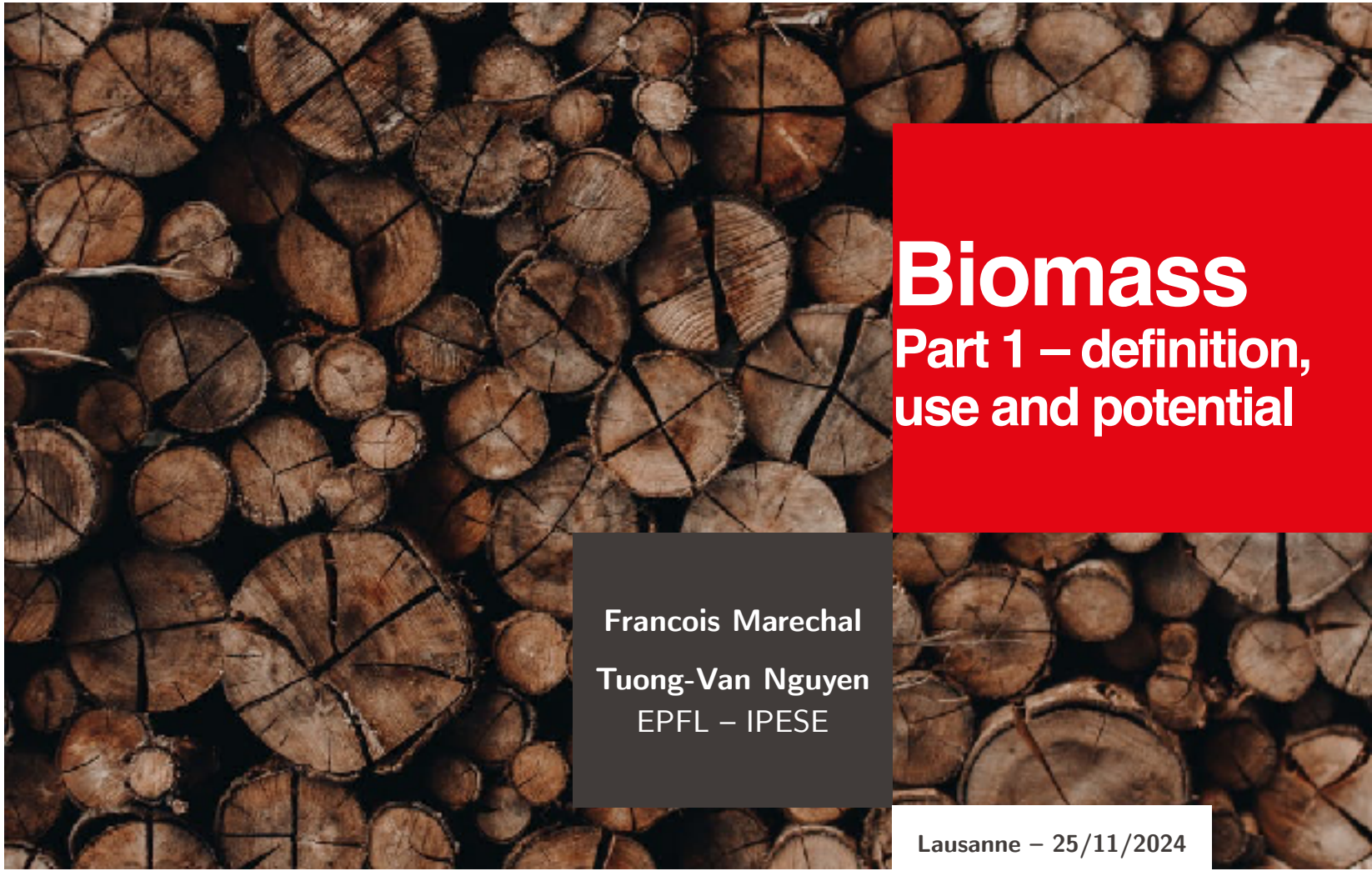

Biomass
Part 1 – definition, use and potential

Francois Marechal

Tuong-Van Nguyen
EPFL – IPESE

Lausanne – 25/11/2024

École polytechnique fédérale de Lausanne

Goals

- **Describe** the origin and formation of biomass
- **Differentiate** biomasses based on "structural", "compositional" and "ultimate" analyses
- **Estimate** the heating value of various feedstocks
- **Describe** the potential role of biomass in the future

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Biomass as a renewable energy resource

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What is biomass?

