

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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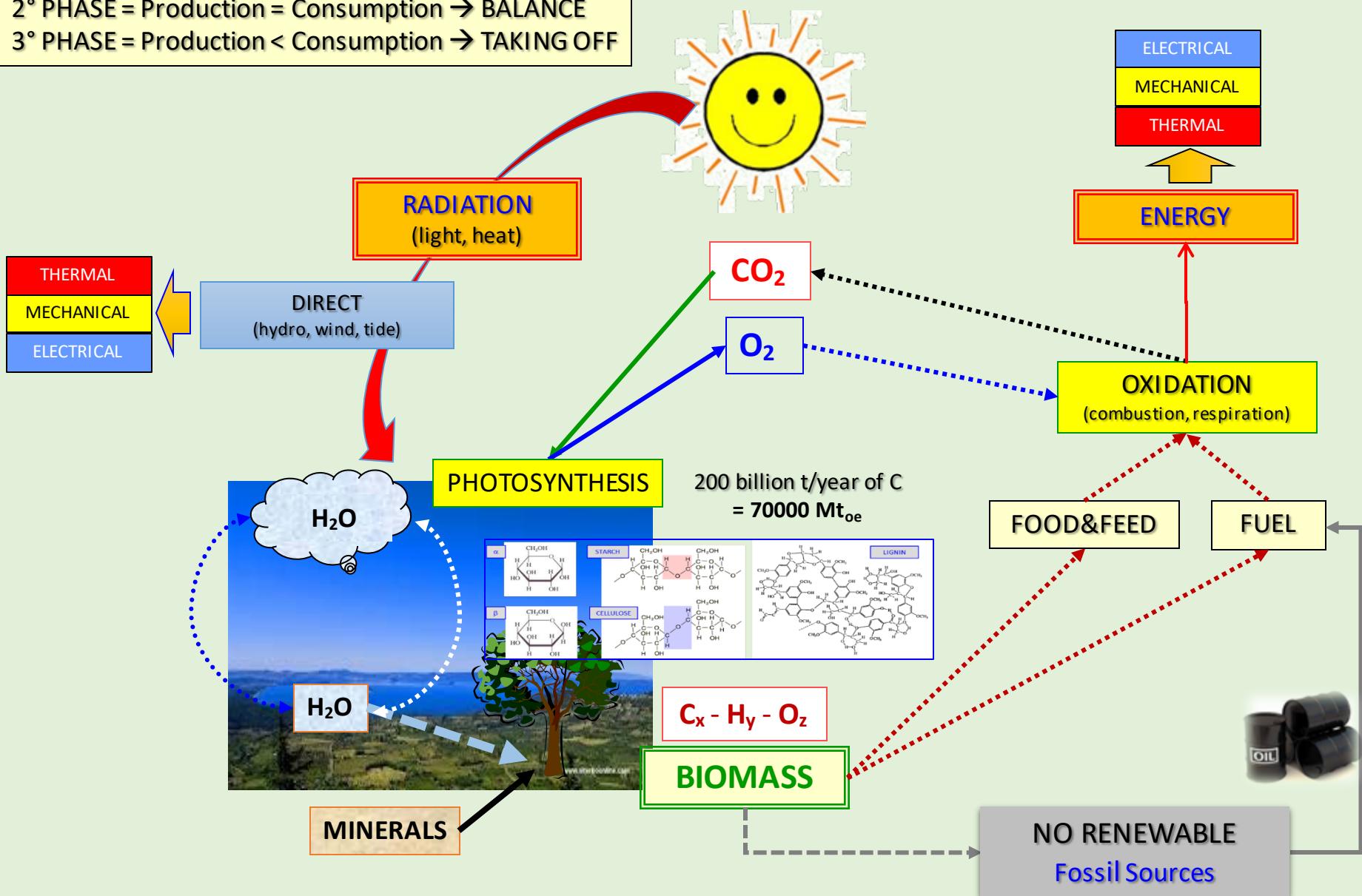


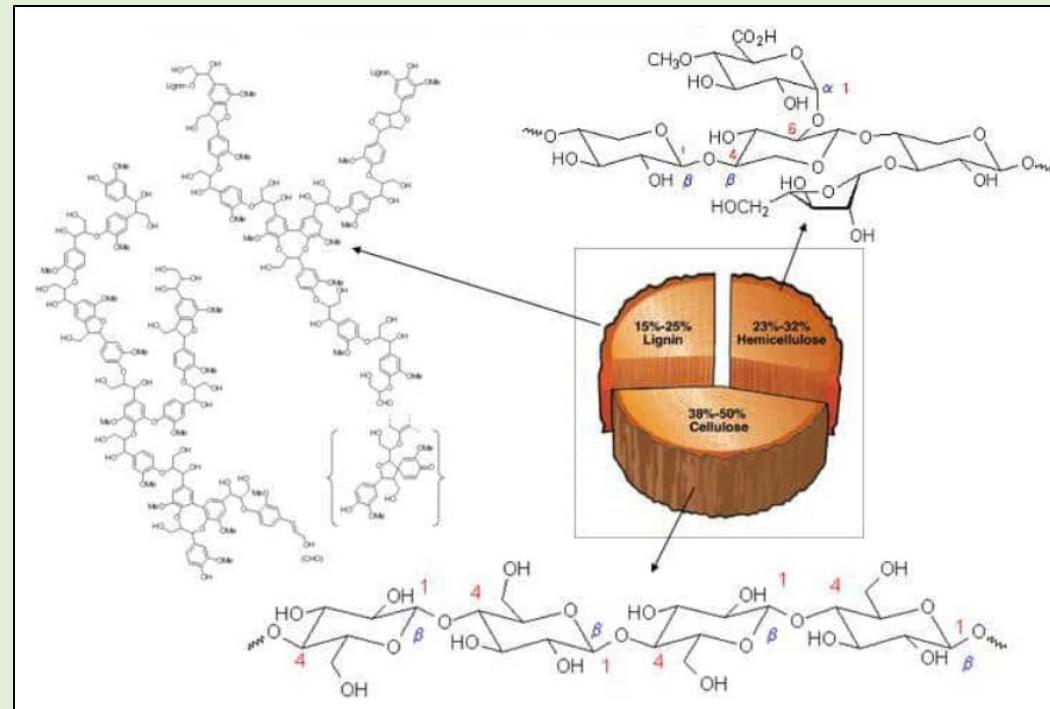
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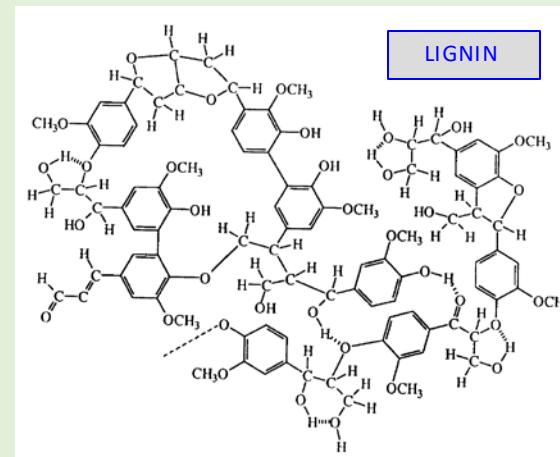
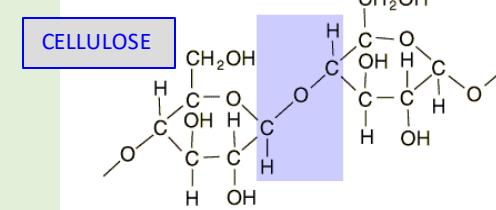
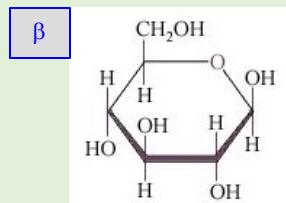
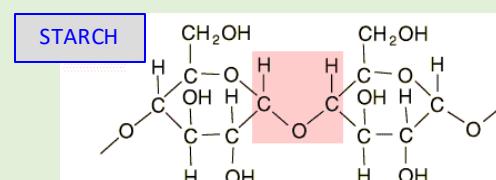
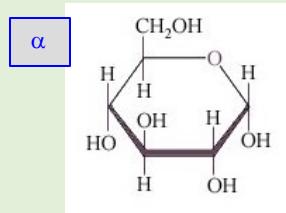
GENERAL ASPECTS and PROPERTIES

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





ENERGY STORED INTO C
HEMICAL BONDS =



Straw
(cereals)



1

Pruning residues
(grape, olive)



Oil Seeds
(sunflower, rape)



2a

Ligno-cellulosic
(miscanthus)



Grains
(corn)



Grape skins/Olive
oil residues



7

Leaves and stems
(fresh vegetable)

Husk, dry skins
(rice)



6

Shell/fruitstones
(almond, nut)



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 (agriculture → 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) |

Wood chips
(poplar SRF)



2b

Oil Seeds
(palm, jatropa)

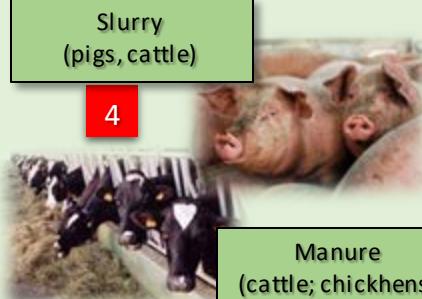


Wood logs and chips
(forestry)



3

Slurry
(pigs, cattle)



4

Manure
(cattle; chickens)

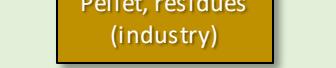


OFMSW

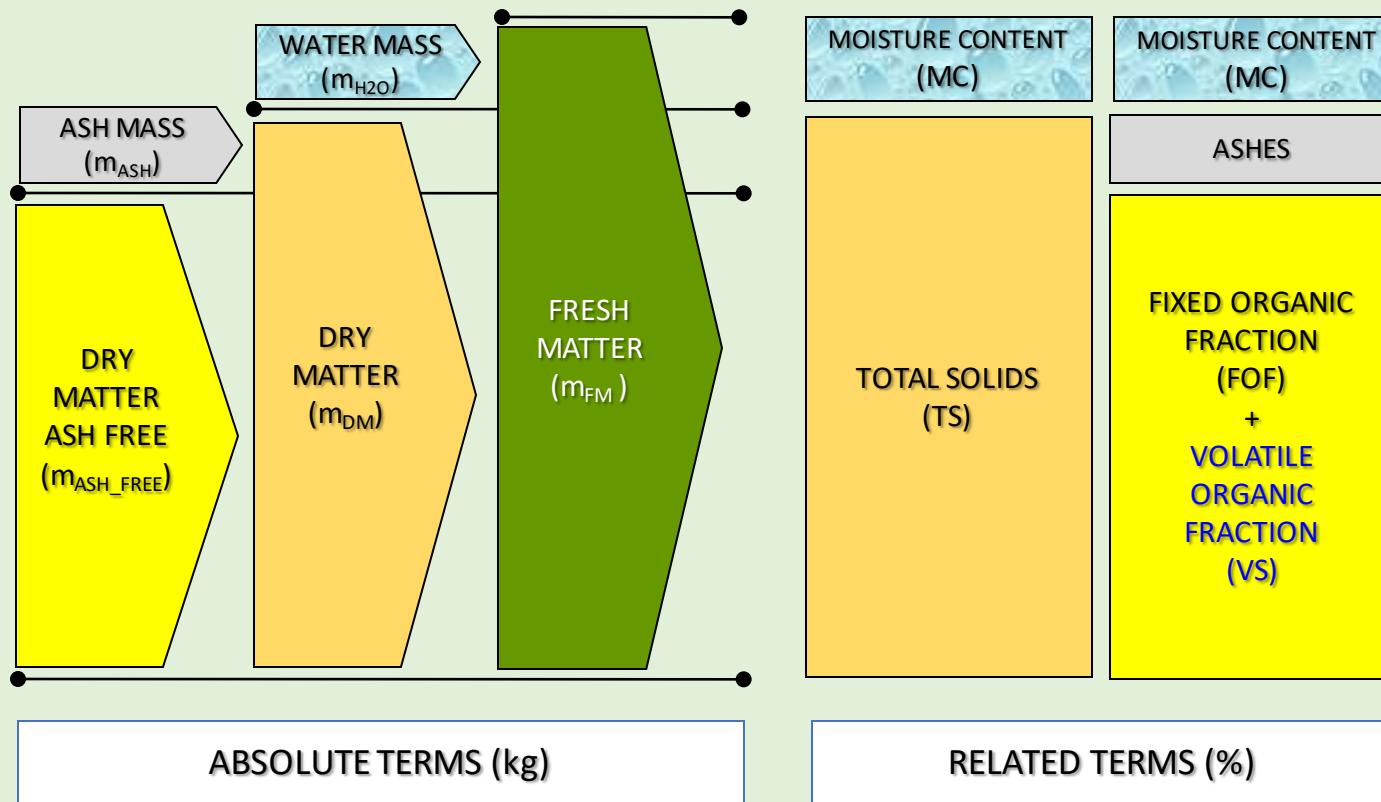


5

Pellet, residues
(industry)



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)



MOISTURE CONTENT (MC; %) → free water inside biomassMoisture 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.

$$MC = \frac{m_{H_2O}}{m_{FM}} = \frac{m_{H_2O}}{m_{DM} + m_{H_2O}}$$

$$MC_{DM} = \frac{m_{H_2O}}{m_{DM}} = \frac{MC}{1 - MC}$$

EXAMPLE: a fresh wood mass of $m_{FM} = 2.3 \text{ kg}$ 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, respectively:

$$m_{H_2O} = m_{FM} * MC = 2.3 * 0.45 = 1.035 \text{ kg}$$

$$MC_{DM} = \frac{m_{H_2O}}{m_{DM}} = \frac{1.035}{1.265} = 0,818 = 81,8\%$$

$$m_{DM} = m_{FM} - m_{H_2O} = 2.3 - 1.035 = 1,265 \text{ kg}$$

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

CARBON-NITROGEN RATIO (C/N; -)

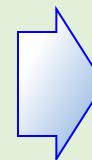
Ratio between carbon and nitrogen content of biomass dry mass (range: from 20-30 to 100-120)

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).

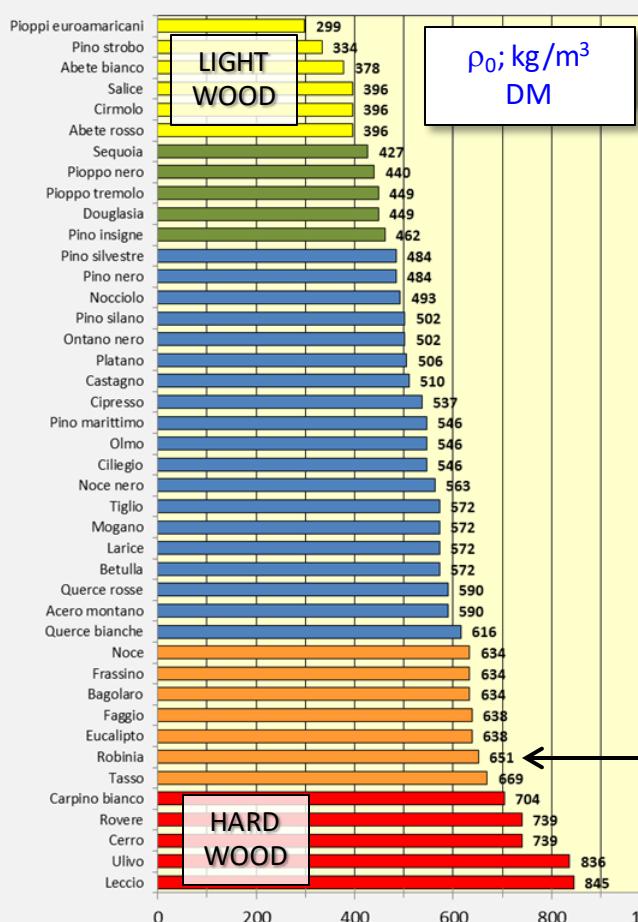
It depends on moisture content: the greater the MC, the higher the ρ_{MC} , (\rightarrow increase of both the fresh mass and – slightly - the volume). Until full water absorption, the mass grows proportionally to MC, while the volume can be considered practically constant $\rightarrow \rho_{MC}$ must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

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



$$\rho_{MC} = \frac{m_{FM}}{V_b}$$

$$\rho_{MC} = \frac{\rho_0}{(1 - MC)}$$



EXAMPLE: the dry biomass density of **robinia** wood is $\rho_0 = 650$ kg/m³ DM. At the time of cutting its moisture content is **MC = 45%**. Consequently, the density is:

$$\rho_{MC} = \frac{\rho_0}{(1-MC)} = \frac{650}{(1-0.45)} = 1182 \text{ kg/m}^3$$

BULK DENSITY (γ_{MC} ; kg/m³ FM)

Mass (m_{FM} ; kg FM) contained in the unit of volume also considering the empty spaces (V_a ; m³) .

