Joint EPS-SIF International School on Energy

Course 4

Advances in Basic Energy Issues

BIOMASS and BIOFULS – Part 1

Biomass properties and classification

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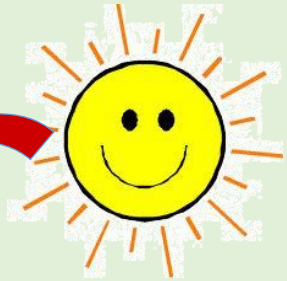
GENERAL ASPECTS and PROPERTIES

1° PHASE = Production > Consumption → STORAGE
2° PHASE = Production = Consumption → BALANCE
3° PHASE = Production < Consumption → TAKING OFF



RADIATION
(light, heat)

THERMAL
MECHANICAL
ELECTRICAL

DIRECT
(hydro, wind, tide)

ELECTRICAL
MECHANICAL
THERMAL

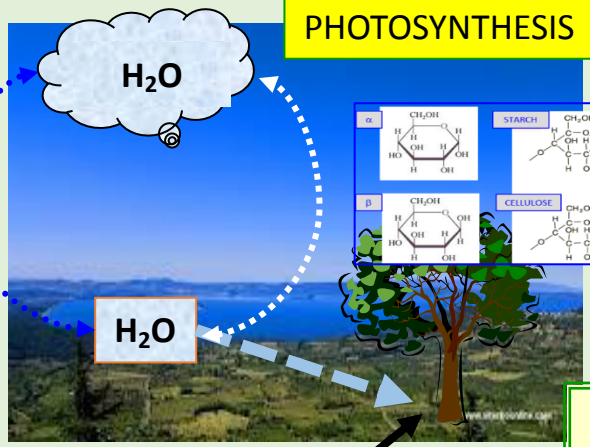
ENERGY

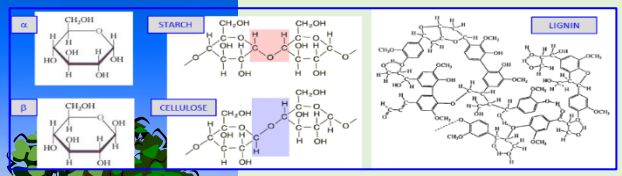
CO_2

O_2

OXIDATION
(combustion, respiration)

PHOTOSYNTHESIS





FOOD&FEED

FUEL

C_x - H_y - O_z

BIOMASS

MINERALS

NO RENEWABLE
Fossil Sources

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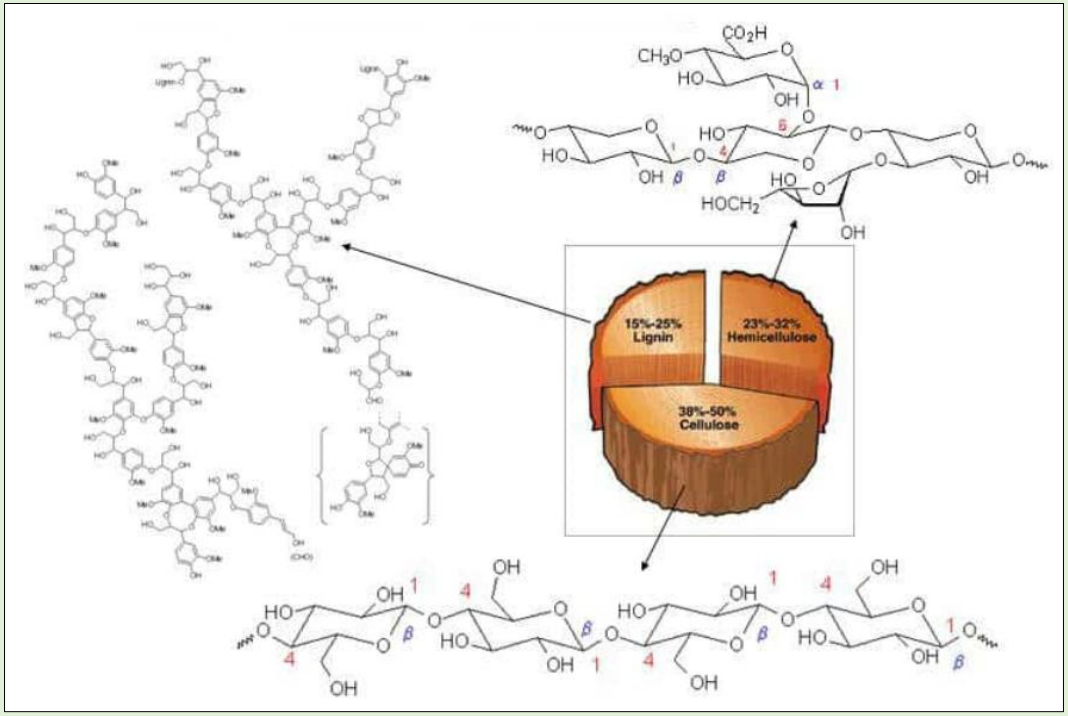
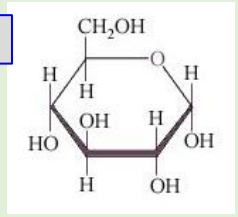
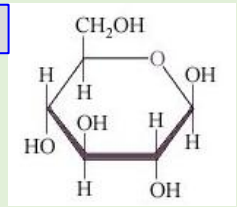
Biomass composition: starch, cellulose, hemicellulose e lignin