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Biomass is all living matter on Earth (McKendry, 2002)

Is biomass a renewable energy resource

Depends on the time frame, but generally admitted as renewable

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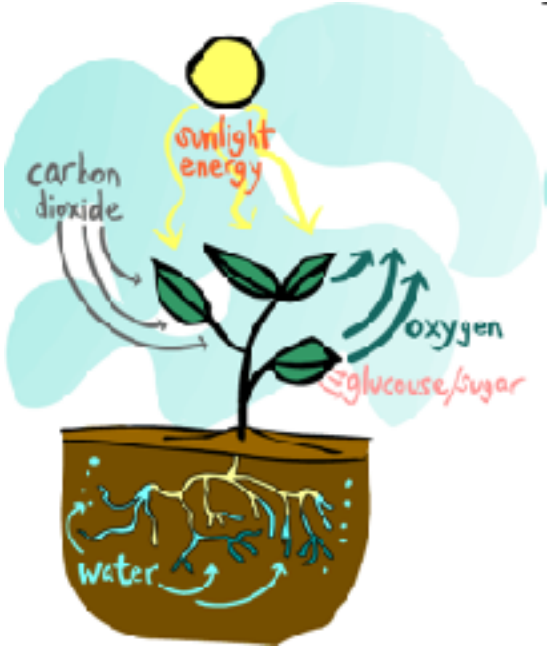
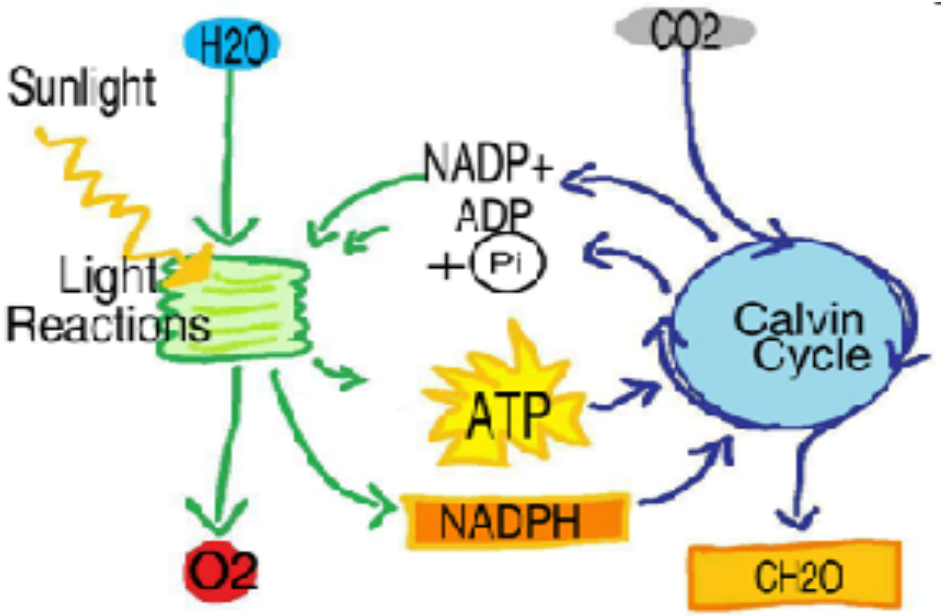
Photo-synthesis : Natural Direct Air CO2 capture and energy harvesting