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

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 | DIMENSIONS |
|--|---------------------------------------|--------------------------------------|---|
| | | kg/m ³ FM | V = volume; \emptyset = 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 | 800-900 (piled) | $\emptyset < 25$ mm |
| Briquettes | Extrusion process | 190-340 (piled) | $\emptyset > 25$ 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/cerealshusk | 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) | - |

GROSS HEATING VALUE (GHV; J/kg DM; kcal/kg DM; kcal/m³_N)

Thermal Energy developed from complete combustion of:

- 1 kg liquid or solid fuel
- 1 m³_N gaseous fuel (**normal** cubic meter → p = 1 bar, T = 0 °C) or 1 m³_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



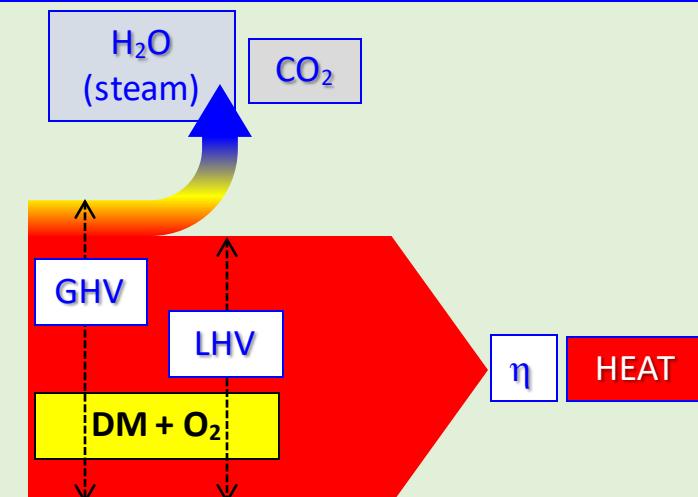
$$\text{GHV} = 0,35 \cdot [C] + 1,18 \cdot [H] + 0,10 \cdot [S] - 0,02 \cdot [N] - 0,10 \cdot [O] - 0,02 \cdot [\text{Ash}] \text{ (MJ/kg)}$$



LOWER HEATING VALUE (LHV; J/kg DM; kcal/kg DM; kcal/m³_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 |



NET HEATING VALUE (NHV; J/kg FM; kcal/kg FM; kcal/m³_N)

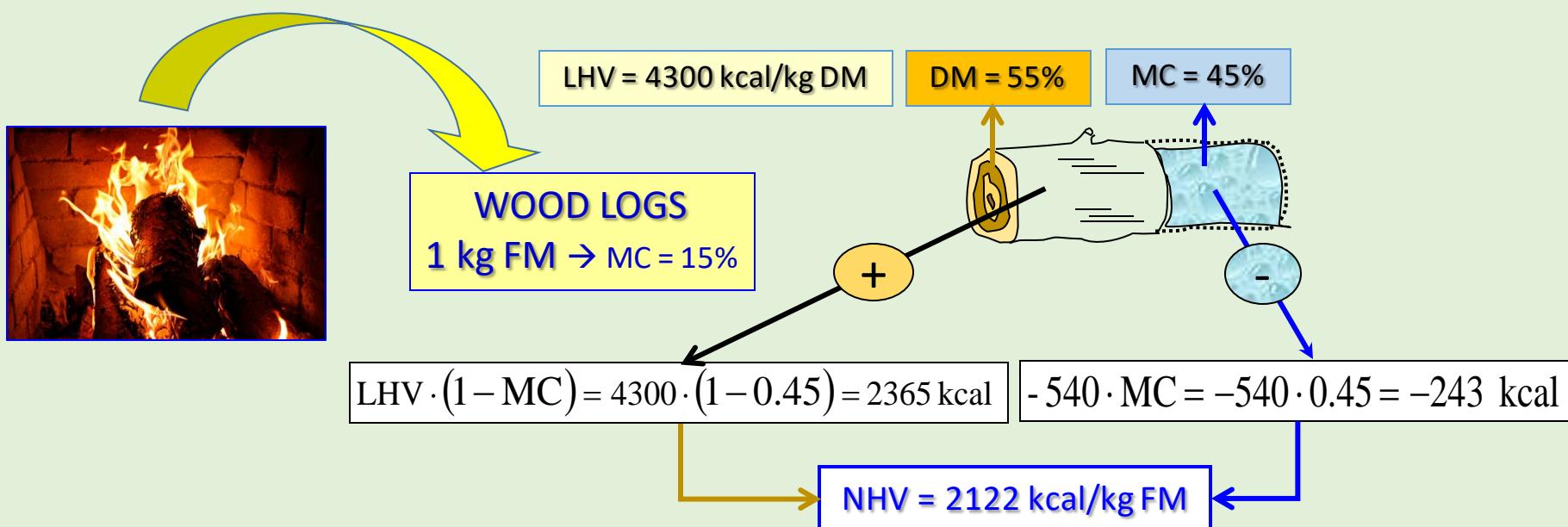
LHV to which is removed the heat necessary to evaporate the free water (m_{H_2O}) inside biomass. Practically, NHV is heat recoverable from the fresh biomass, releasing combustion smokes into the atmosphere.

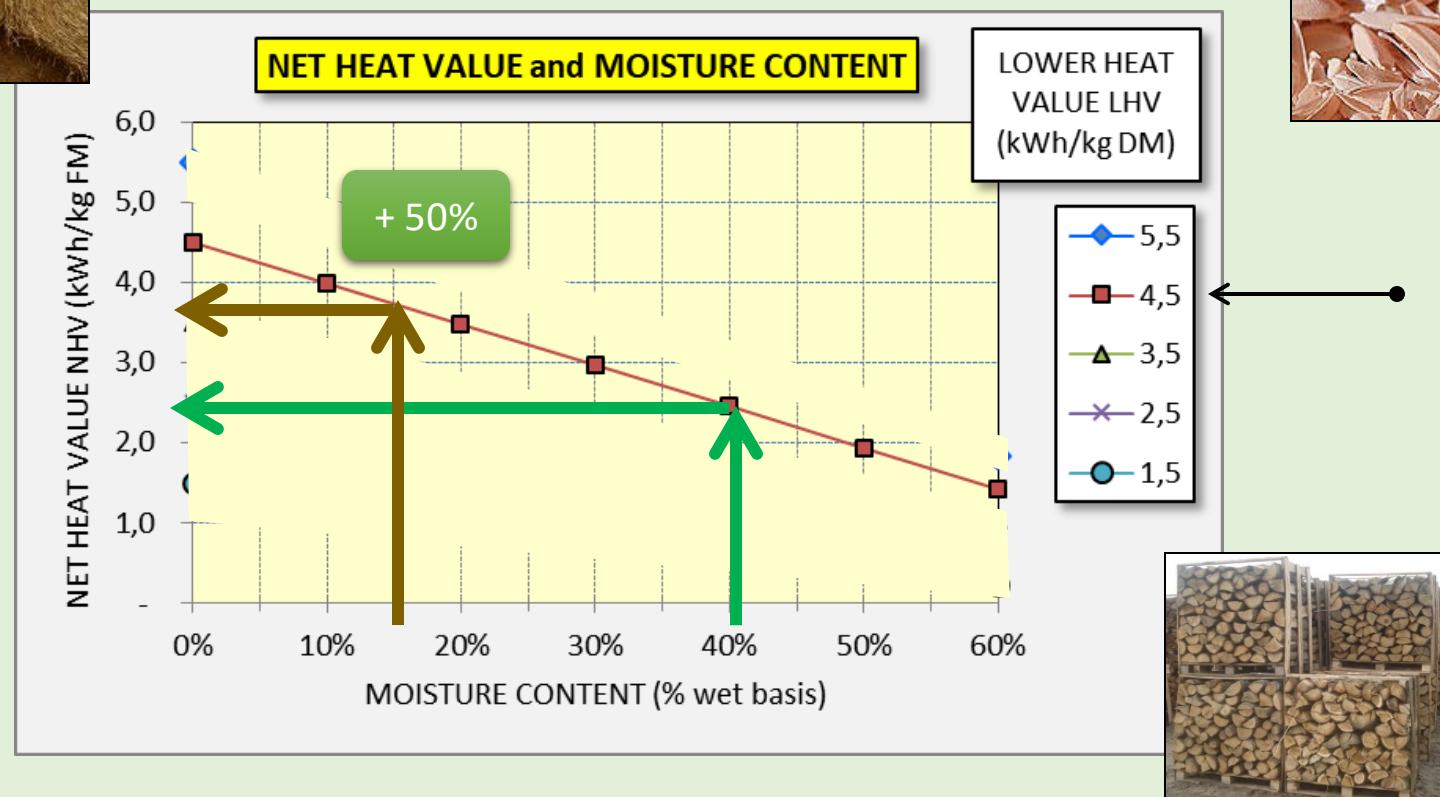
$$NHW = LHV \cdot (1 - MC) - c_{EV} \cdot MC$$

c_{EV} = heat of H_2O vaporization

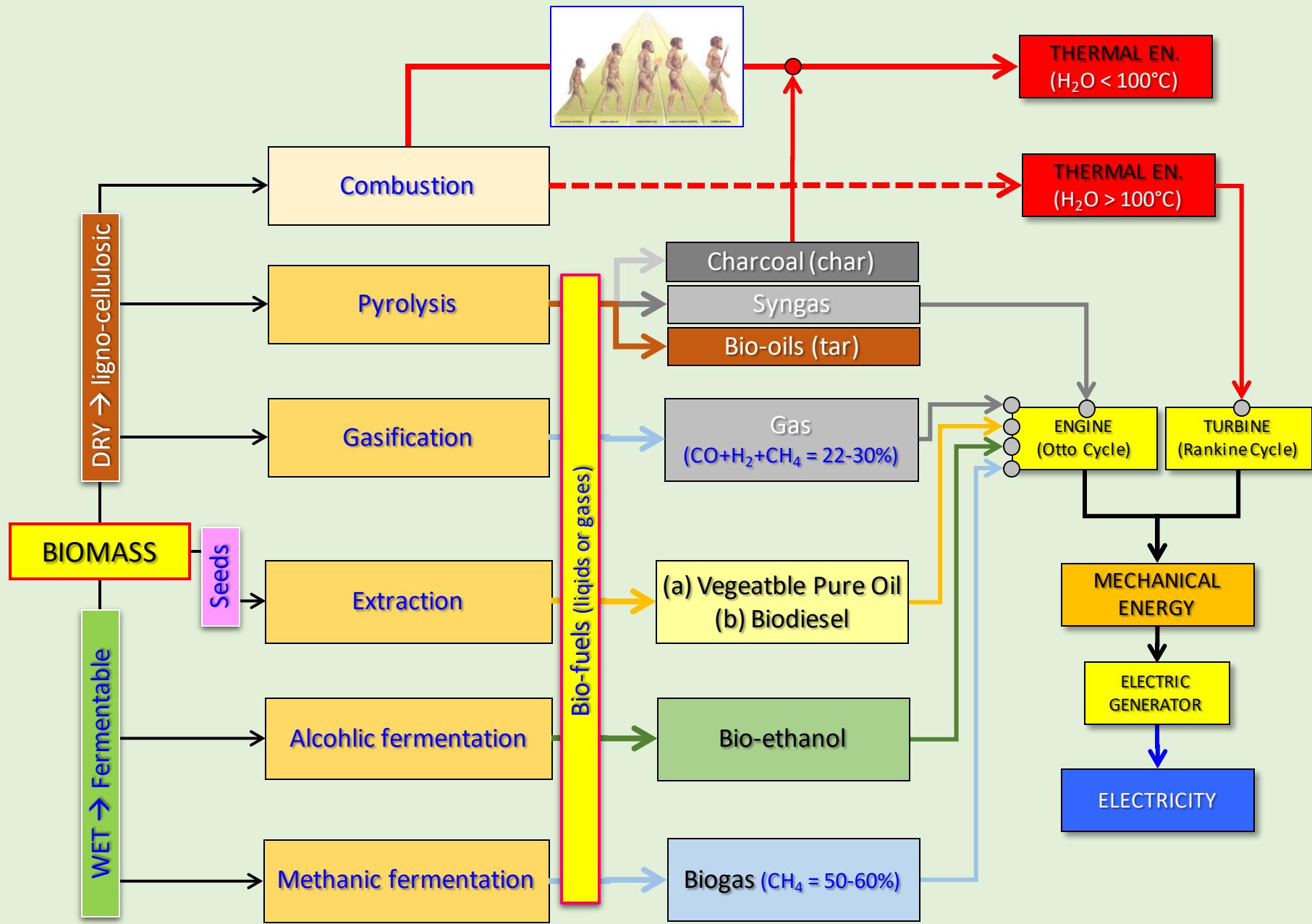
$$2261 \text{ kJ/kg } H_2O = 540 \text{ kcal/kJ } H_2O = 0,628 \text{ kWh/kJ } H_2O$$

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:





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

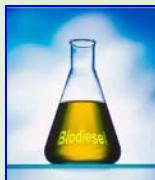


LIGNOCELLULOSIC BIOMASS



$\cong 2,0-2,5 \text{ kg FM}$

BIO-FUELS



Bio-diesel: $1,2 \text{ kg} \cong 1,3 \text{ Liters}$



Bio-ethanol: $1,6 \text{ kg} \cong 1,9 \text{ Liters}$



Biogas: $2,1 \text{ kg} \cong 1,7 \text{ m}^3_N$



$1 \text{ kg}_{oe} = 10000 \text{ kcal}$



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% DM; 3000 kcal/kg DM); **Lignin** (20-30% DM, 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** ($T < 1000^\circ C$)



Combustion



Gassification



Gas cleaning

Carbonization



Low efficiency
Deforestation



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: $500\text{-}700 \text{ m}^3_{\text{N}}/\text{t SV}$

$\text{CH}_4 = 55\text{-}65\%$ vol. → LHV biogas = $5.0\text{-}6.2 \text{ kWh/m}^3_{\text{N}}$

**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: $300\text{-}550 \text{ m}^3_{\text{N}}/\text{t SV}$;

$\text{CH}_4 = 50\text{-}65\%$ vol. → LHV biogas = $4.8\text{-}6.2 \text{ kWh/m}^3_{\text{N}}$



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** (*Elaeis 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** (*Helianthus annuus*), **castor** (*Ricinus communis*), **soybean** (*Glycine 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)



Soil competition

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,

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** ($T < 1000^\circ C$)

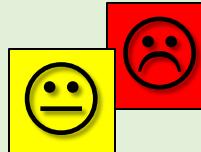


Combustion



Soil competition

Alcholic fermentation



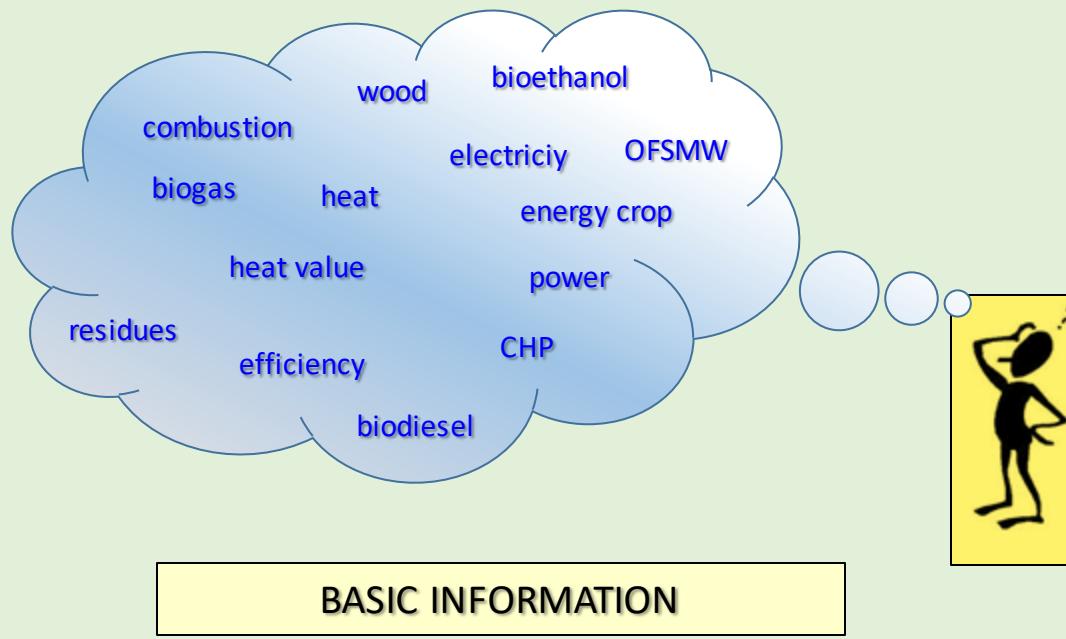
Soil competition

Type D2

ON REPORT TABLES SPECIFIC
PARAMETERS ARE INDICATED



...conclusion ?



| TYPE | C/N | MOISTURE CONTENT | CONVERSION PROCESS | ENERGY PRODUCTS |
|---|--------------------------------------|------------------|--------------------|---|
| Wood, straw, «dry» residues/waste | Thermochemical (heat) | > 30 | < 40% | Combustion Gasification Pyrolysis |
| Animal waste, «wet» residues, energy crops | Biochemical (bacteria) | < 30 | > 70% | Anaerobic Digestion Alcholic Fermentation |
| Seeds | Other (physical, chemical) | - | - | Extraction Esterification |
| | | | | Straight Vegetable Oil (SVO) Biodiesel |

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BIOMASS and BIOFULS – Part 2

