

Algal bloom cultivation, NZ

What is Biomass Energy

Biomass:- term used to describe all organic material that stems from plants and includes algae, trees, crops and some animal wastes

Can define four main groups:

1. Woody crops
2. Grasses/herbaceous plants
3. Aquatic plants
4. Manures, wastes

How is biomass formed?

Photosynthesis:- Green plants utilize the solar energy to convert carbon dioxide and water into organic matter

$$6H_2O + 6CO_2 + 4.66 \times 10^{-18} J \rightarrow C_6H_{12}O_6 + 6O_2$$

This effectively acts as a storage for the solar energy in sunlight in the form of chemical energy in organic matter

These chemical bonds between C,H and O atoms can be broken by digestion, combustion or decomposition to release their stored chemical energy

However, not all reactions are of above form and a generalised chemical equation for photosynthesis is:

$$6CO_2 + 2H_2A + 4.66 \times 10^{-18} J \rightarrow (CH_2O) + A_2$$

In this expression H_2A represents a compound that can be oxidised (loss of electrons) and (CH_2O) is a general formula for the carbohydrates formed in the growing process of the organisms.

For most organisms (e.g. algae and green plants) H_2A is water and A is oxygen. However, different systems exist, e.g. in some photosynthetic bacteria H_2A is H_2S.

Also, photosynthetic reactions consist of two processes:

Firstly, a series of light controlled reactions that can be increased by **increasing light intensity** but are independent of temperature.

Secondly, a series of temperature dependent reactions that can be increased by **higher temperature** (e.g. warmer climate or using a greenhouse) but are independent of light intensity

Historical and present day biomass use

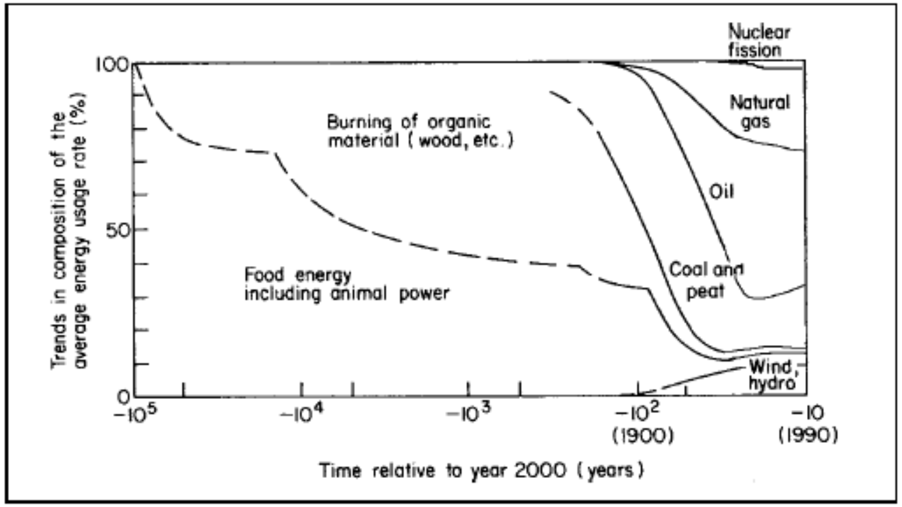
Biomass has always been a major source of man's energy supply

From 10^5 YBP – 200 years YBP extensively used in form of wood/peat for heat and cooking + food is use of biomass and chemical energy