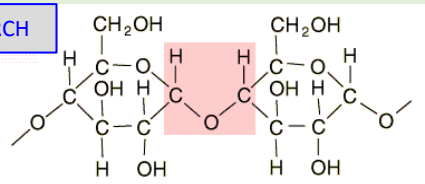
α



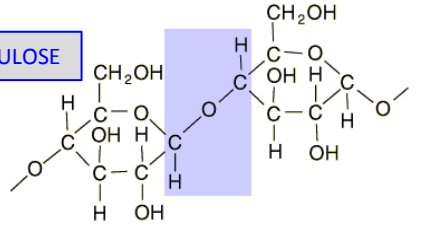
β



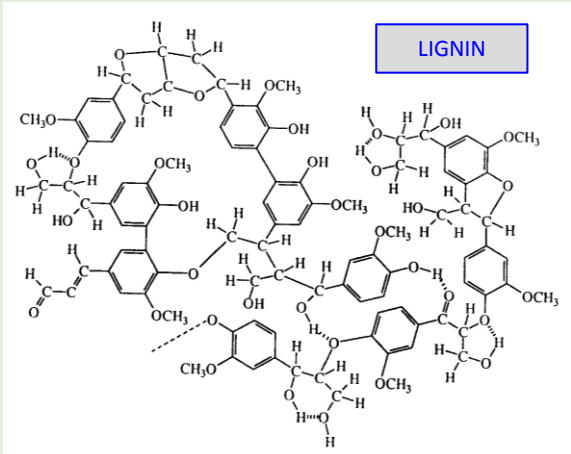
STARCH



CELLULOSE



LIGNIN



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Biomasse per filiere energetiche: tante, diversa provenienza, caratteristiche differenti

Straw (cereals)

1

Pruning residues (grape, olive)

Oil Seeds (sunflower, rape)

2a

Grains (corn)

Ligno-celluosic (miscantus)

ORIGIN	BIOMASS TYPE (sector)	
Plant (vegetable)	1 – Agricultural by-products (food, no-food crops) (agriculture → crop cultivation)	☺
	2a – Erbaceous energy crops (agriculture → crop cultivation)	☹
	2b - Arboreous energy crops (agricolture → crop cultivation)	😐
	3 – Wood and residues, wood derivates (forestry; wood industry) Wood waste (end-use wood)	☺
Animal	4 – Animal wastes (agriculture → animal breedings)	☺
Household	5 – Organic Fraction Municipal Solid Waste OFMSW (urban areas)	☺
Industrial	6 – Dry (lignocellulosic) residues (industry → agri-food)	☺
	7 – Wet (fermentable) residues (industry → agri-food)	☺

Grape skins/Olive oil resideues

7

Leaves and stems (fresh vegetable)

Wood chips (poplar SRF)

2b

Oil Seeds (palm, jatropa)

Wood logs and chips (forestry)

3

Pellet, residues (industry)

Husk, dry skins (rice)

6

Shell/fruit stones (almond, nut)