Biomass-to-energy processes and plants

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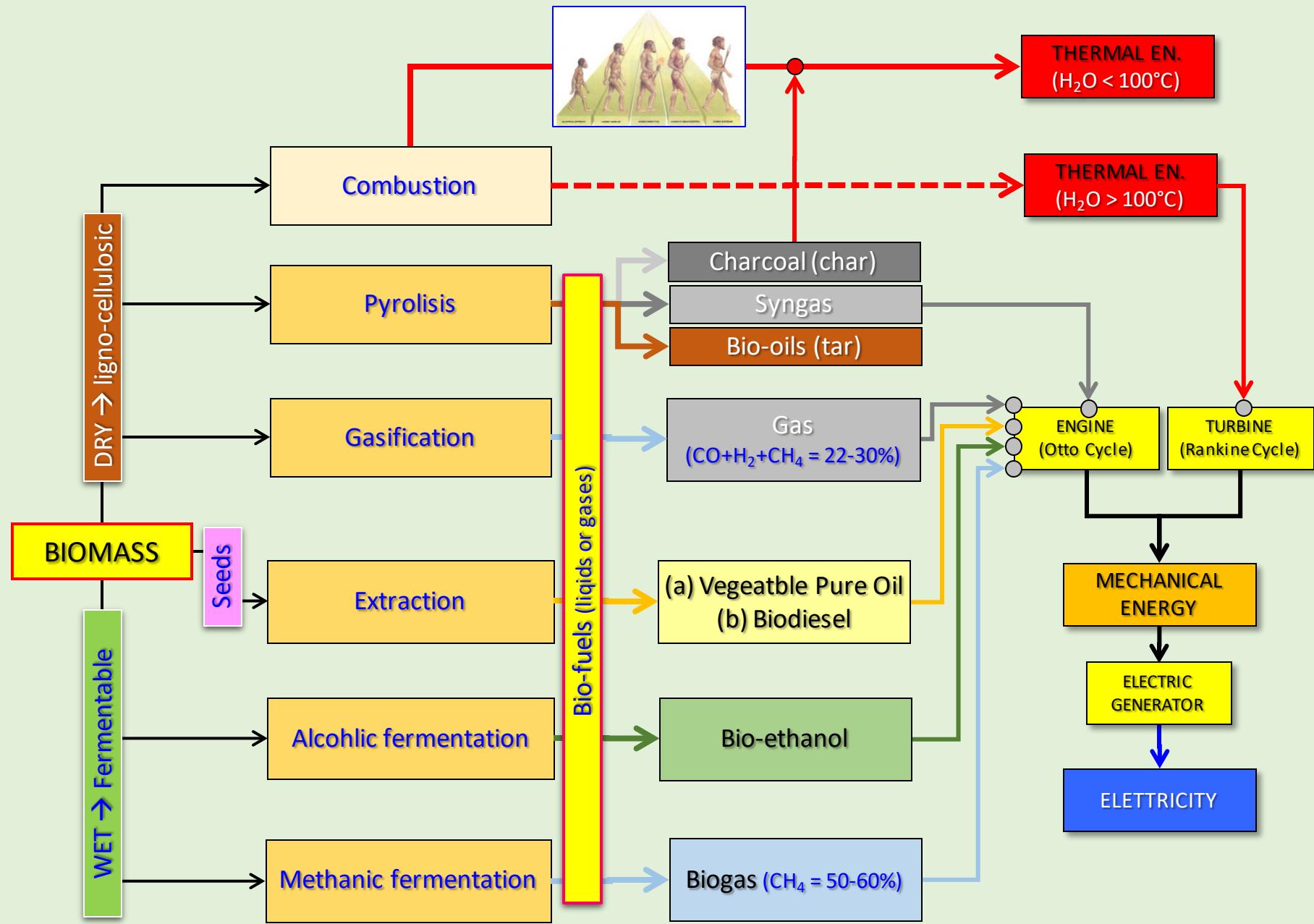
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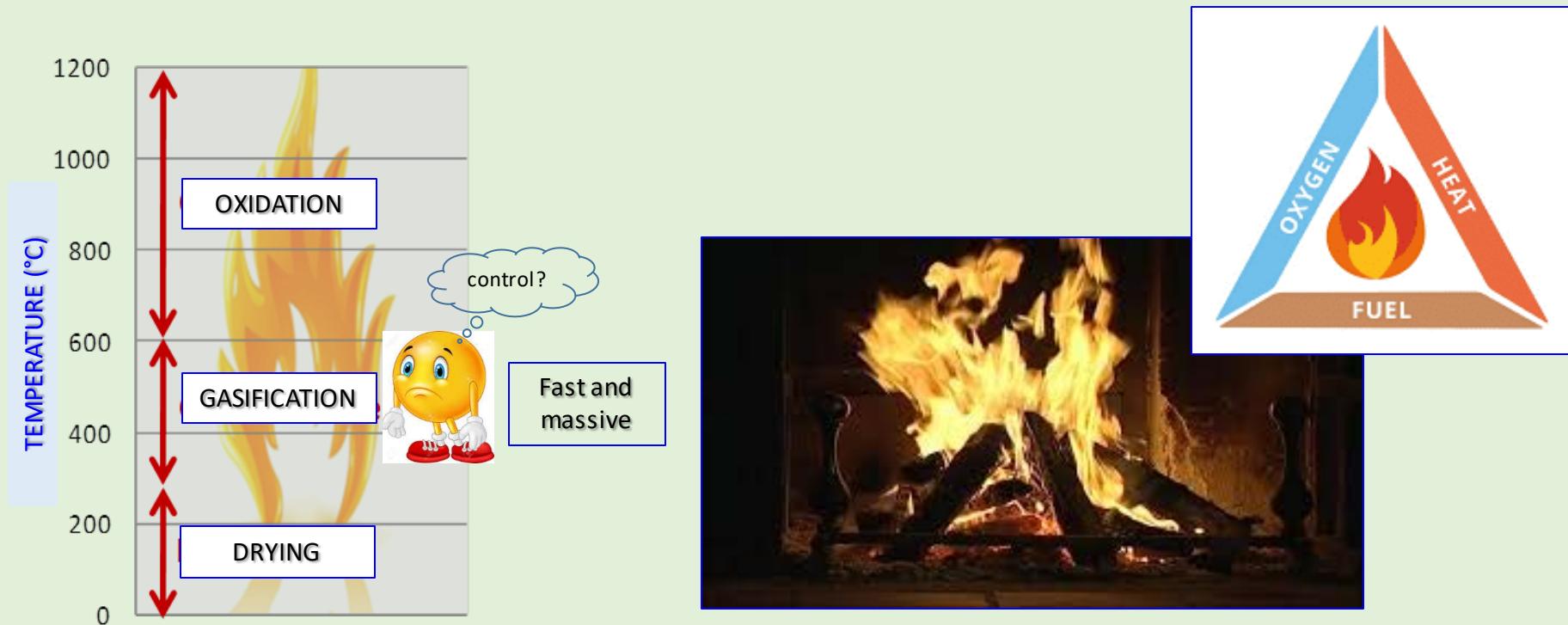


COMBUSTION → Heat (→ Mechanical energy → Electricity)

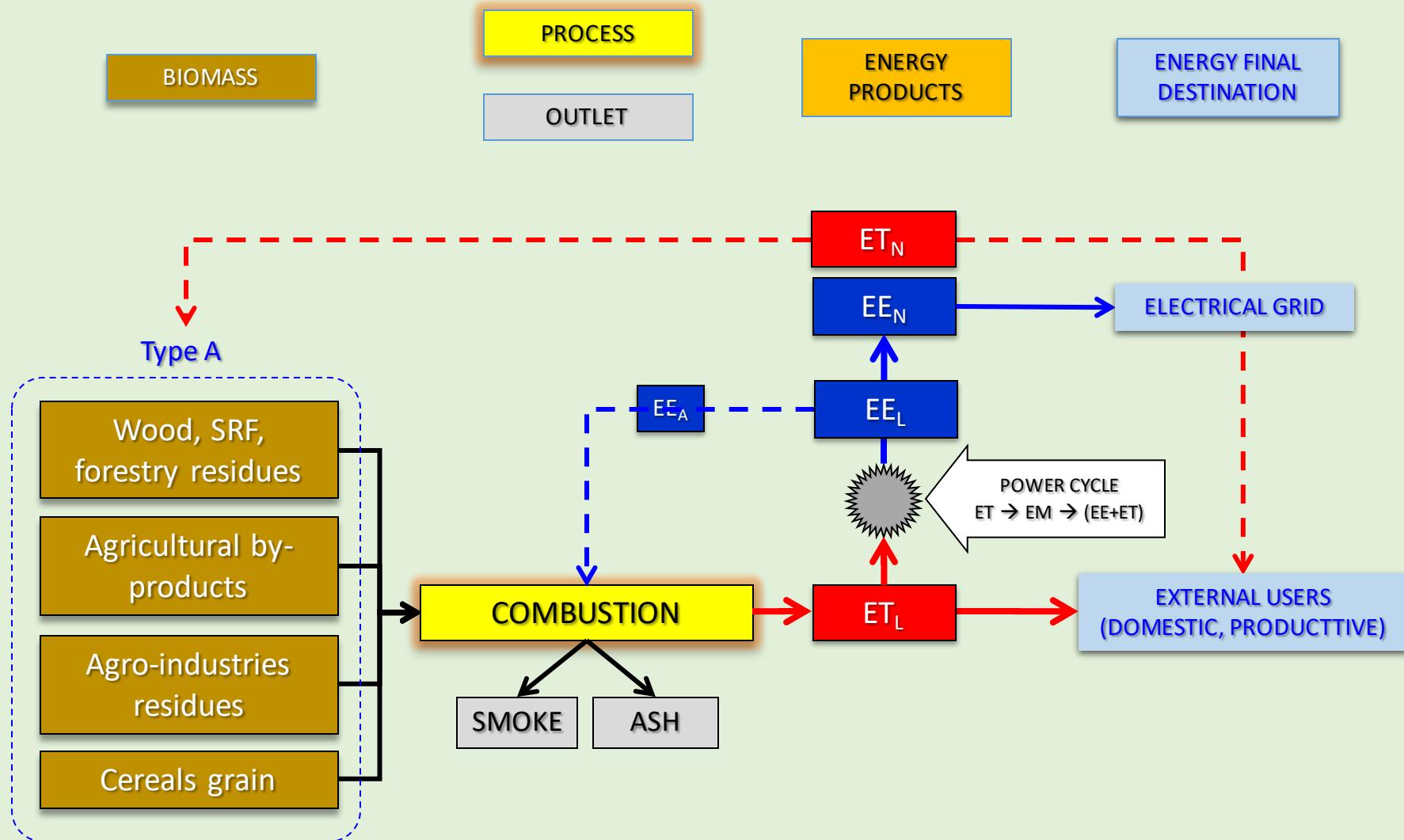
Thermochemical process → ligno-cellulosic biomass (Type A)

COMBUSTION

Sequence of chemical reactions for which - in the presence of heat (starter) – a biomass (**fuel**) combines with the oxygen (of the air) developing **Thermal Energy (ET)**. From chemical point of view, Exothermic oxide reduction in which some elements (mainly C, contained in cellulose, hemicellulose and lignin) oxidize while another (O) reduces, with release of **energy** and formation of **carbon dioxide** (CO_2) and **water** (H_2O as vapour).



The process is divided into three phases that occur in thermal devices at the same time:
Drying: water loss from biomass → Gasification: very fast emission of a **volatile fraction** (gases) and final formation of a **solid fraction** (char) → Oxidation of the gasification products, gases (flame formation) and char (without flame).



$EE_L, EE_A, EE_N =$ Gross, Self-consumed, Net Electrical Energy
 $ET_L, ET_A, ET_N =$ Gross, Self-consumed, Net Thermal Energy



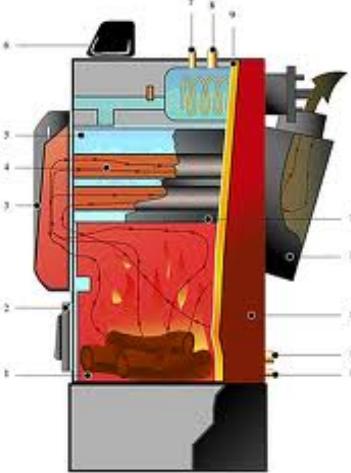
WOOD LOGS (coppice)

WOOD LOGS

300-800 kg/m³
MC = 15-20%

BASIC TECHNICAL CHARACTERISTICS

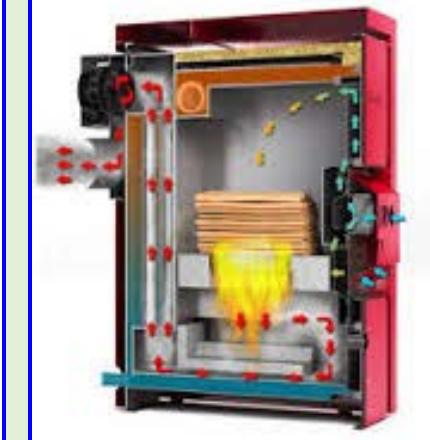
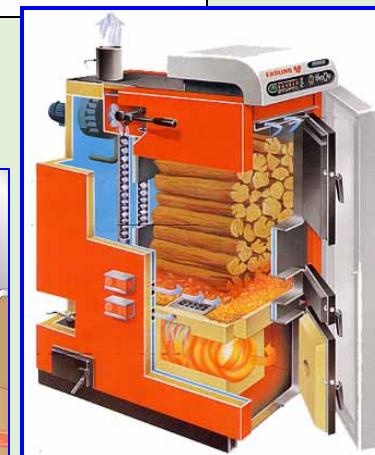
BIOMASS LOAD: manual. **GRATE:** yes (flat). **AIR SUPPLY:** 1st and 2nd fluxes, adjustable, natural draft or fan. **ASH REMOVAL:** manual. **HEAT STORAGE:** recommended (puffer; 800-1000 lt). **COMBUSTION TYPE:** rising or reverse. **THERMAL EFFICIENCY:** 60-65% or 85-95% (rising or reverse combustion, respectively). **ENERGY USE:** heat home requirements. **THERMAL FLUID:** water. **PLANT INTEGRATION:** possible (solar collectors).

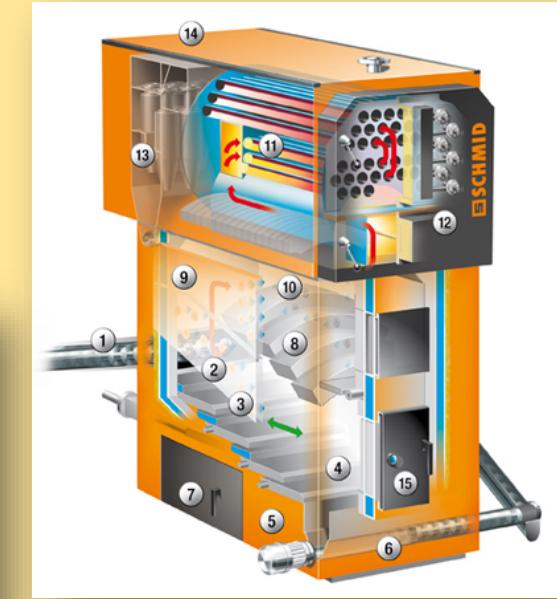
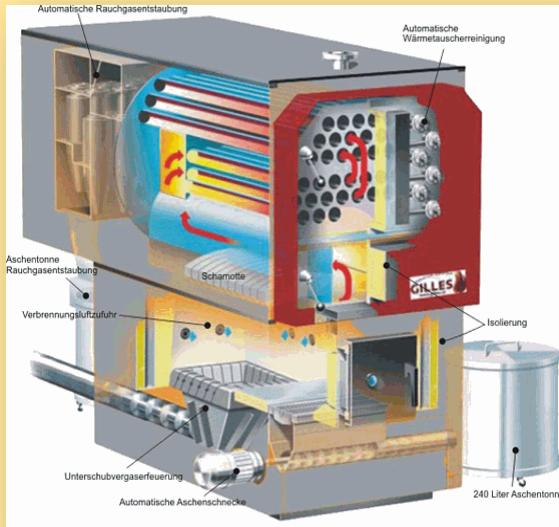


RISING COMBUSTION



REVERSE COMBUSTION





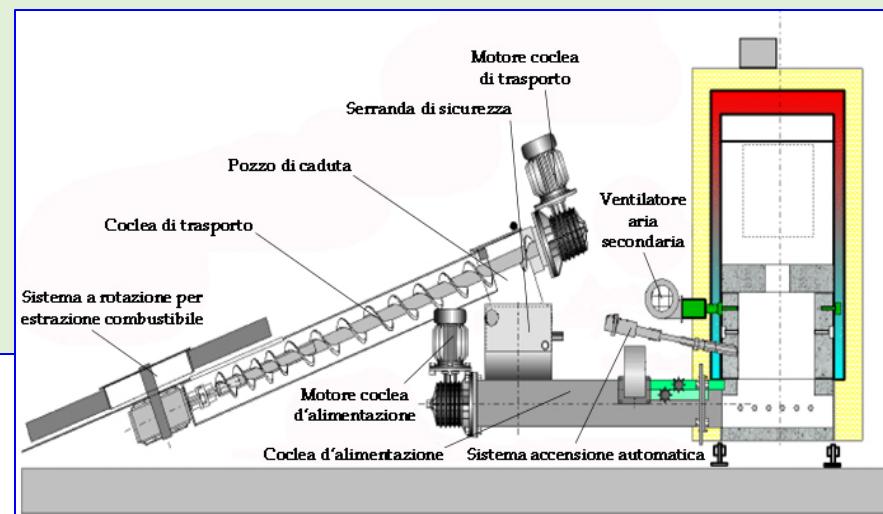
CHIPPED WOOD (coppice/tall trees, SRC, wood residues)

WOOD CHIPS

250-350 kg/m³
MC = 25-40%

BASIC TECHNICAL CHARACTERISTICS

BIOMASS LOAD: mechanical (screw). **GRATE:** no. **AIR SUPPLY:** 1st and 2nd fluxes, adjustable, fan. **ASH REMOVAL:** manual or mechanical. **HEAT STORAGE:** recommended (puffer; 1000-2000 lt). **COMBUSTION TYPE:** rising. **THERMAL EFFICIENCY:** 75-85%. **ENERGY USE:** heat home requirements. **THERMAL FLUID:** water. **PLANT INTEGRATION:** possible (solar collectors).