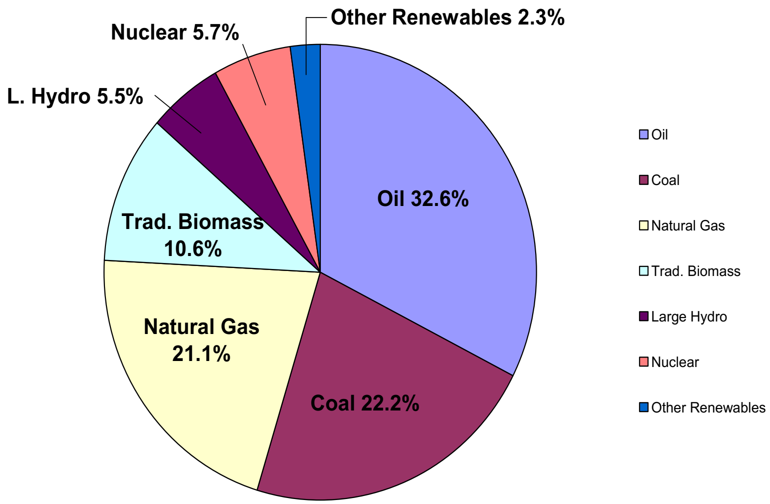
100 YBP - Fossil fuels became abundant and inexpensive in the developed world

Developed world used fossil fuels and used less biomass

Remained extensively used in the developing world and still contributes between 10-14% of the global energy supply



Trends in contribution of different types of energy resources to the average global rate of energy use. (Source: Sorensen, B. 'Renewable Energy' 3rd ed., Darmstadter et al. (1971) and European Commission (1997))



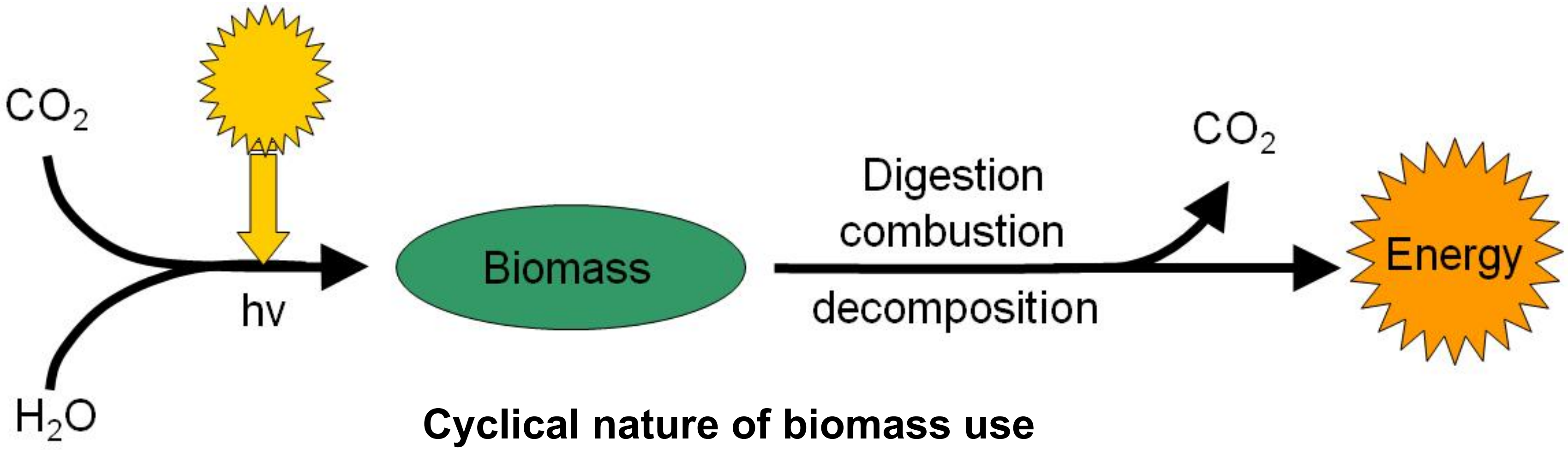
Percentage contributions of different energy sources to global primary energy consumption in 2002

Changing biomass view

Today: Biomass seen as a potential replacement to widespread fossil fuels use

What are the drivers for biomass development?

- Depleting reserves of fossil fuels (particularly liquid fuels such as diesel and gasoline which are required for automotive and aviation transport)
- Instability in fossil fuel supply and fact that it is concentrated resource (biomass resource is distributed more evenly globally)
- Climate change pressure – requirements on nations to achieve significant CO_2 emission reduction
- Food surplus in developed world



Cyclical nature of biomass use

Size of the biomass resource?