OFMSW

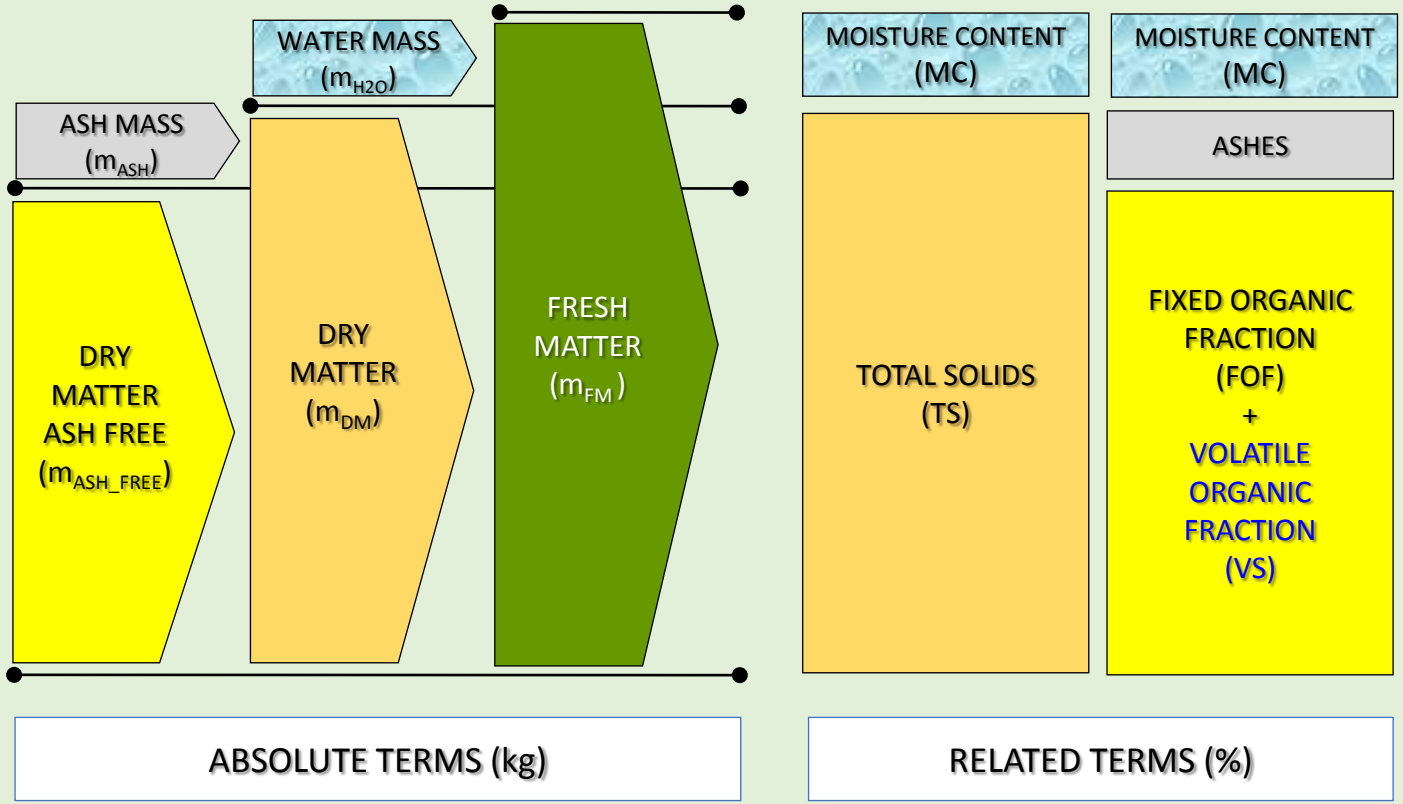
5

Slurry (pigs, cattle)

4

Manure (cattle; chickhens)

The fresh biomass (FM) is always composed by:
a mass of water (Moisture Content, MC)
and
a dry mass (Total Solid, TS or Dry Matter, DM → C, N, O, H, S, ash)



Biomass chemical and physical properties: misture content; Carbon-Nitrogen ratio C/N)

MOISTURE CONTENT (MC; %) → **free water** inside biomass
Moisture Content on wet basis (MC) → related to fresh mass m_{FM} (range: from 4-5% to 90-92%)
Moisture Content on dry basis (MC_{DM}) → related to dry mass m_{DM}

Water is contained in two forms: (i) **bound** to the molecular structure, (ii) **free** within cells and plant tissues; the amount of contained water depends on climatic conditions, period of harvest and conservation processes.

$$MC = \frac{m_{H2O}}{m_{FM}} = \frac{m_{H2O}}{m_{DM} + m_{H2O}}$$

$$MC_{DM} = \frac{m_{H2O}}{m_{DM}} = \frac{MC}{1 - MC}$$

EXAMPLE: a fresh wood mass of m_{FM} = 2.3 kg has a moisture content (wet basis) of MC = 45%. Consequently, the dry matter is DM = 55% and water mass (kg) and the dry mass (kg) are, rispectively:

$$m_{H2O} = m_{FM} * MC = 2.3 * 0.45 = 1.035 \text{ kg}$$

$$m_{DM} = m_{FM} - m_{H2O} = 2.3 - 1.035 = 1{,}265 \text{ kg}$$

$$MC_{DM} = \frac{m_{H2O}}{m_{DM}} = \frac{1.035}{1.265} = 0{,}818 = 81{,}8\%$$

$$MC_{DM} = \frac{MC}{1-MC} = \frac{0.45}{0.55} = 0{,}818 = 81{,}8\%$$

CARBON-NITROGEN RATIO (C/N; -)
Ratio between carbon and nitrogen content of biomass dry mass (range: from 20-30 to 100-120)

In biomass derived from plants indicates the **biomass lignification degree**, while in animal waste (manure, slurry), it depends of **animal species, diet, farm characteristics and type of animal waste management.**