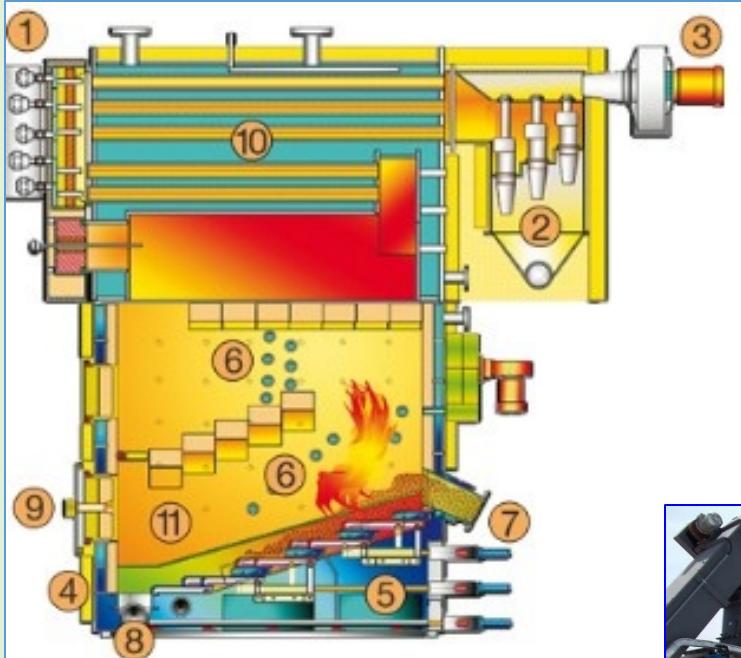
WOOD CHIPS



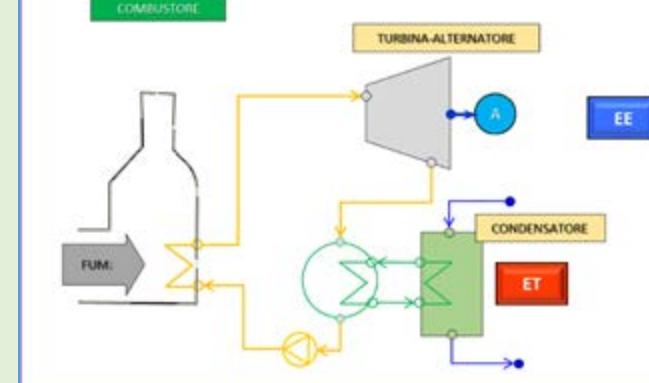
250-350 kg/m³
MC = 25-40%

BASIC TECHNICAL CHARACTERISTICS

BIOMASS LOAD: mechanical (screw, hydraulic piston). **GRATE:** yes (fix or inclined and mobile). **AIR SUPPLY:** 1st and 2nd fluxes, adjustable, fans. **ASH REMOVAL:** mechanical (screw). **HEAT STORAGE:** yes. **COMBUSTION TYPE:** rising. **THERMAL EFFICIENCY:** 75-85%. **ENERGY USE:** industrial requirements, heating districts, electricity/heat generation. **THERMAL FLUID:** water (T = 90-95 °C), steam, diathermic oil. **PLANT INTEGRATION:** no.



RANKINE CYCLE → Electricity





PELLET

PELLETS



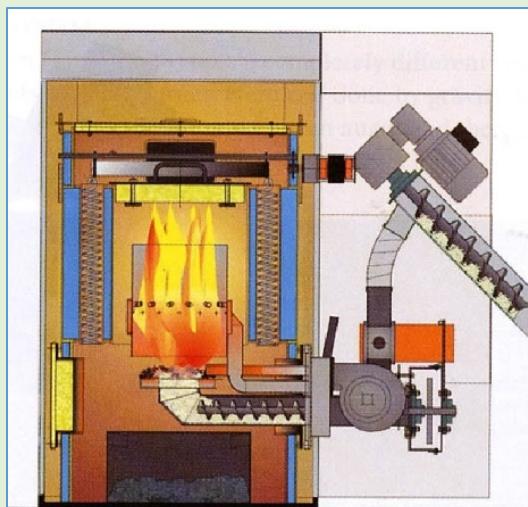
750-850 kg/m³
MC = 10-12%

BASIC TECHNICAL CHARACTERISTICS

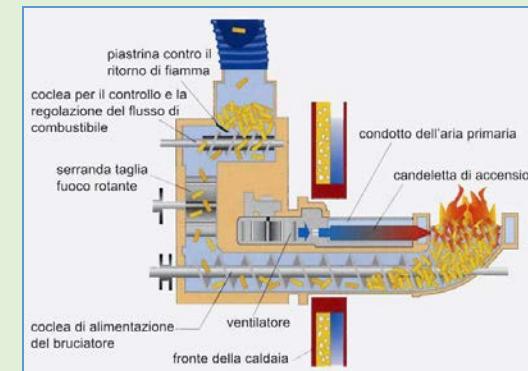
BIOMASS LOAD: semi-manual (bags) or mechanical (screw + hopper). **GRATE:** no. **AIR SUPPLY:** 1st and 2nd fluxes, adjustable, fan. **ASH REMOVAL:** manual. **HEAT STORAGE:** recommended (puffer; 800-1000 lt). **COMBUSTION TYPE:** rising. **THERMAL EFFICIENCY:** 75-85%. **ENERGY USE:** heat home requirements. **THERMAL FLUID:** water. **PLANT INTEGRATION:** possible (solar collectors).



SEMI-MANUAL LOAD



MECHANICAL LOAD





CORN GRAIN



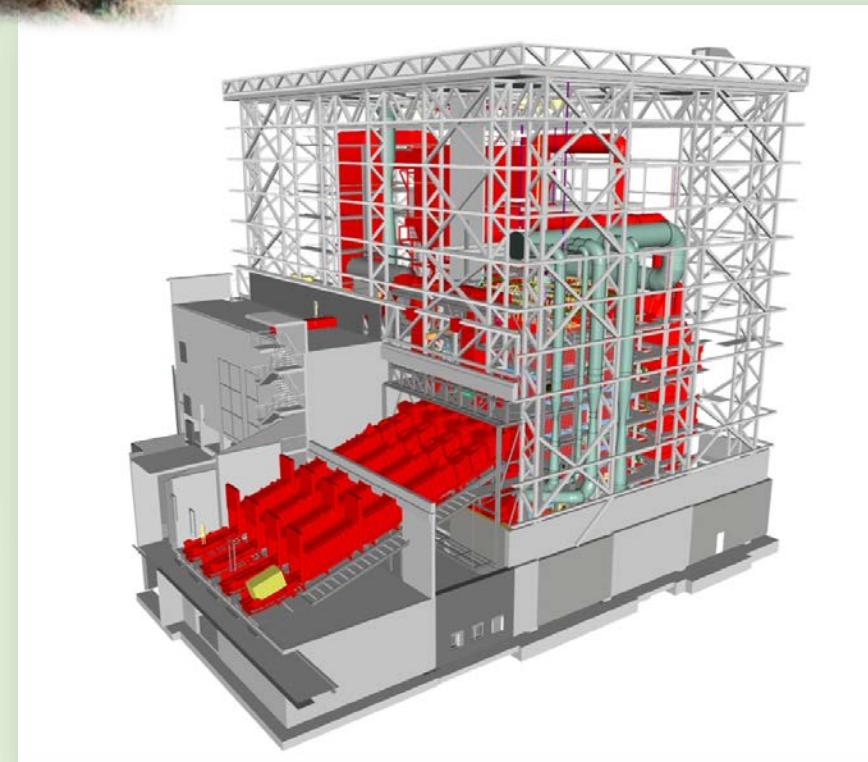
CEREALS GRAIN (corn)

800-850 kg/m³
MC = 25-30%

BASIC TECHNICAL CHARACTERISTICS

BIOMASS LOAD: mechanical (hopper + screw). **GRATE:** no. **AIR SUPPLY:** 1st and 2nd fluxes, adjustable, fan. **ASH REMOVAL:** manual. **HEAT STORAGE:** recommended (puffer; 800-1000 lt). **COMBUSTION TYPE:** rising. **THERMAL EFFICIENCY:** 75-85%. **ENERGY USE:** heat home requirements. **THERMAL FLUID:** water. **PLANT INTEGRATION:** possible (solar collectors). **OPERATING PROBLEMS:** low melting ash, Cl ≥ 1% (corrosion); high level particulate (PM₁₀).





AGRICULTURAL BY-PRODUCTS → STRAW

CEREALS BALED STRAW

120-220 kg/m³
MC = 12-15%

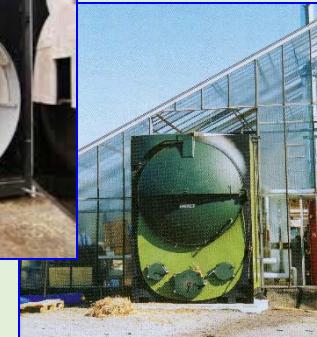
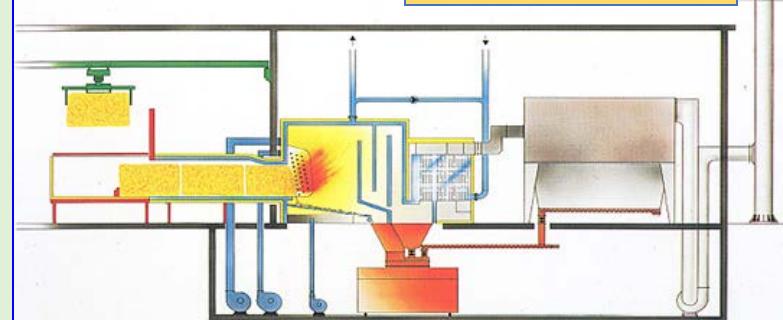
BASIC TECHNICAL CHARACTERISTICS

BIOMASS LOAD: manual (lp), mechanical (hp). **GRATE:** no/yes (lp). Yes (hp), Flat or mobile. **AIR SUPPLY:** 1st and 2nd fluxes, adjustable, natural draft (lp) or fan (hp). **ASH REMOVAL:** manual (lp), mechanical (hp). **HEAT STORAGE:** yes. **COMBUSTION TYPE:** rising **THERMAL EFFICIENCY:** 50-55% (lp), 75-80% (hp). **ENERGY USE:** heat home requirements (lp), electricity/heat (hp). **THERMAL FLUID:** water (lp), steam (hp). **PLANT INTEGRATION:** no.

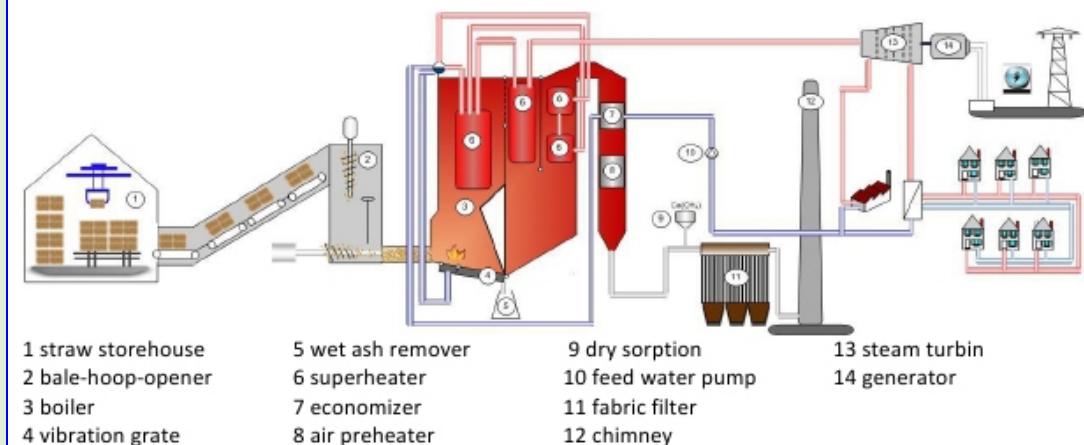
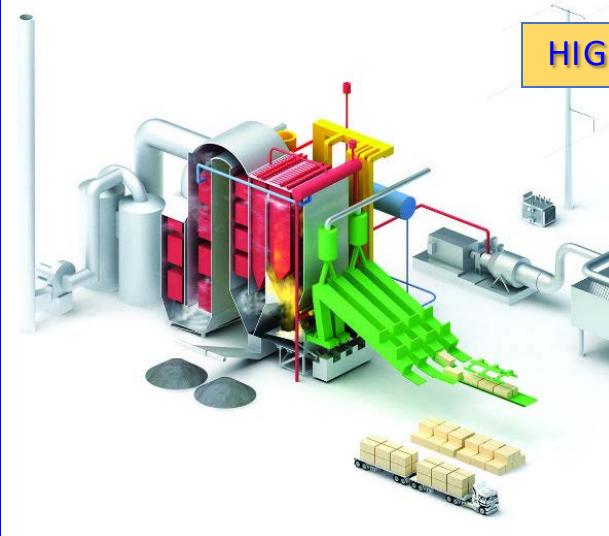
LOWPOWER (lp)



MEDIUM POWER



HIGH POWER (hp)





INDUSTRY RESIDUES (food industry; wood industry)



INDUSTRIAL RESIDUES

250-400 kg/m³
MC = 25-55%

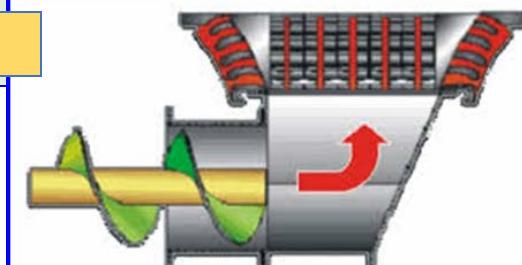
BASIC TECHNICAL CHARACTERISTICS

BIOMASS LOAD: mechanical (hopper + screw). **GRATE:** no. **AIR SUPPLY:** 1st and 2nd fluxes, adjustable, fan. **ASH REMOVAL:** mechanical. **HEAT STORAGE:** yes. **COMBUSTION TYPE:** rising. **THERMAL EFFICIENCY:** 75-85%. **ENERGY USE:** processing heat; heating district. **THERMAL FLUID:** water, steam, diathermic oil. **PLANT INTEGRATION:** -, **OPERATING PROBLEMS:** low melting ash, high level particulate (PM₁₀).