Production and storage

Stored biomass:

Amount of solar energy stored in biosphere is ~$2x10^{22}$ J or 20,000 EJ

Production rate:

Average capture/storage rate of biomass is $1.33x10^{14}$ W

This corresponds to an average of 0.26 W/m^2 but as production rate slower in oceans the average production rate on land is 0.51 W/m^2

Global primary energy consumption ~451 EJ/yr or 14.3 TW

Biomass consumption:

- Today biomass energy consumption rate of ~56 EJ/yr or 1.6 TW (this gives ~11% of primary energy)

- Biomass Food energy consumption 16 EJ/yr or 0.5 TW

Conversion efficiency of process:

Average availability of solar radiation is ~ 200 W/m^2

Average biomass production is 0.26 W/m^2

Energy conversion efficiency typically only 1% of available sunlight to organic matter by photosynthesis

Comparison to other technologies:

Photovoltaic conversion efficiency of ~15%

Biomass benefits:

- Available naturally on a renewable basis from sunlight and carbon dioxide/water but it can be made available as a by product of anthropogenic activities i.e. organic wastes
- Also distributed resource – not geologically concentrated like fossil fuels

Regional biomass choices

<u>Choice of plant species</u> for biomass feedstock depends upon the end-use application, bio-conversion option of interest, nature of soil and the climatic conditions of the region.

<u>Regional Examples:</u>

Northern Europe – much interest has been given to the C_3 woody species, particularly those grown as short rotation coppice (SRC) e.g. willow and poplar and oil seed rape is of wide interest for bio-diesel production

USA – more interest in the C_3 herbaceous species, such as cereals, and their conversion to alcohol (ethanol) fuels as substitute for gasoline. Also interest in the herbaceous C_4 species switchgrass

Brazil – similar to USA, has much interest in growth of sugarcane and has pioneered the large-scale production of fuel alcohol derived from biomass, again as substitute for gasoline

UK – *Miscanthus*, a herbaceous C_4 grass, has been identified as a promising energy crop. It is easy to grow and harvest and provides a high dry matter yield. It requires high rainfall, which is not a problem in the UK (particularly in the wetter west)

UK biomass energy policy

Renewable Energy Sources: Today contribute ~1% to UK primary energy supply and 2.6% to electricity supplies

RCEP 2000 recommendations: "large deployment of alternative energy sources will be needed if the UK is to make deep and sustained cuts in carbon dioxide emissions"

"Longer-term targets should be set for expanding the contribution from renewable sources well beyond 10% of electricity supplies to cover a much larger share of primary energy demand"

Renewable energy contributions to primary energy in UK, 2000

Energy source	Electricity ($/10^{15}J$)	Heat energy ($/10^{15}J$)	% of all Renewables
Hydro	18.4		14.7
Biofuels			
MSW combustion	23.4	3.20	
Landfill gas	30.0	0.57	
Sewage sludge	5.03	1.57	
Wood waste		20.7	
Straw		3.00	
Other wastes	13.1	2.01	
Total biofuels			82.2
Wind	3.4		2.72
Geothermal		0.03	0.03
Solar energy	0.004	0.44	0.35
Totals	93.4	31.6	100

- Over >80% of the renewable contribution comes from biomass

- Main contribution is from **municipal solid wastes (MSW)** and the product of its processing, **landfill gas (LFG)**

- 90% of domestic refuse is disposed of by landfill where it is broken down by bacteria in the absence of air to produce methane rich gas (LFG)

- This is increasingly being collected and used in small scale electricity generating plants

Biomass properties

Ideal characteristics of energy crop are:

- High crop yield (max dry matter production per hectare)
- Low energy input to produce crop
- Low cost
- Composition with least contaminants
- Low nutrient requirements