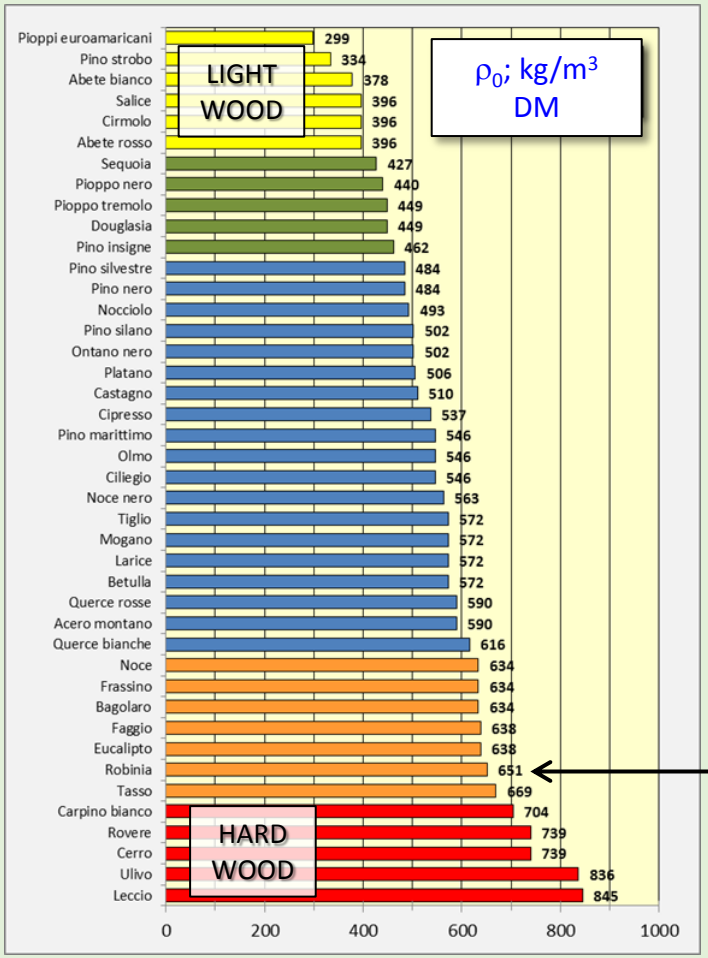
DENSITY (ρ_{MC}; kg/m³ FM)

Mass (m_{FM}; kg FM) contained in the unit of volume (V_b; m³).

It depends on moisture content: the greater the MC, the higher the ρ_{MC}, (→ increase of both the fresh mass and – slightly - the volume). Until full water absorption, the mass grows proportionally to MC, while the volume can be considered practically constant → ρ_{MC} must always be referred to MC.

Literature very often refers to biomass density as dry biomass density (ρ_0; kg/m³ DM).

$$\rho_{MC} = \frac{m_{FM}}{V_b} \qquad \rho_{MC} = \frac{\rho_0}{(1 - MC)}$$



EXAMPLE: the dry biomass density of robinia wood is ρ_0 = 650 kg/m³ DM. At the time of cutting its moisture content is MC = 45%. Consequently, the density is:

$$\rho_{MC} = \frac{\rho_0}{(1-MC)} = \frac{650}{(1-0{,}45)} = 1182 \text{ kg/m}^3$$

Biomass chemical and physical properties: bulk density

BULK DENSITY (γ_{MC}; kg/m^3 FM)

Mass (m_{FM}; kg FM) contained in the unit of volume also considering the empty spaces (V_a; m^3) .

$$\gamma_{MC} = \frac{m_{FM}}{V_a}$$

Directly related to the technical aspects concerning biomass storage and/or handling (volumes, and transport costs). Extremely variable parameter, depending on the biomass moisture content and its final collection and/or packaging methods.

BIOMASS	PREPARATION	BULK DENSITY kg/m^3 FM	DIMENSIONS V = volume; ∅ = diameter
Cereals straw. herbaceous stem and leaves energy crops	Raw material	30-40	-
	Small bales (prismatic)	80-120 (stacked)	V = 0.1-0.2 m^3
	Cilindric bales	120-180 (stacked)	V = 1.5-3.0 m^3
	Big bales (prismatic)	120-180 (stacked)	V = 2.0-4.0 m^3
	Chopped	150-250 (piled)	10-250 mm
Mais stem and leaves	Raw material	50-60 (piled)	-
	Cilindric bales	100-150 (stacked)	V = 1.5-3.0 m^3
Pruning residues	Raw material	50-70	-
	Small cilindric bales	150-210 (stacked)	V = 0.6-0.8 m^3
	Chipped	200-300 (piled)	1-100 mm ; V 2.5 10^{-3} dm^3
Wood	Logs	600-700 (stacked) 300-400 (piled)	300-1000 mm; V = 1.5-15 dm^3
	Chipped	200-300 (piled)	1-100 mm ; V 2.5 10^{-3} dm^3
Sawdust	Milling process	120-180 (piled)	1-5 mm
Mais silage	Cut	450-750 (pressed) 350-400 (piled)	10-25 mm
Pellet	Extrusion process	800-900 (piled)	∅ < 25 mm
Briquettes	Extrusion process	190-340 (piled)	∅ > 25 mm; V = 1-1.5 dm^3
Fruit shells	-	250-450 (piled)	5-20 mm
Fruit kernels	-	350-550 (piled)	5-20 mm
Olive oil residues	Compression. centrifugation process	400-500 (piled)	1-5 mm
Grape residues	Compression process	250-500 (piled)	1-5 mm
Rice/cereals husk	Separation process	130-140 (piled)	1-5 mm
Animal slurry	Collected/moved by pumps	1000 (piled)	-
Animal manure	Collected/moved by mechanical devices	500-650 (piled)	-