LOWPOWER

SCREW FEEDER



HIGH POWER



MEDIUM POWER





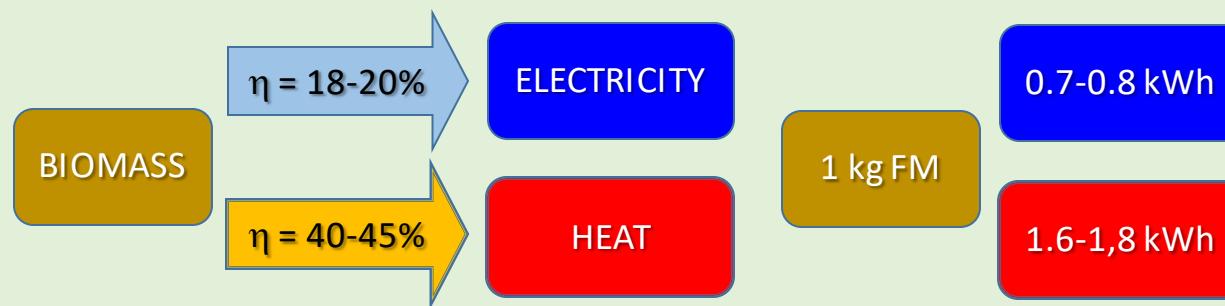
GASIFICATION → Gas → Mechanical energy → Electricity (Heat)

Thermochemical process → ligno-cellulosic biomass (Type A)

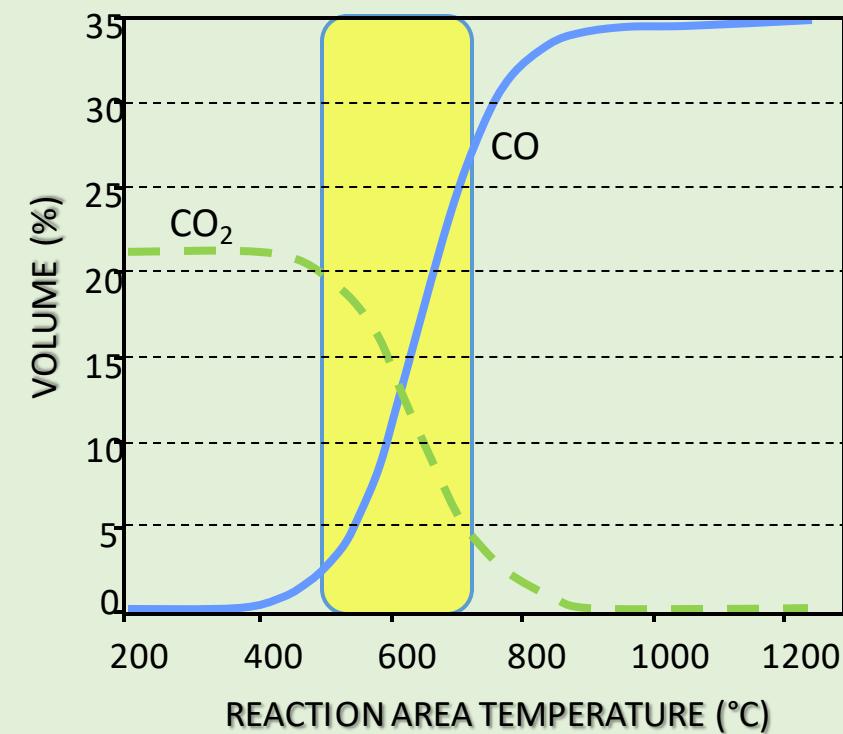
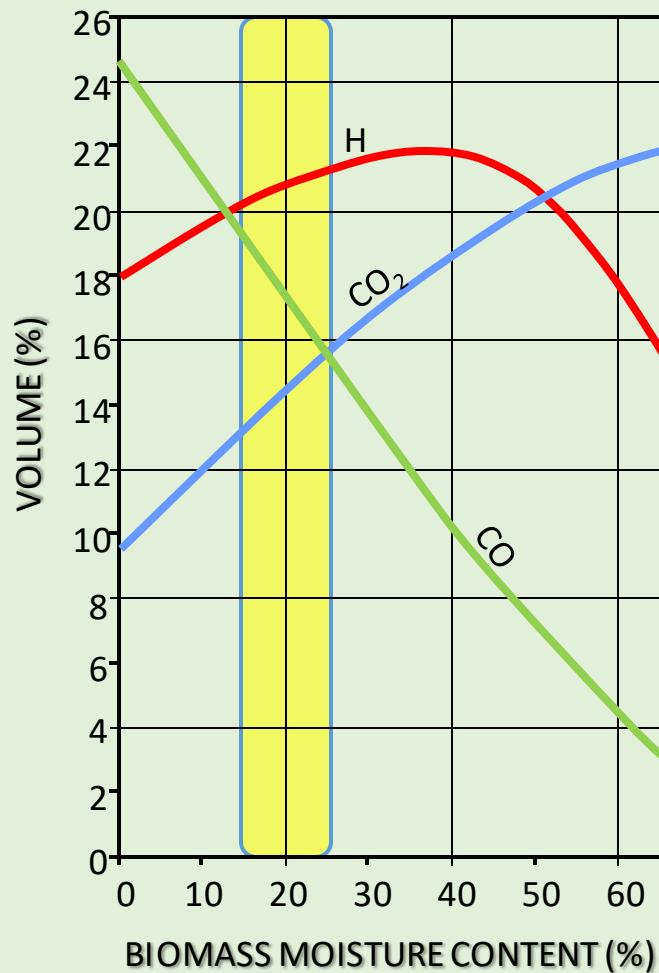
GASSIFICAZIONE

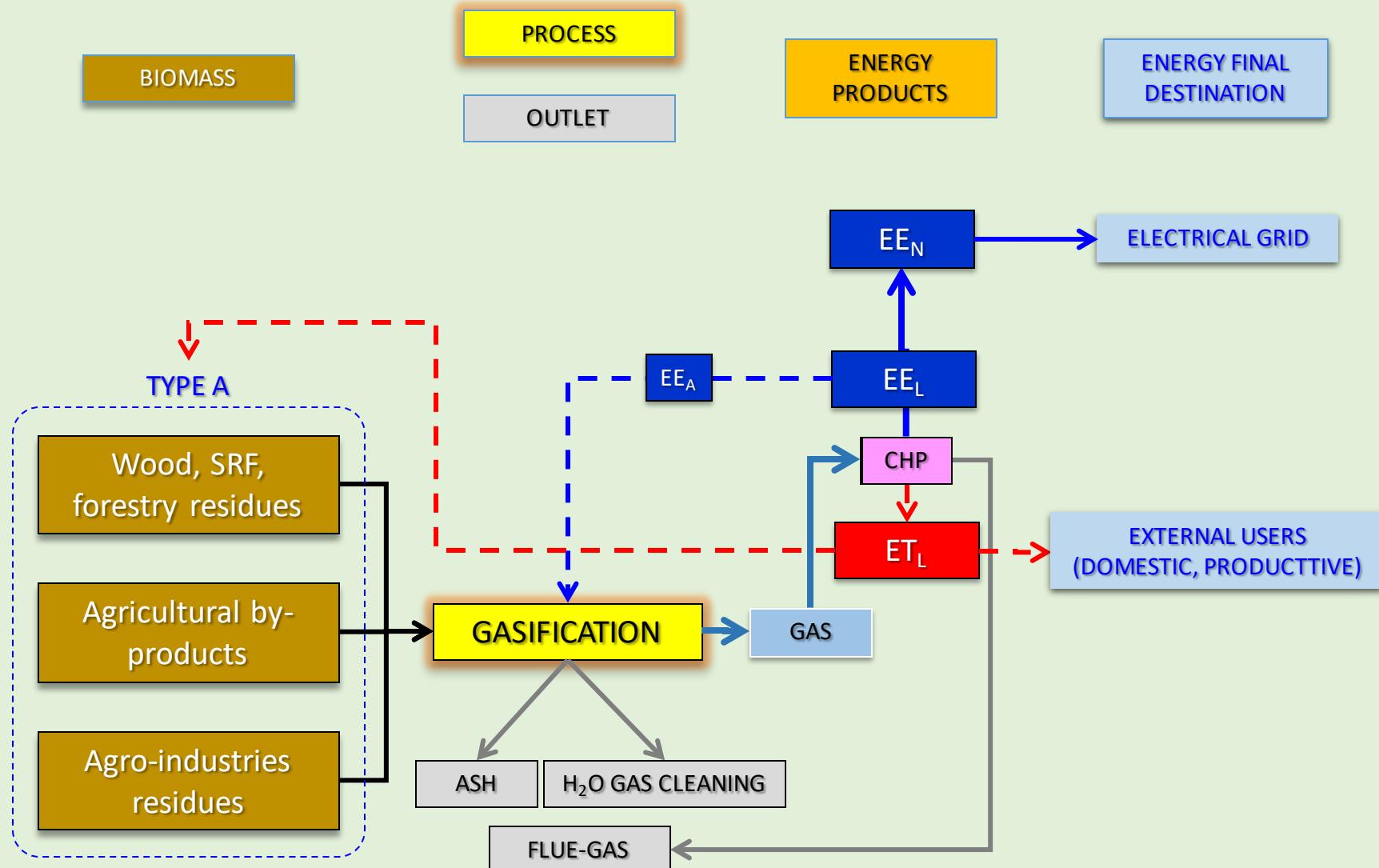
Incomplete oxidation of a substance in a high temperature environment (900÷1000 °C) for the production of a gas (gasogen gas or **producer gas**) with a low **LHV = 1.1-1.2 kWh/m³_N**. This gas is used – after a **gas cleaning action** - to supply I.C. engines, generating **mechanical energy** (EM) and, consequently, **electricity** (EE). Using a CHP unit the recovery **heat** (ET) can be used within the same process (eg: biomass drying) or for covering external requirements. Global efficiency (biomass-to-electricity) is **18-20%**.

| | AIR | OXIGEN | STEAM |
|--|---------|---------|---------|
| CO | 12-15 | 30-37 | 32-41 |
| CO ₂ | 14-17 | 25-29 | 17-19 |
| H ₂ | 9-10 | 30-34 | 24-26 |
| CH ₄ | 2-4 | 4-6 | 12,4 |
| C ₂ H ₄ | 0,2-1 | 0,7 | 2,5 |
| N ₂ | 56-59 | 2-5 | 2,5 |
| LHV (kWh/m ³ _N) | 1,0-1,3 | 2,7-2,8 | 3,3-3,6 |
| Yield (m ³ _N /kg DM) | 2,3-3,0 | 1,3-1,5 | - |



The **gas composition** varies depending on the characteristics of the biomass (**moisture content**) and the operating parameters (**temperature**) as well as the **oxidizing agent**.

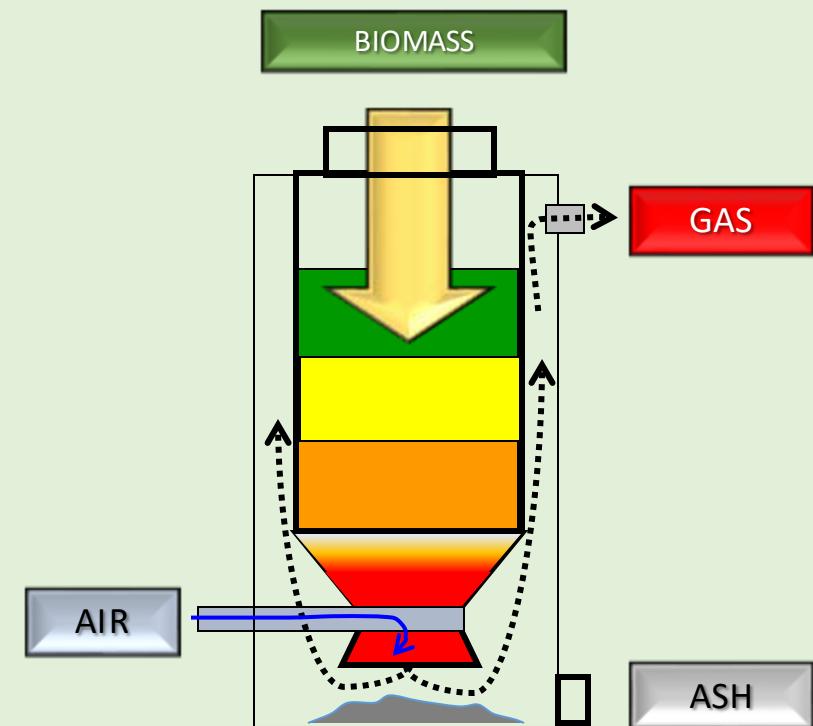
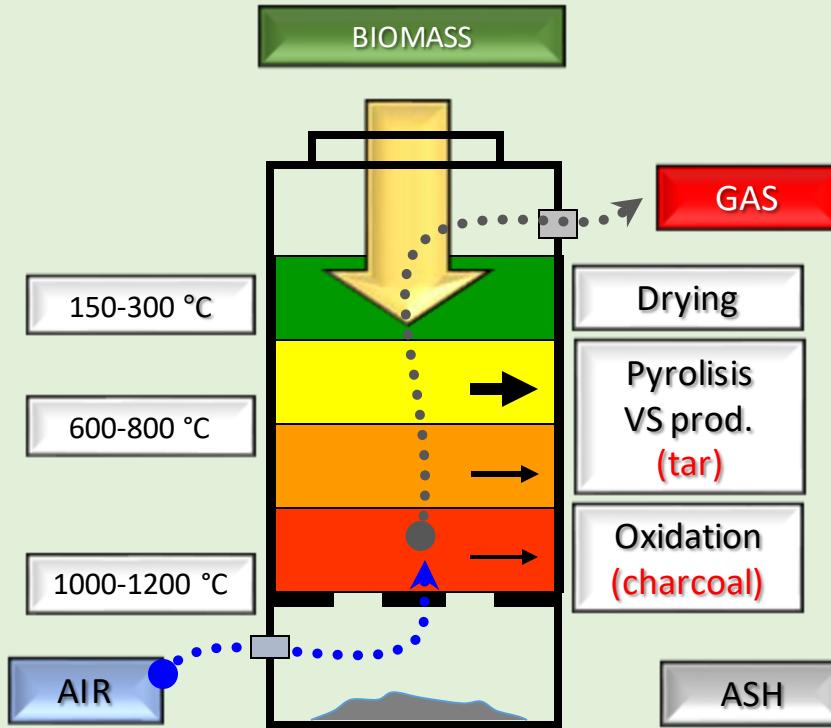




EE_L, EE_A, EE_N = Gross, Self-consumed, Net Electrical Energy
 ET_L, ET_A, ET_N = Gross, Self-consumed, Net Thermal Energy



FIXED BED GASIFIERS





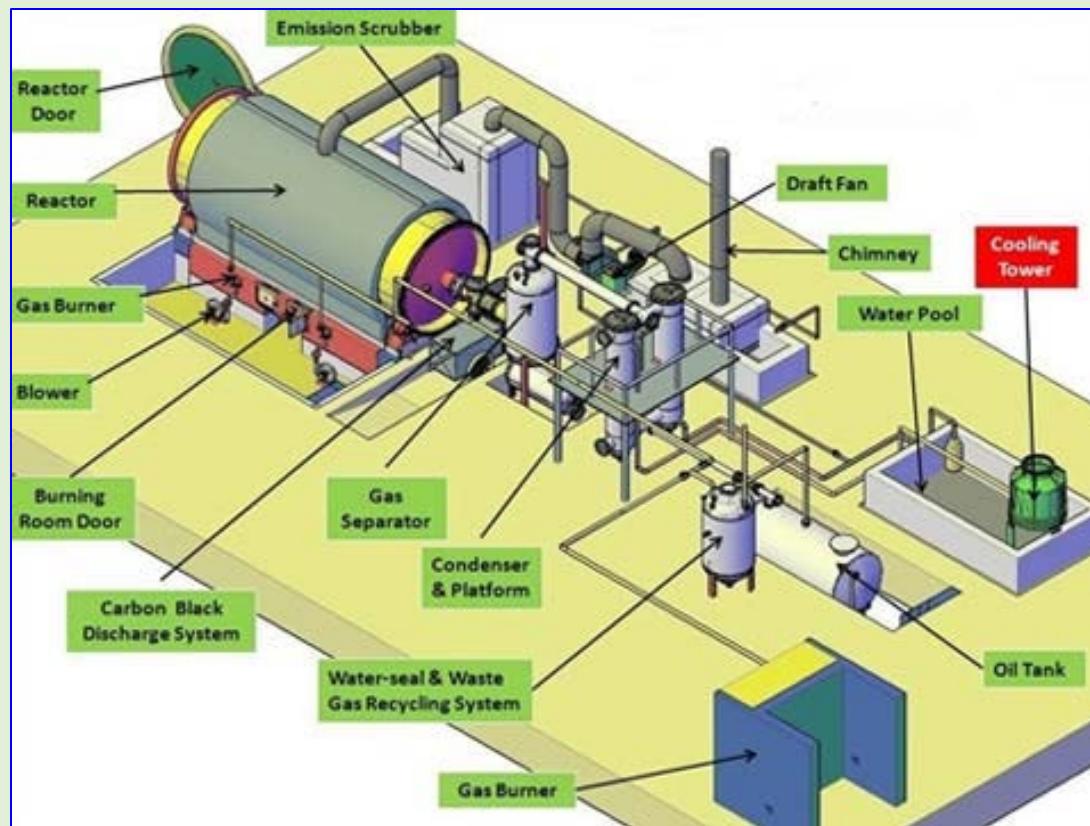
PYROLISIS → Syngas, tar, char → Mechanical Energy → Electricity (Heat)