Composition of various biomass feeds

Material	Moisture content (%H_2O)	HHV (MJ/Kg)	FC Content (%)	VM Content (%)	Ash Content (%)	Alkali Metals (%)
Fir	6.5	21.0	17.2	82.0	0.8	-
Danish pine	8.0	21.2	19.0	71.6	1.6	4.8
Willow	60	20.0	-	-	1.6	15.8
Poplar	45	18.5	-	-	2.1	16
Cereal straw	6	17.3	10.7	79.0	4.3	11.8
Miscanthus	11.5	18.5	15.9	66.8	2.8	-
Bagasse	45-50	19.4	-	-	3.5	4.4
Switchgrass	13-15	17.4	-	-	4.5	14
Bituminous coal	8-12	26.0	57	35	8	-

HHV value based on dried biomass fuel

Energy yields from selected biomass crops

Biomass	Crop yield (dmt/ha/a)	HHV (MJ/kg, dry)	Energy yield (GJ/ha)
Wheat	14	12.3	172.2
Poplar	10-15	17.3	173-259
SRC willow	10-15	18.7	187-280
Switchgrass	8	17.4	139
Miscanthus	12-30	18.5	222-555

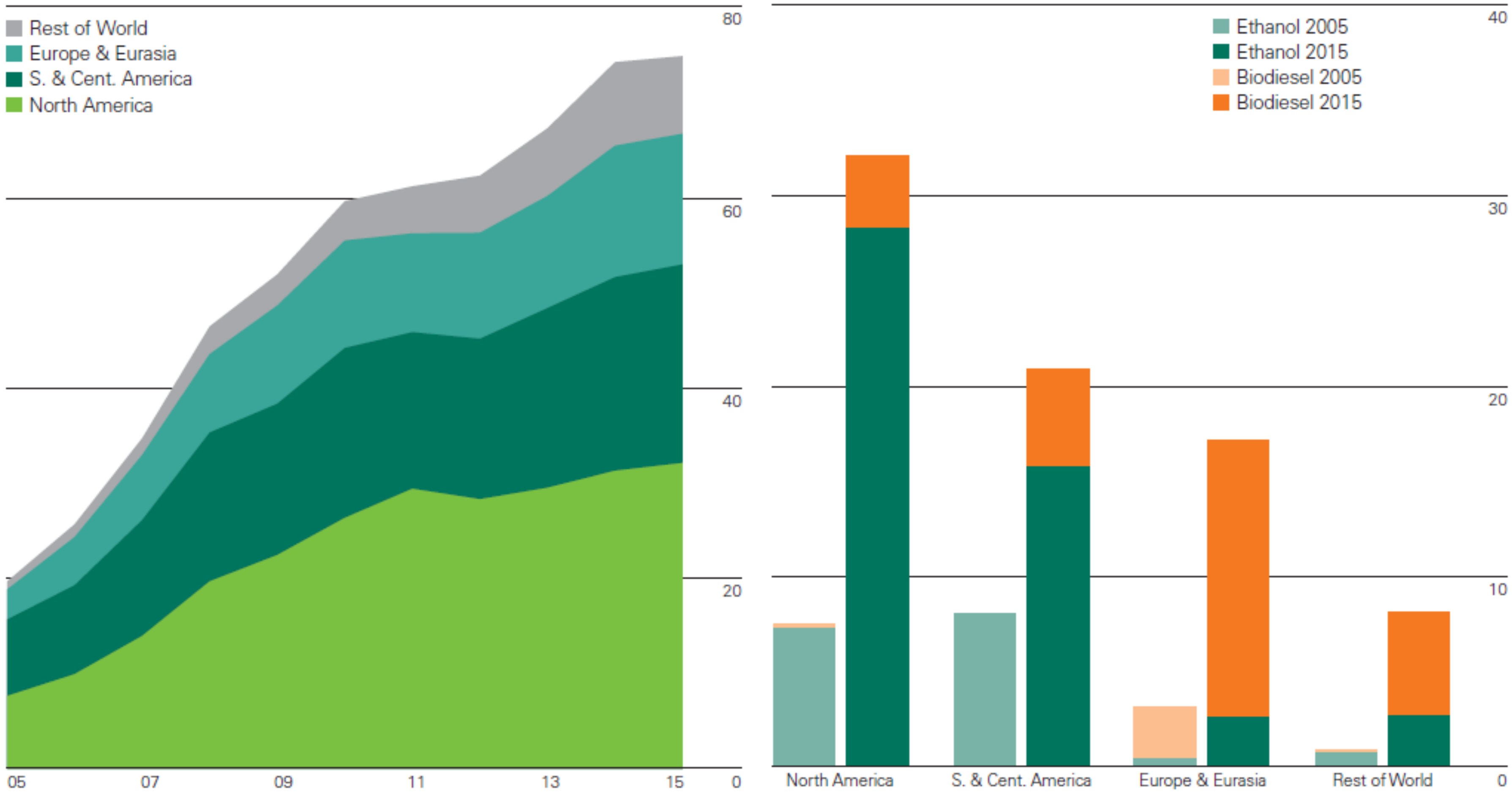
Crop Yield – quantity of dry matter produced by biomass per unit area of production