Biomass chemical and physical properties: heat values (GHV, LHV)

GROSS HEATING VALUE (GHV; J/kg DM; kcal/kg DM; kcal/m^3_N)

Thermal Energy developed from complete combustion of:

- ❑ 1 kg liquid or solid fuel
- ❑ 1 m^3_N gaseous fuel (normal cubic meter → p = 1 bar, T = 0 °C) or 1 m^3_S (standard cubic meter p = 1 bar, T = 20 °C)

It takes into account the energy due to vapor condensation generated during the complete fuel oxidation

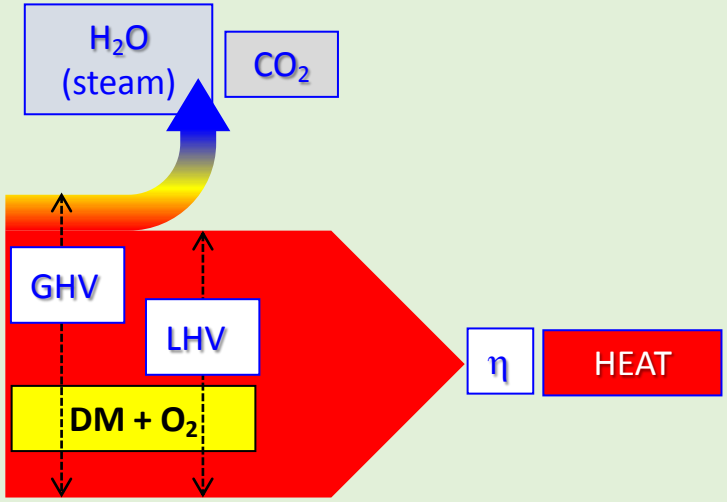
$$C_xH_yO_z + O_2 \rightarrow CO_2 + H_2O + \underline{ENERGY}$$

$$GHV = 0{,}35 \cdot [C] + 1{,}18 \cdot [H] + 0{,}10 \cdot [S] - 0{,}02 \cdot [N] - 0{,}10 \cdot [O] - 0{,}02 \cdot [Ash] \ (MJ/kg)$$

LOWER HEATING VALUE (LHV; J/kg DM; kcal/kg DM; kcal/m^3_N)

Determined subtracting the heat of vaporization of the water vapor from the GHV. The energy required to vaporize the water contained in the biomass is not released as useful heat (lost at the chimney inside the smokes).

BIOMASS	MC (%)	YIELD (t/ha FM)	ASH (%)	LHV (kWh/kg_s DM)
Wheat straw	14-20	3-6	7-10	4,8-4,9
Rice straw	20-30	3-5	10-15	4,3-4,4
Corn stalks	40-60	4,5-6	5-7	4,6-5,0
Pruning residues	45-55	3-4	2-5	5,0-5,1
Wood (robinia, 20-30 yrs)	40-45	30-75	2-3	5,0-5,1
Carpino (30-40 anni)	40-45	55-100	1-2	4,9-5,0



Biomass chemical and physical properties: heat values (NHV)

NET HEATING VALUE (NHV; J/kg FM; kcal/kg FM; kcal/m^3_N)

LHV to which is removed the heat necessary to evaporate the free water (m_{H2O}) inside biomass. Practically, NHV is heat recoverable from the fresh biomass, releasing combustion smokes into the atmosphere.

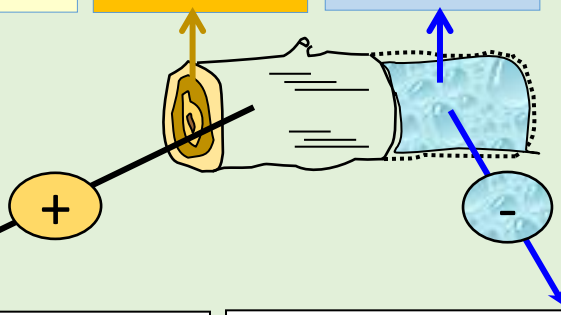
$$NHV = LHV \cdot (1 - MC) - c_{EV} \cdot MC$$

C_{EV} = heat of H_2O vaporization
2261 kJ/kg H_2O = 540 kcal/ kJ/kg H_2O = 0,628 kWh/ kJ/kg H_2O

EXAMPLE: The wood of robinia has a Lower Heating Value LHV = 5,0 kWh/kg DM (= 4300 kcal/kg DM); the Net Heating Value at the cut (fresh wood → MC = 45%) is:

WOOD LOGS
1 kg FM → MC = 15%

LHV = 4300 kcal/kg DM | DM = 55% | MC = 45%

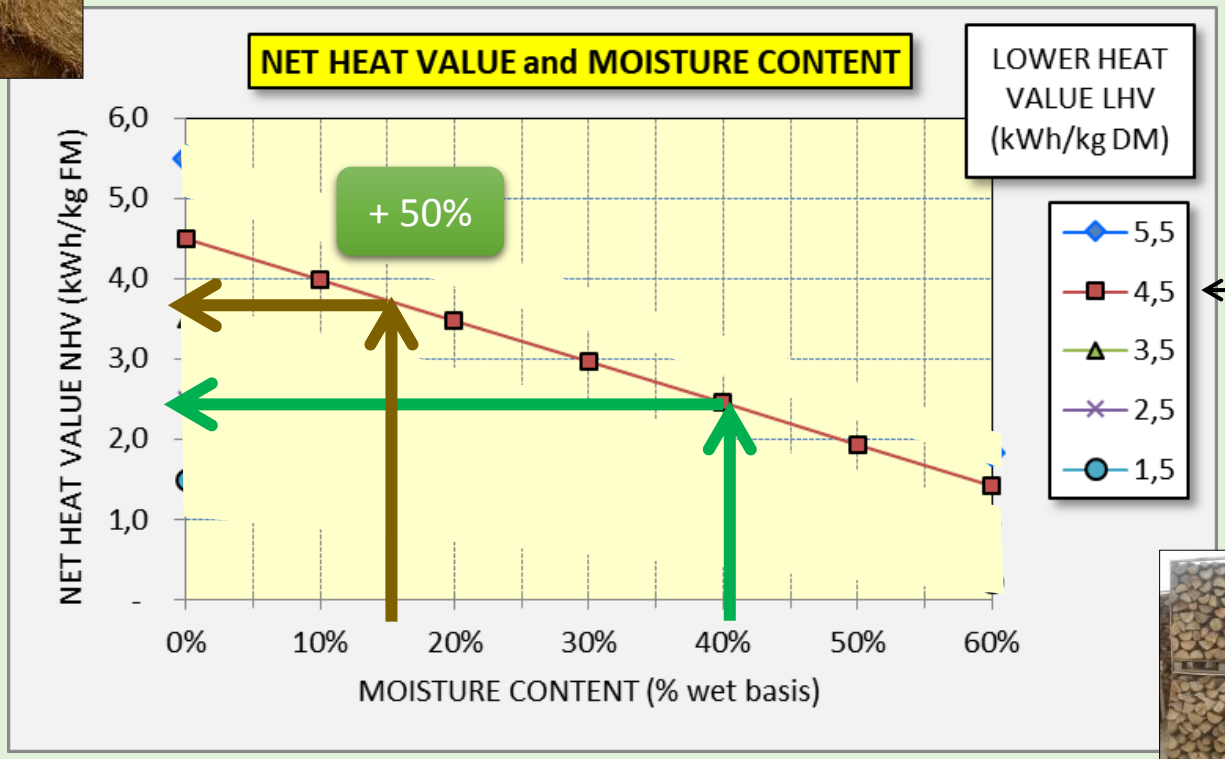


$LHV \cdot (1 - MC) = 4300 \cdot (1 - 0.45) = 2365\ kcal$

$-540 \cdot MC = -540 \cdot 0.45 = -243\ kcal$

NHV = 2122 kcal/kg FM

Biomass chemical and physical properties: heat values (NHV)



The sale of lignocellulosic biomass (example: wood) is "by weight". Knowing the moisture content is therefore crucial to buy energy and not water.

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Biomass and energy conversion processes: general scheme

THERMAL EN. (H_2O < 100°C)

Combustion

THERMAL EN. (H_2O > 100°C)

DRY → ligno-cellulosic

Pyrolysis

Charcoal (char)

Syngas

Bio-oils (tar)

Gasification

Gas ($CO+H_2+CH_4$ = 22-30%)

ENGINE (Otto Cycle)

TURBINE (Rankine Cycle)

BIOMASS

Seeds

Extraction

(a) Vegeatble Pure Oil
(b) Biodiesel

MECHANICAL ENERGY

ELECTRIC GENERATOR

ELECTRICITY

WET → Fermentable

Alcohlic fermentation

Bio-ethanol

Bio-fuels (liqids or gases)

Methanic fermentation

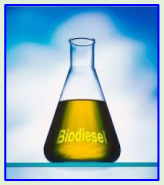
Biogas (CH_4 = 50-60%)