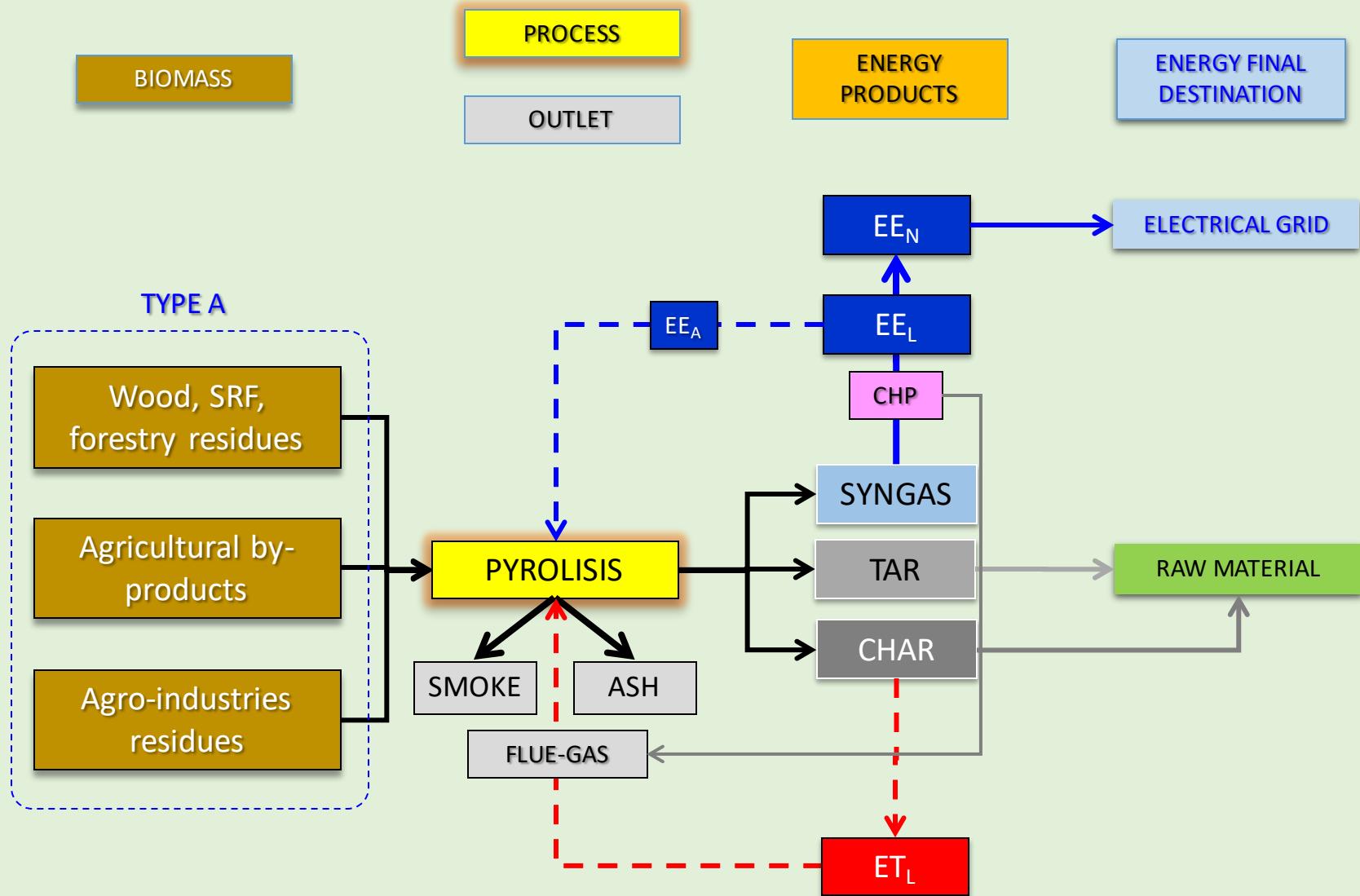
Thermochemical process → Ligno-cellulosic biomass (Type A)

PYROLYSIS

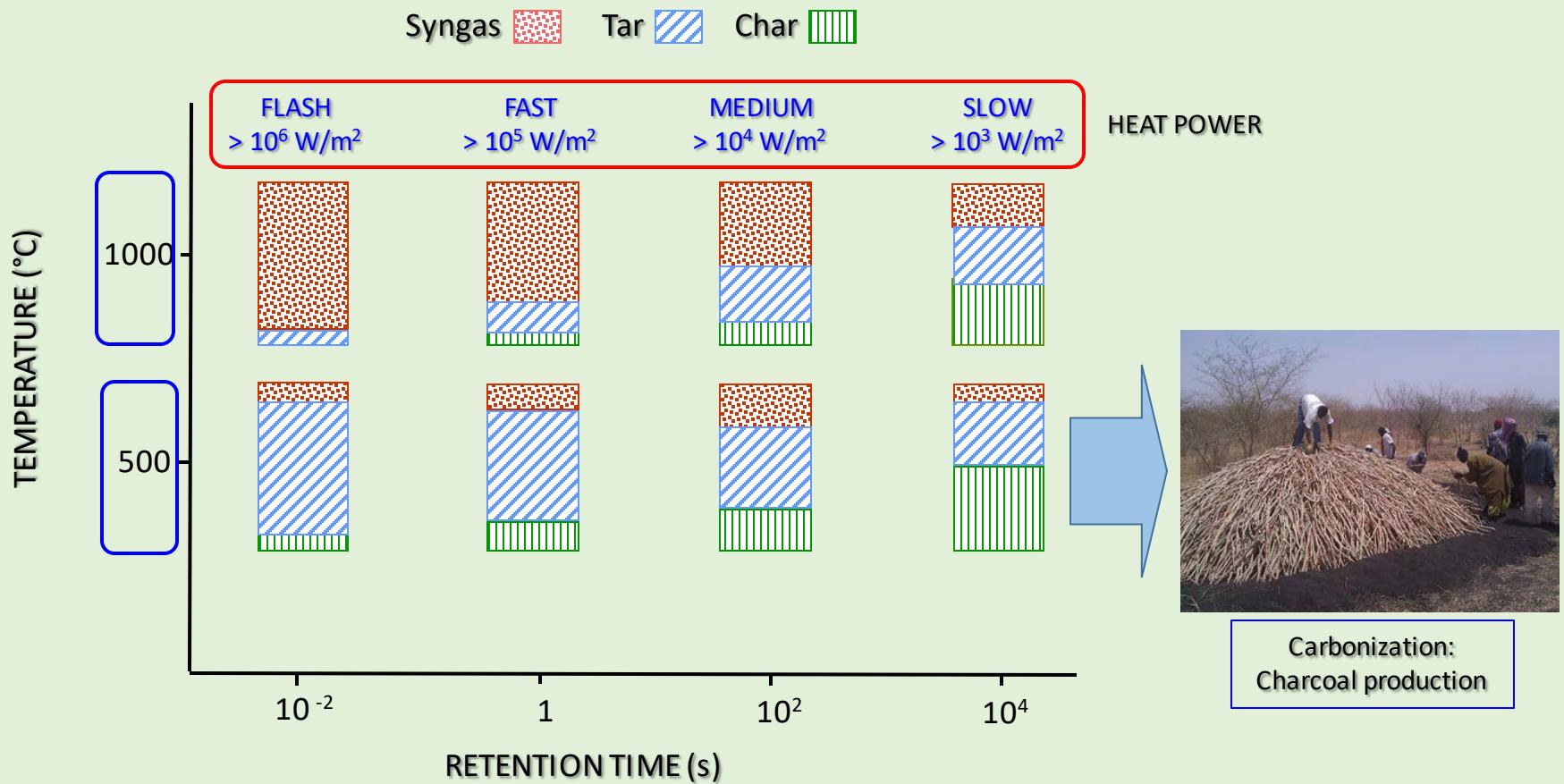
Thermal degradation in the **absence of oxidants** that occurs by providing medium-temperature heat ($400\text{--}800\text{ }^{\circ}\text{C}$) indirectly through the reactor walls, or directly by shaking a heating medium in the biomass bed and leading to the production of:

- non-condensable gases (**syngas**) which can be (i) burnt to provide heat to the pyrolysis reactor (ii) used as fuel I.C. engines, producing electricity (EE).
- condensable volatile compounds (**tar or bio-oil**), complex and variable composition liquid (heavy hydrocarbons)
- solid (**char**) compounds consisting of carbonaceous residues (similar to wood charcoal) and ashes. Char can be used as a fuel for the production of activated carbon or as intermediate in the chemical industry.





EE_L , EE_A , EE_N = Gross, Self-consumed, Net Electrical Energy
 ET_L , ET_A , ET_N = Gross, Self-consumed, Net Thermal Energy



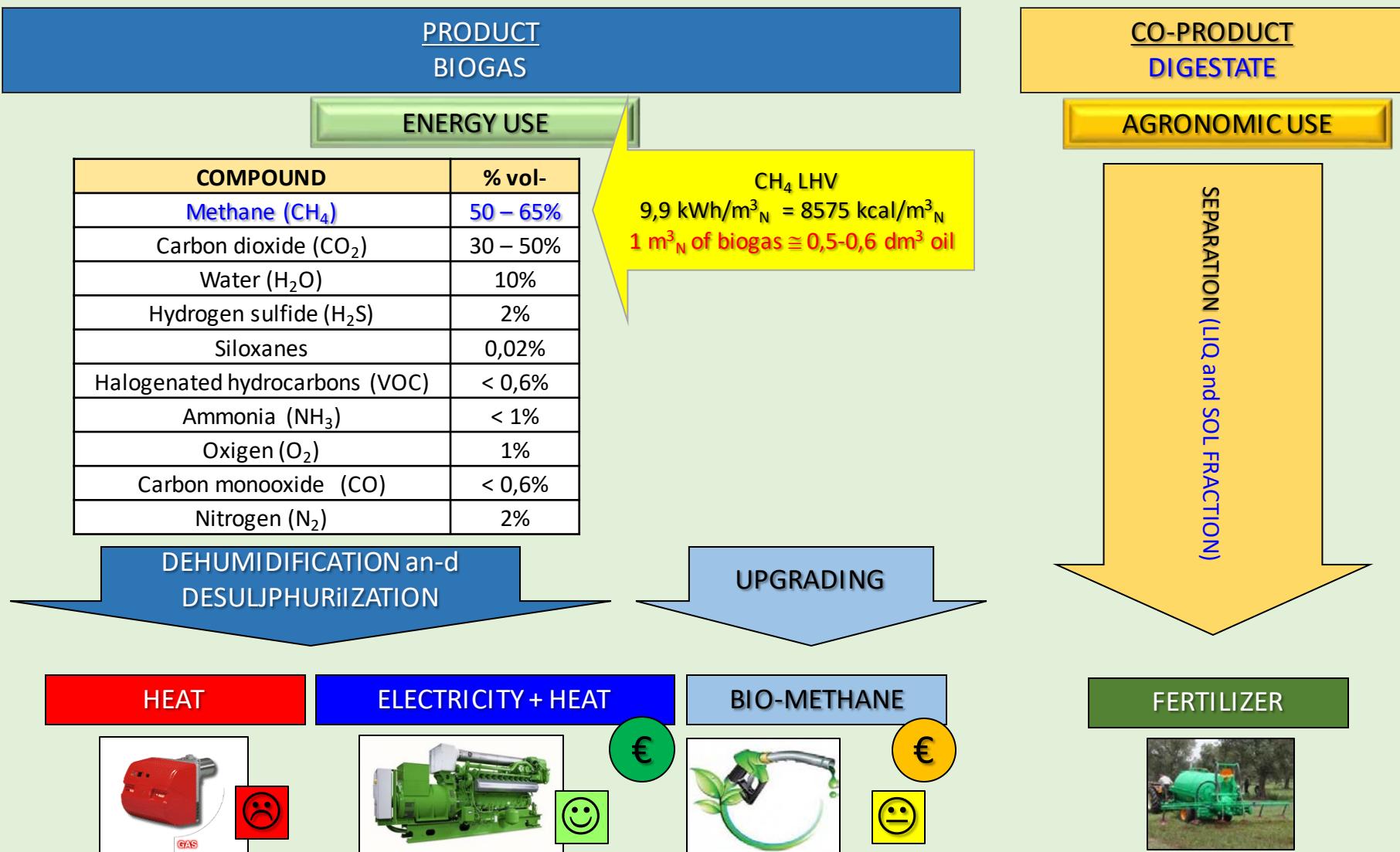


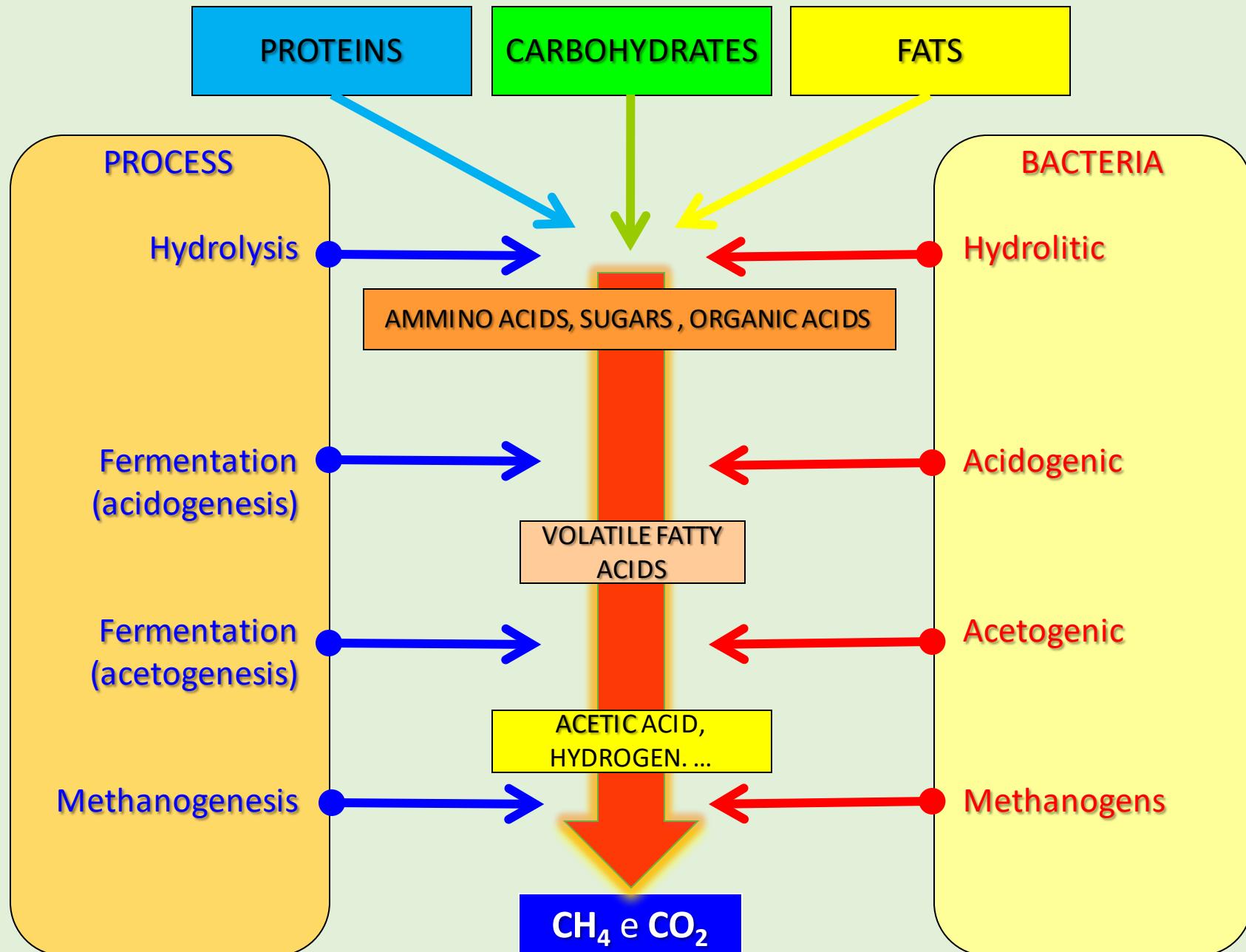
ANAEROBIC DIGESTION → Biogas → Mechanical energy → Electricity (Heat)

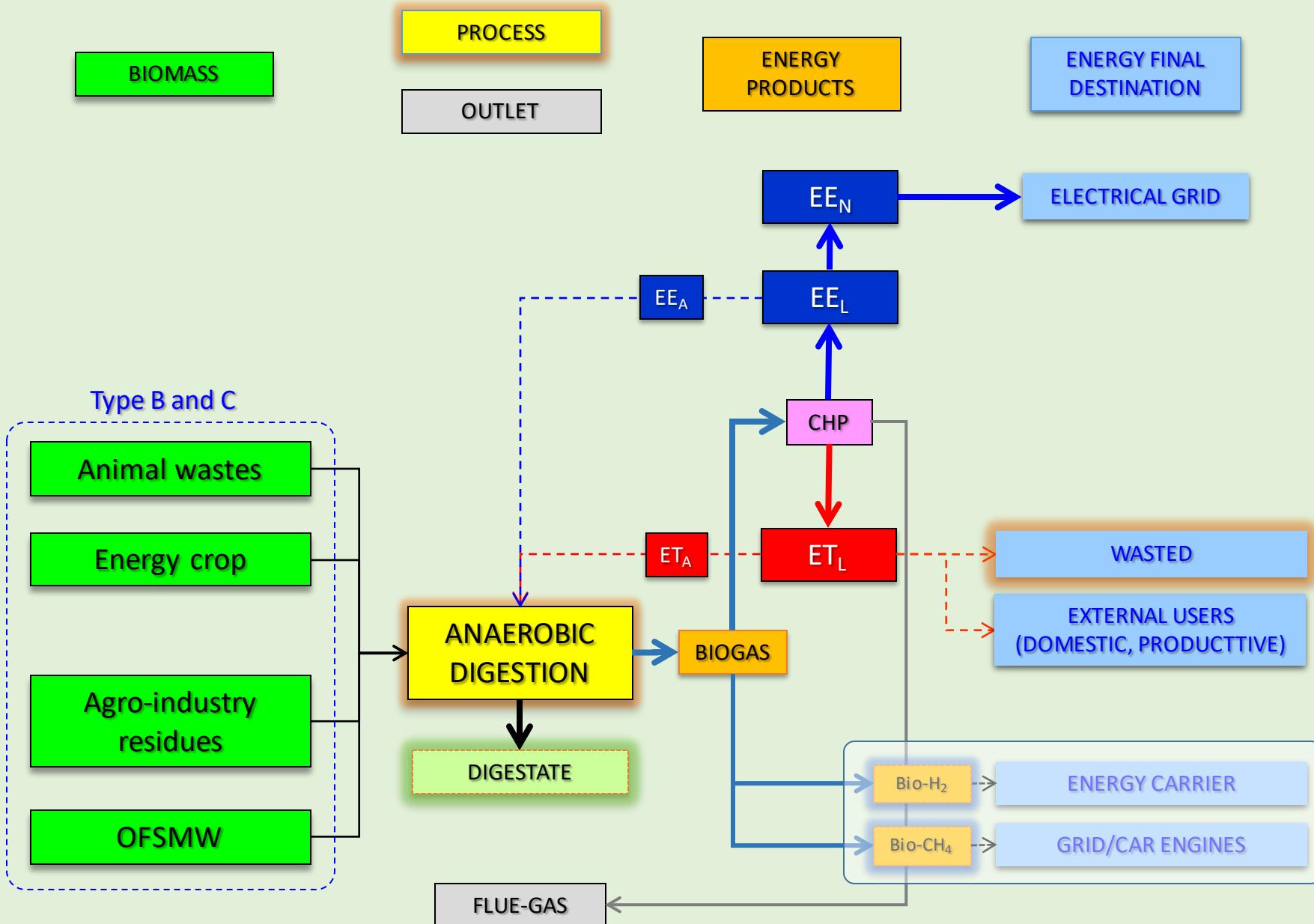
Biochemical process → Fermentable biomass (Type B and C)