Values above are given as dry matter tonnes produced per hectare per year (dmt/ha/a) where 1ha = 10^4 m^2

The crop yield combined with the HHV value allows the energy yield of a crop to be calculated

World biofuels production

Million tonnes oil equivalent



World biofuels production increased by 0.9% in 2015, the slowest rate of growth since output declined in 2000. Global ethanol production increased by 4.1%, the third consecutive year of growth, led by increases from Asia Pacific, South & Central America, and North America. Biodiesel production declined by 4.9% in 2015, with output declining in all of the major producing regions.

How green are biofuels?

(1) Atmospheric emissions

Forest re-growth as a means of ‘fixing’ atmospheric CO_2 has received much attention. The absorption of CO_2 by a new forest is a one-off process which occurs over the 40-60 years it takes a tree to mature

Hence, a wider bio-energy strategy to implement the progressive substitution of fossil fuels would give a more sustainable and lasting solution

Life cycle analysis – In order to fully assess the effects of introducing biofuels must perform a full analysis

This analysis must take into account emissions from all processes in production of the biofuel, for example

- Emissions associated with fertilizer use (production of H_2)
- Fossil fuel use in transportation of biomass and biofuel
- Energy input into cultivation and irrigation

How green are biofuels?

(1) Atmospheric emissions

Net life cycle emissions from electricity generation in the UK

	Emissions[1] /g kWh^{-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: 'best practice'	955	11.8	4.3
coal: FGD & low NO_x[3]	987	1.5	2.9

Source: *Renewable energy*, Boyle, G. (2000)

No system is truly carbon-neutral

However, all bio-energy systems have some benefits over fossil fuel plants due to lower CO_2 emissions

Other emissions such as NO_x will still occur if high temperature furnaces are used in biofuel combustion

Also, some controversy over CH_4 emissions from digestion of biomass – more powerful greenhouse gas than CO_2

How green are biofuels?

(2) Land Use

Low efficiency of energy capture makes biomass a very land intensive energy source

For example – considering the land requirements for electricity generation equivalent to a 1.5 MW power station