Biomass-to-energy: oil equivalent

LIGNOCELLULOSIC BIOMASS

≅ 2,0-2,5 kg tq

BIO-FUELS



Bio-diesel: 1,2 kg ≅ 1,3 litri

Bio-ethanol: 1,6 kg ≅ 1,9 litri

Biogas: 2,1 kg ≅ 1,7 m^3_N

$1\ kg_{oe} = 10000\ kcal$

Type A

LIGNOCELLULOSIC BIOMASS → combustion, gasification, pyrolysis

PLANT DERIVED, LIGNOCELLULOSIC, GROWTH FUNCTIONS → (herbaceous and tree species: leaves, steams, branches)

Essentially made by: cellulose (50% DM, 3900 kcal/kg DM); hemicellulose (10-30% SS; 3000 kcal/kg DM); Lignin (20-30% SS, 6000 kcal/kg DM). Other simpler organic compounds (resins, fats, oils, waxes, starches, sugars, proteins, tannins, pigments, alkaloids, etc.) and inorganic materials (Na, K, Mg, Ca, Cd, Zn, As, Pb, S, Cl, N, P, Si, Al etc.)

BASIC ENERGY PARAMETERS

C/N Ratio > 30 → Lower Heating Value *f* (C%): 4.5-5.2 kWh/kg DM

MC = 25-45% → Net Heating Value *f* (1/MC): 1.8-2.5 kWh/kg DM

Ash (2-10% DM), frequently low melting point (T < 1000 °C)

Type A

Combustion

Gassification

Carbonization

AGRICULTURAL BY-PRODUCTS

- STRAW → cereals (wheat, rice, corn), oil crop (sunflower). Leaves and stems that, when harvesting the main product, are usually left in the field;
- WOODY → pruning residues (grape, olive, fruit trees). From winter cut operations, made to shape and/or balance the plants grown according to the various cultivation systems in use.

INDUSTRIES RESIDUES and WASTE

- RESIDUES → fruit-processing (shell and stones; olive oil (olive oil pomace; virgin and exhausted); wine (grape resisues)
- RESIDUES → wood-processing (bark, chips and shavings, sawdust)

HERBACEOUS ENERGY-CROPS

- STALKS & LEAVES → poli-annual cycle crops (miscanthus, giant cane, etc.)
- GRAINS → cereals (wheat, rice, corn)

TREE SPECIES ENERGY CROPS

- WOOD CHIPS → Short Rotation Coppice (SRC) of poplar, eucalyptus, robinia (two or five years cut frequency).

WOOD and WOOD DERIVED PRODUCTS

- LOGS or CHIPPED WOOD → forestry (coppice and tall trees)
- RESIDUES (END-USE WOOD) → different origins related to human activities
- DERIVED PRODUCTS → specialized industries for extrusion products (pellets, briquettes)

Type A

ON REPORT TABLES SPECIFIC PARAMETERS ARE INDICATED

Type B and C

FERMENTABLE BIOMASS → methanic fermentations

Type B

PLANT DERIVED, FERMENTABLE, GROWTH FUNCTIONS → (herbaceous: leaves, steams)

Composed mainly of cellulose and hemicellulose, poorly lignified. Other simpler organic compounds (organic extracts) and inorganic material (Na, K, Mg, Ca, Cd, Zn, As, Pb, S, Cl, N, P, Si, Al .)

BASIC ENERGY PARAMETERS

C/N Ratio < 30 MC = 65-80% Ash (1-2% DM)

VS: 85-95% TS; biogas yield: 500-700 m^3_N/t SV

CH_4 = 55-65% vol. → LHV biogas = 5.0-6.2 kWh/m^3_N

Type C

ANIMAL DERIVED, FERMENTABLE → (slurry and manure)

Livestock effluents, a mix of: excreta (feces and urine), water, feed residues and litter (straw, sawdust, husk, etc.) when used. Extremely variable composition according to: (i) animal species (cows, pigs, poultry), (ii) breeding methods, (iii) characteristics of the feed (iv) waste management system

BASIC ENERGY PARAMETERS

VS: 65-85% TS (slurries), 75-90% TS (manures); biogas yield: 300-550 m^3_N/t SV;

CH_4 = 50-65% vol. → LHV biogas = 4.8-6.2 kWh/m^3_N

Methanic fermentation

HERBACEOUS ENERGY-CROPS

- SILAGES → corn, wheat, triticale, (waxy maturation) sorghum (anaerobic co-digestion).

ANIMAL WASTE

- SLURRY → liquid, fluid or dense consistency, TS < 20%, moved by a pump (up to 16% TS);
- MANURE → thick, semi-solid or solid consistency, TS ≥ 20%, moved by a shovel.

INDUSTRIES RESIDUES and WASTE

- RESIDUES → fruit-processing (pulps and peel); vegetable-processing (tomatoes and potatoes peel); olive oil (vegetation water); milk processing (whey)
- WASTE → meat processing (blood, fat, whey, gut, stomach contents, etc.)

DOMESTIC WASTE

- WASTE → Organic Fraction of Municipal Solid Waste (OFMSW).