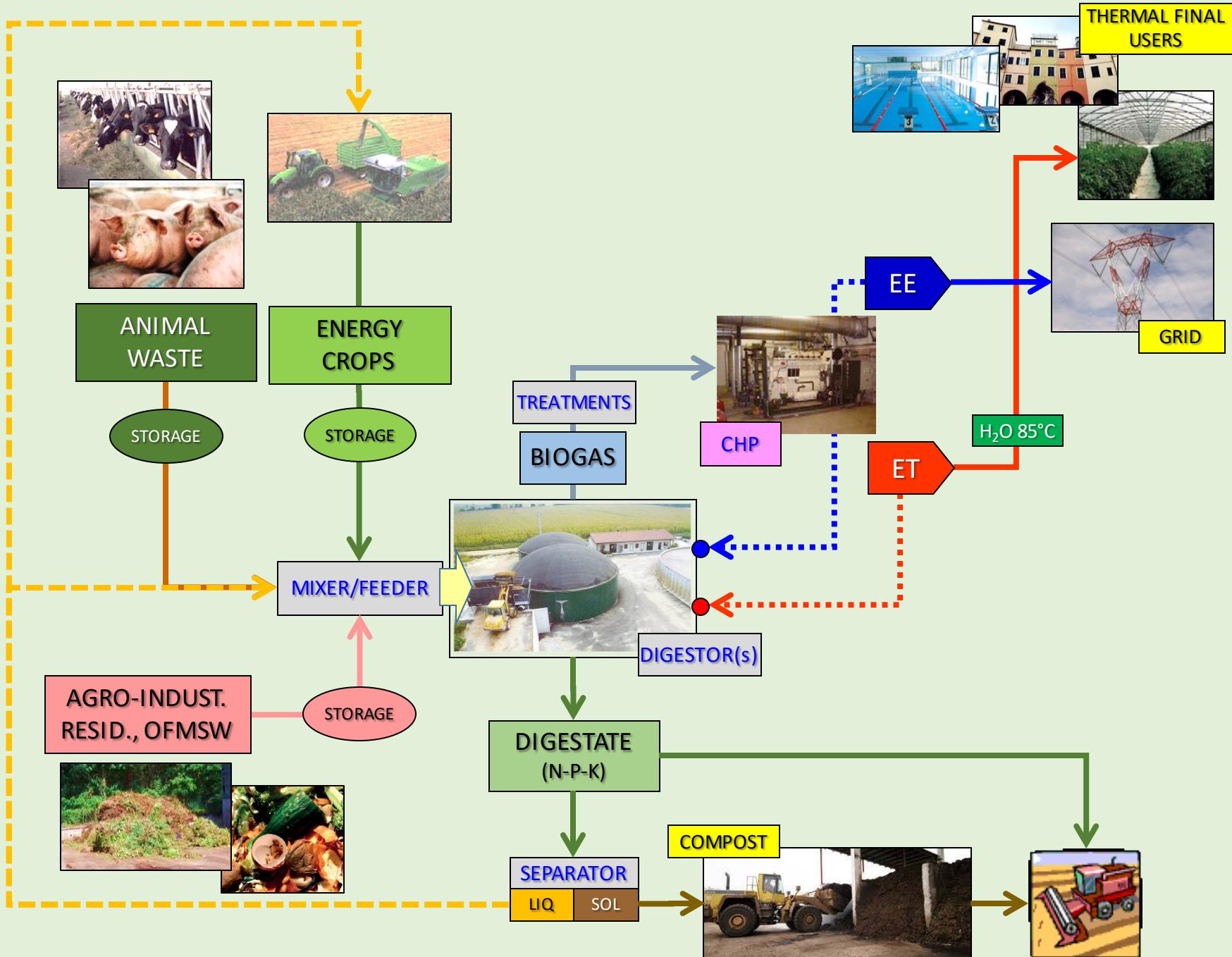
ANAEROBIC DIGESTION (AD)

Biological process (**bacterial consortium**) by which the organic matter (plant or animal origin), in the **absence of oxygen** (anerobiosis), is degraded by the formation of a gas mixture (**biogas**), and a co-product (**digestate**) used as fertilizer.







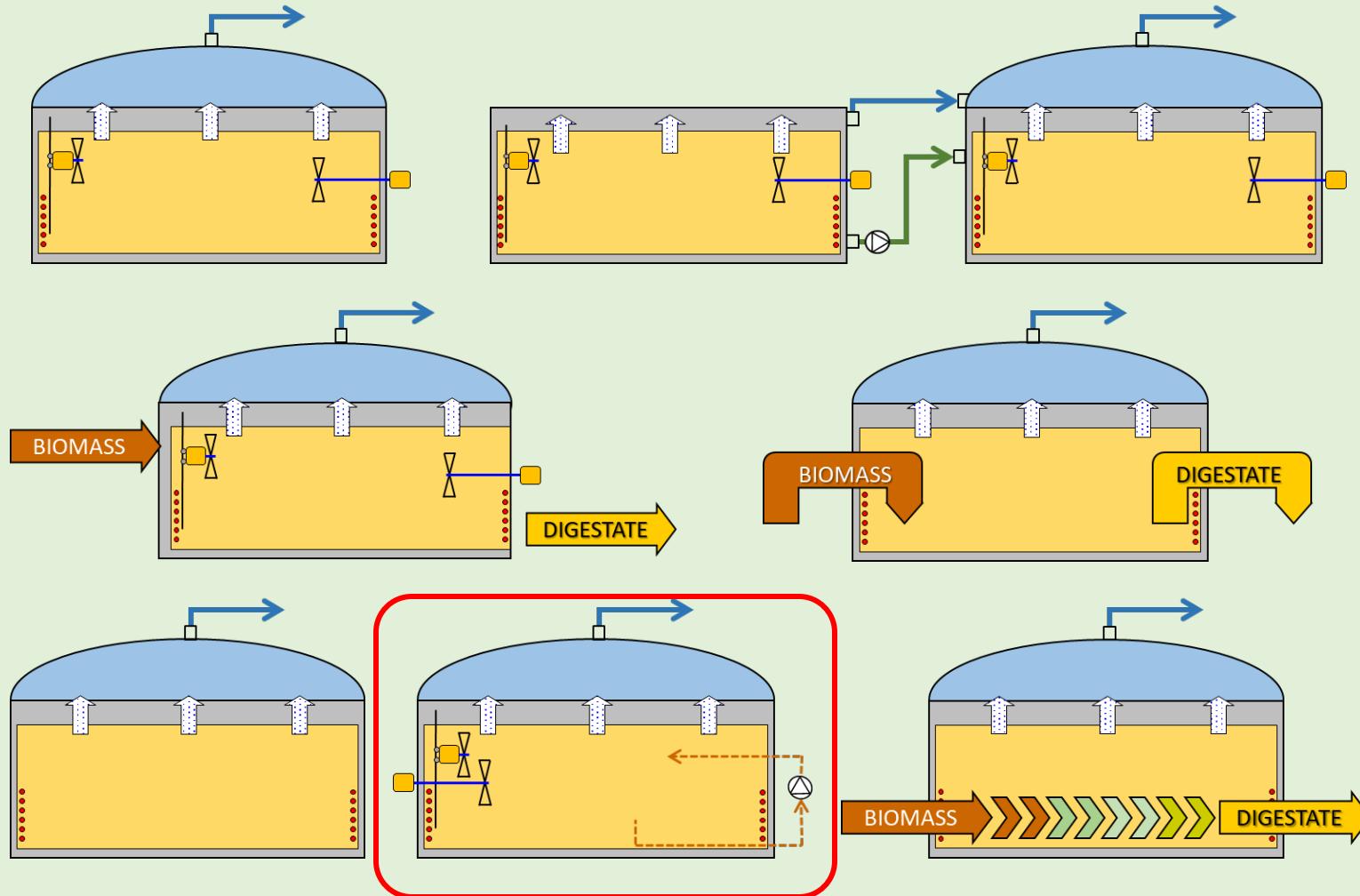


Plant types (from left to right and from top to bottom):

(1) single-stage plant, mechanical mixing;

(3) continuous load system;

(5) not mixed plant; (6) mixed plant (Completely Stirred Tank Ractor, CSTR); (7) plug-flow plant.