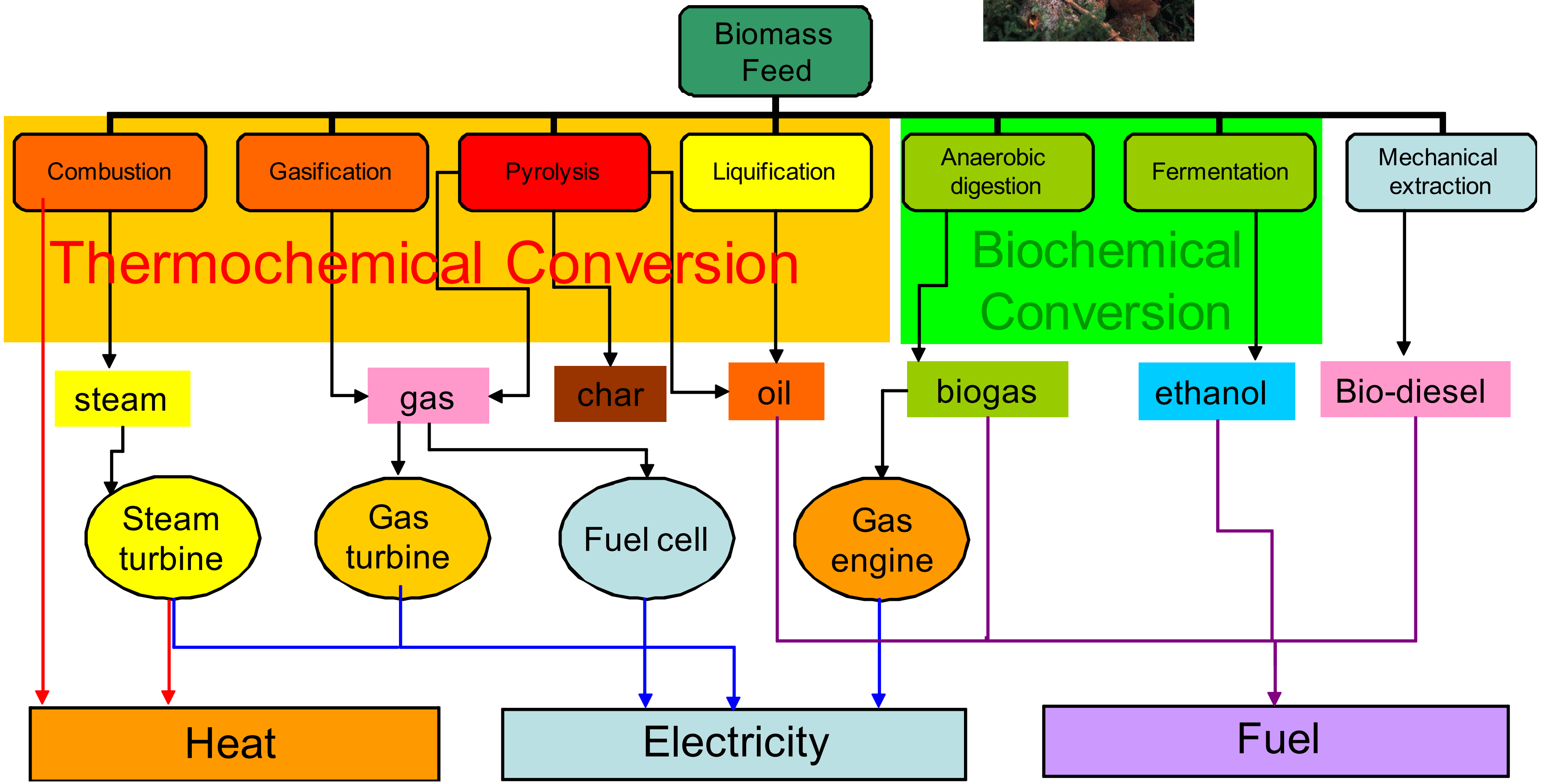
- PV array would require ~ 40 ha (1 ha = 10^4 m^2)
- A windfarm would need ~ 100 ha
- Biomass would need in the range 300-1000 ha

However, not all technologies are likely to compete for same land area e.g. PV arrays can be mounted on roofs and windfarms can be off-shore

Also, concerns regarding the effects of extensive production of energy crops on biodiversity – impact on flora and fauna

Biomass conversion routes

Flexibility of feed



Biomass summary

- Biomass composed of organic matter originating from photosynthesis reactions
- Large variety of biomass types
- Biomass can be converted into gas, liquid or solid fuels – have most benefits of fossil fuels
- No biofuel is truly carbon-neutral at present – associated CO_2 emissions
- Some concerns over biodiversity