Type B and C

ON REPORT TABLES SPECIFIC PARAMETERS ARE INDICATED

Type D

SEEDS → oil extraction, alcholic fermentation, combustion

Type D1

PLANT DERIVED, OIL, REPRODUCTIVE FUNCTIONS → (herbaceous and tree species: seed)

Oleaginous species seeds.

TROPICAL CLIMATE (Southeast Asia, India, China, Africa):

- palm (*Elaies guineensis*) → tree species with edible seeds
- jatropha (*Jatropha curcas*) and pongamia (*Pongamia pinnata*) → herbaceous/shrubby species, non-edible seeds;

TEMPERATE CLIMATE (Central-South Europe, North America):

- rapeseed (*Brassica napus*), sunflower (*Heliantus annuus*), castor (*Ricinus communis*), soybean (*Glicine max*) herbaceous, with edible seeds

BASIC ENERGY PARAMETERS

Oil content: 25-45% FM; LHV oil (SVO): 10,0-11,0 kWh/kg

Oil extraction (SVO)

Type D1

ON REPORT TABLES SPECIFIC PARAMETERS ARE INDICATED

Type D2

ORIGINE VEGETALE con FUNZIONI RIPRODUTTIVE → (herbaceous: seeds)

Cereals seeds (grains).

TROPICAL CLIMATE (Central-South Europe, North America):

- corn, wheat and barely, con cariossidi.

BASIC ENERGY PARAMETERS

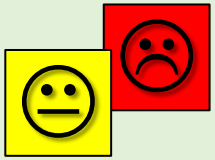
C/N Ratio > 100 → Lower Heating Value *f* (C%): 4.1-4.2 kWh/kg DM

MC = 15-25% → Net Heating Value *f* (1/MC): 3.5-4.0 kWh/kg DM

Ash (2-5% DM), frequently low melting (T < 1000 °C)

Combustion

Alcholic fermentation

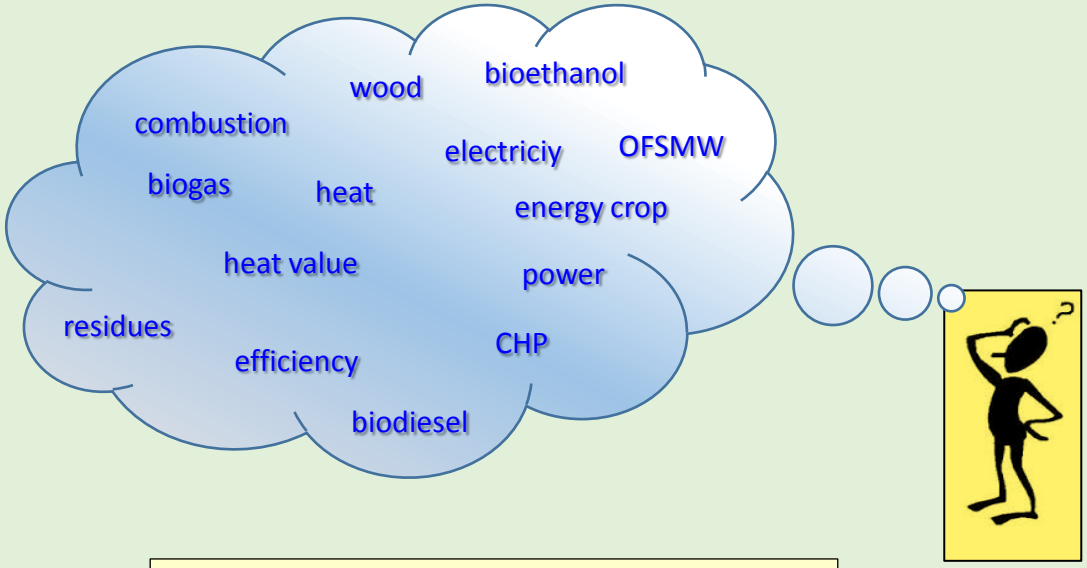


Type D2

ON REPORT TABLES SPECIFIC PARAMETERS ARE INDICATED

…conclusion ?

Biomass-to-energy: some basic information



BASIC INFORMATION

TYPE	C/N	HUMIDITY	CONVERSION PROCESS	ENERGY PRODUCTS
Wood, straw, «dry» residues/waste → Thermochemical (heat)	> 30	< 40%	Combustion Gasification Pyrolisis	Heat → Electricity Syngas Syngas, Tar, Char
Animal waste, «wet» residues, energy crops → Biochemical (bacteria)	< 30	> 70%	Anaerobic Digestion Alcholic Fermentation	Biogas, BioCH_4, BioH Bioethanol
Seeds → Other (physical, chemical)	-	-	Extraction Esterification	Straight Vegetable Oil (SVO) Biodiesel

Biomasse

TUTTO E' POSSIBILE !

Beh… quasi tutto.

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Life Cycle Assessment in AgriFood Chains