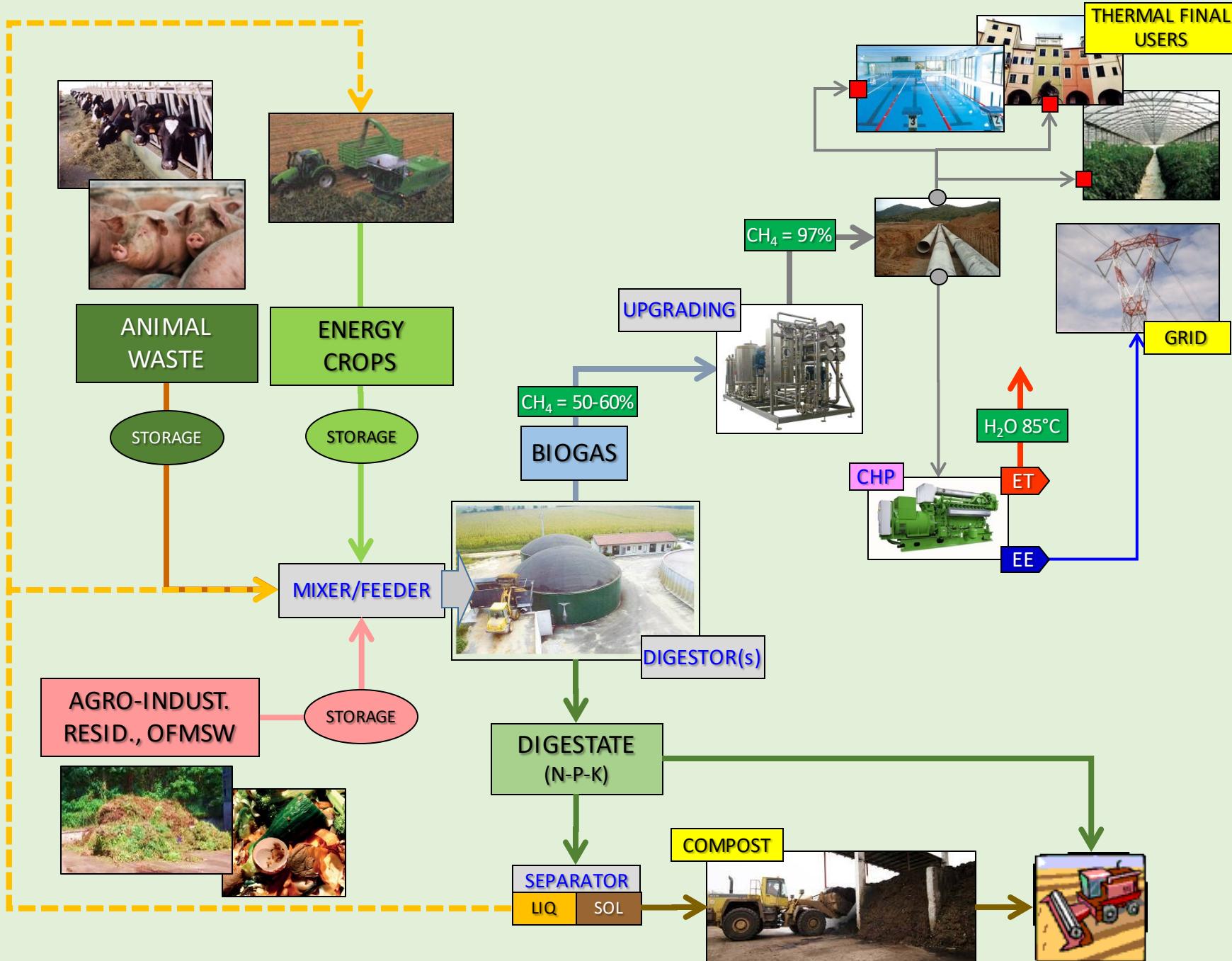


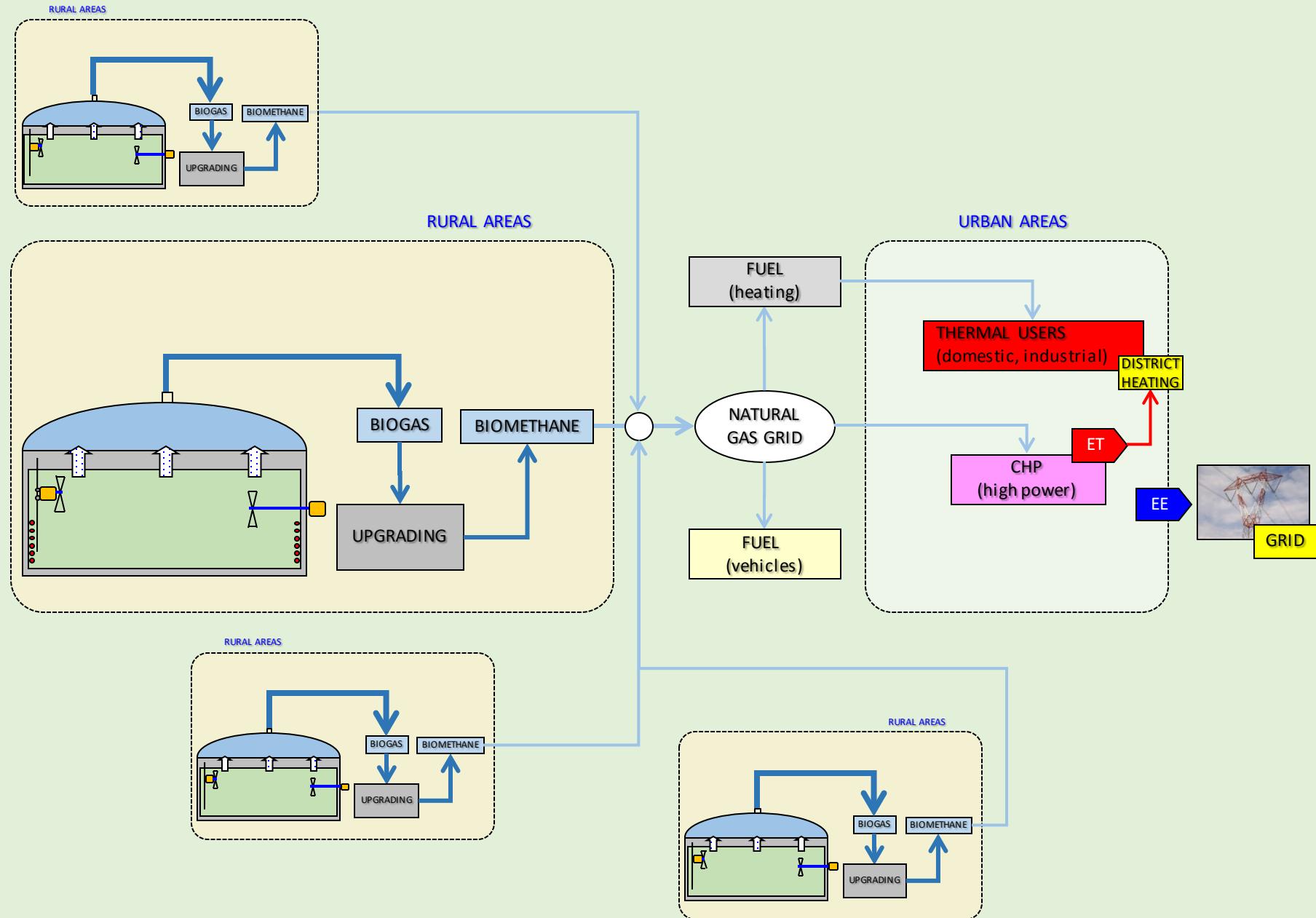


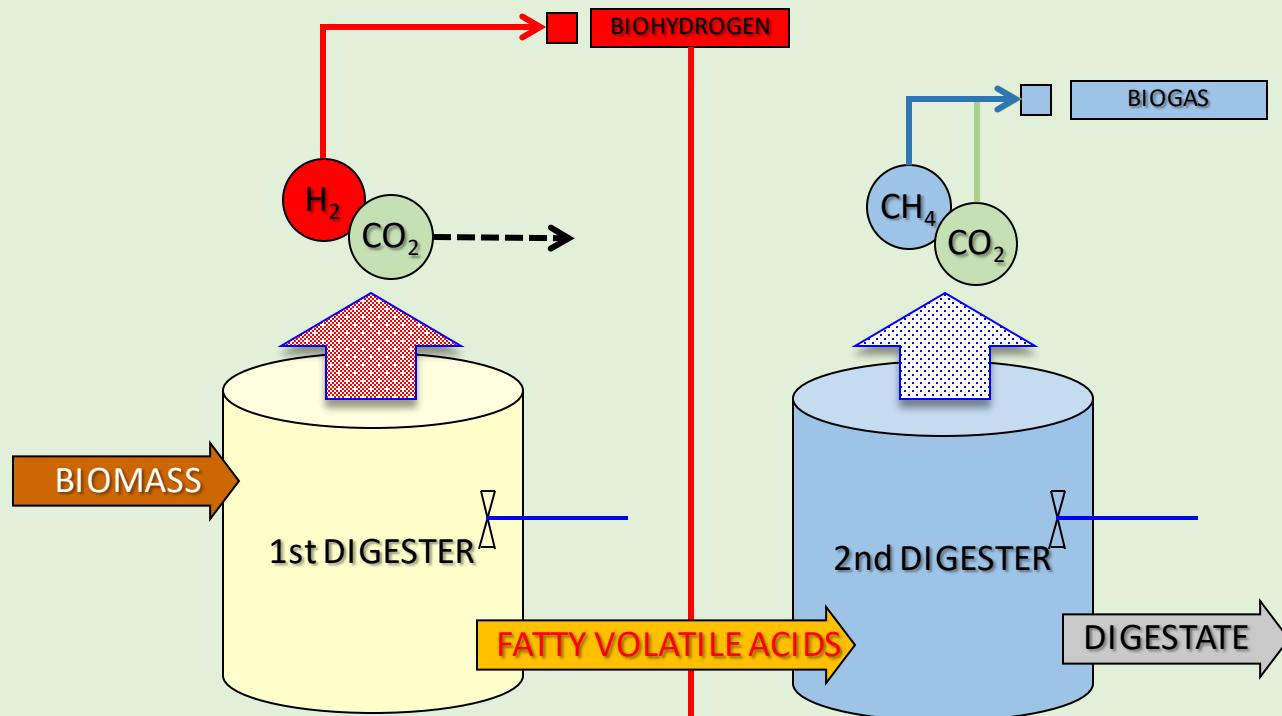


ANAEROBIC DIGESTION → BioCH_4 , BioH

Biochemical process → Fermentable biomass (Type B and C)

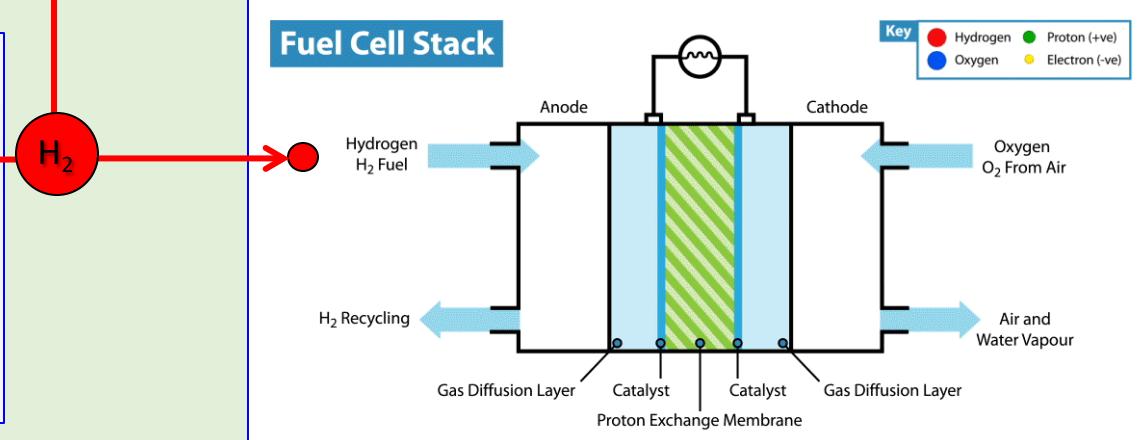
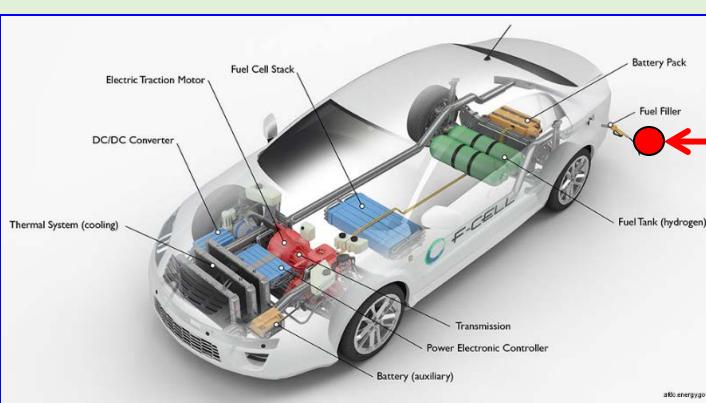






PHASE 1
HYDROLYSIS and ACIDOGENIC

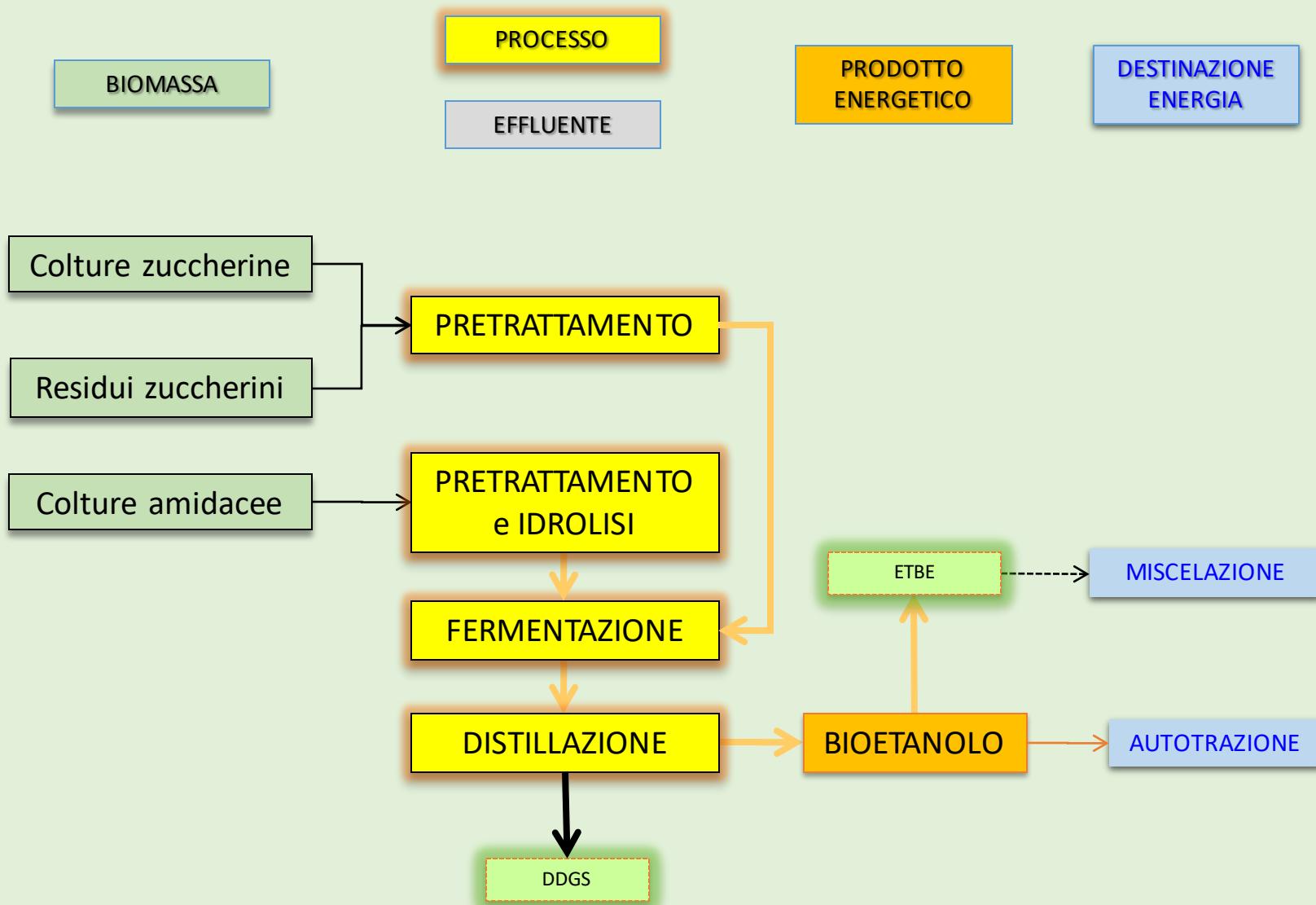
PHASE 2
METHANOGENIC

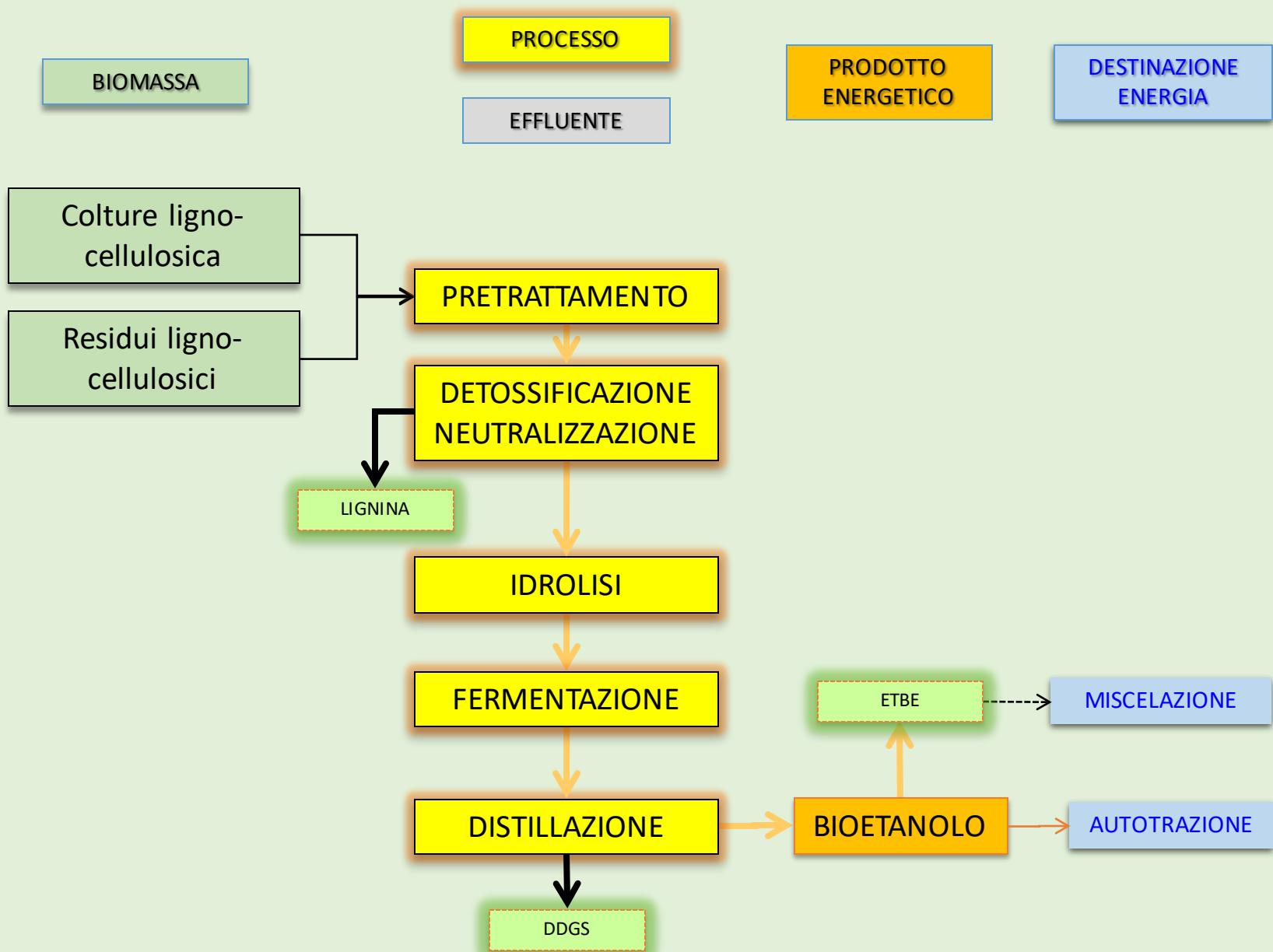




ALCHOLIC FERMENTATION → BioEthanol

Biochemical process → biomass for sugar, starch (Type D)

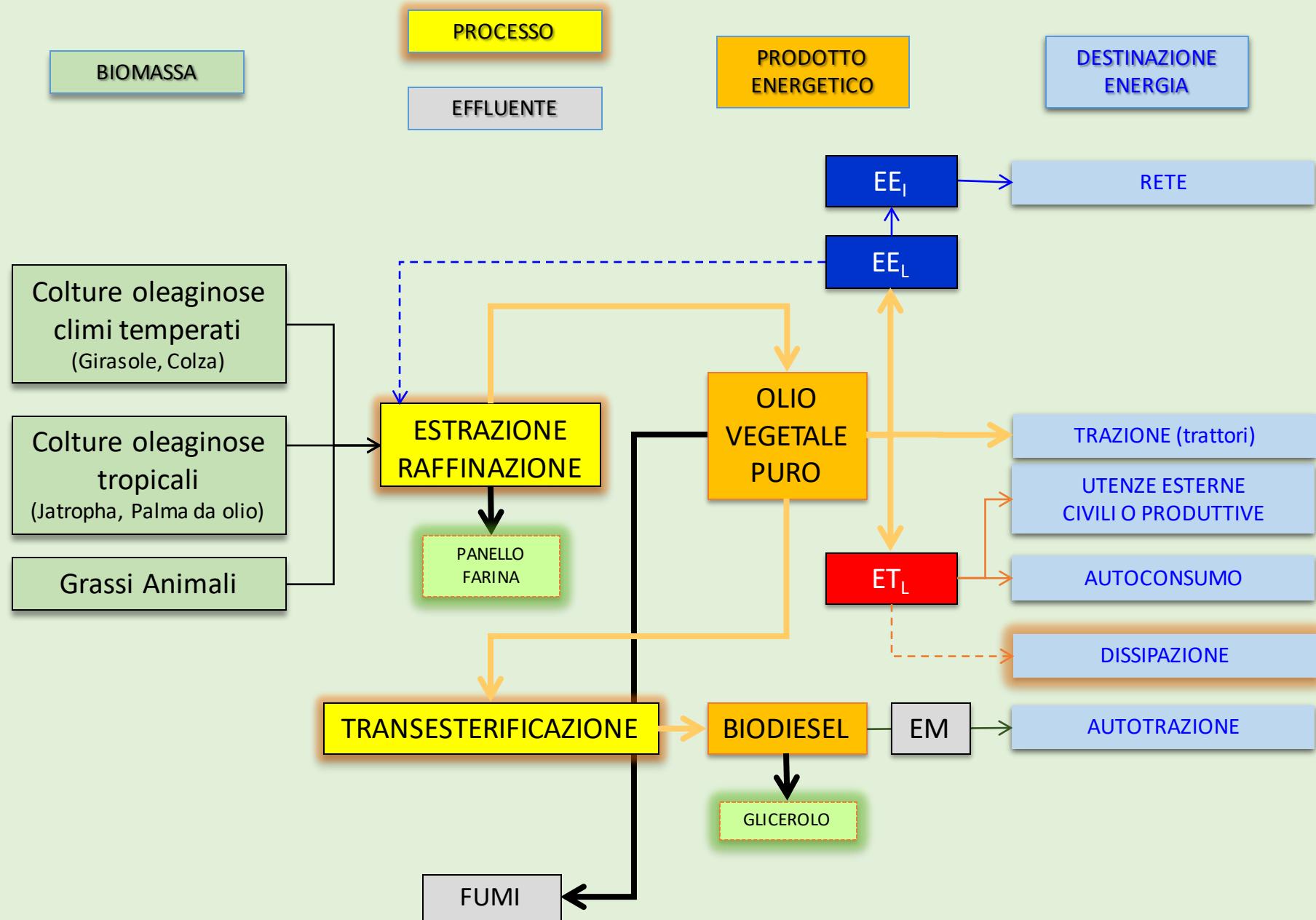






OIL EXTRACTION → SVO, BioDiesel

Mechanical/chemical process → Oil crop seeds (Type D)





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Landscape, Agroenergy