- **Photosynthesis** = conversion of light into stored chemical energy

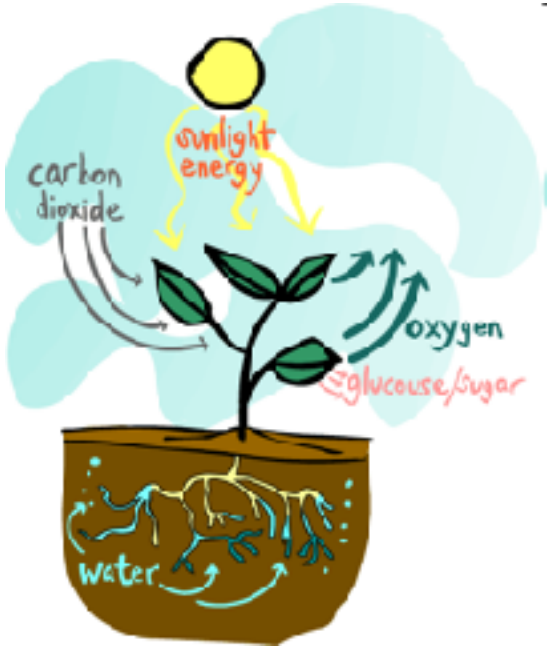
  The Calvin cycle : $nCO_2 + nH_2O$ + sunlight -> $C(H_2O)_n + nO_2$

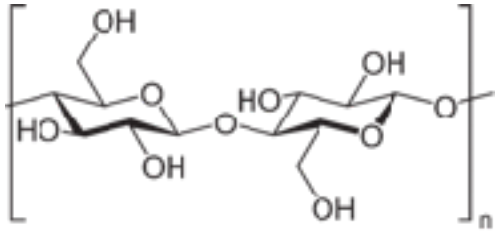




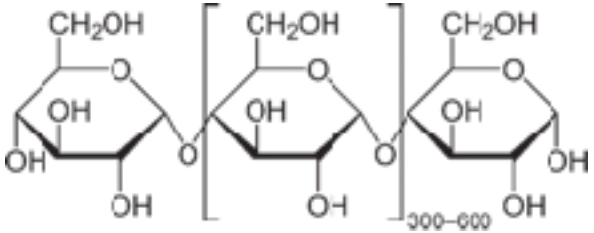
Building blocks

- The Calvin cycle : $nCO_2 + nH_2O$ + sunlight -> $C(H_2O)_n + nO_2$





β **Cellulose (structure molecule)**



α **Starch (reserve molecule)**

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The structure of biomass

= Species

AS RECEIVED

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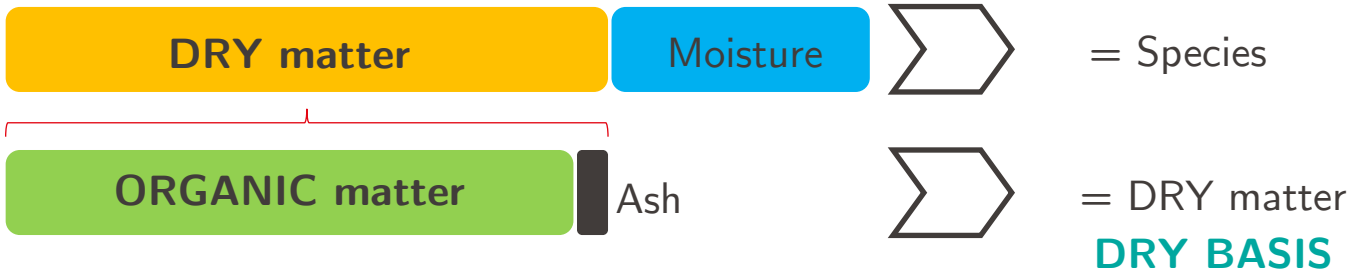
The structure of biomass



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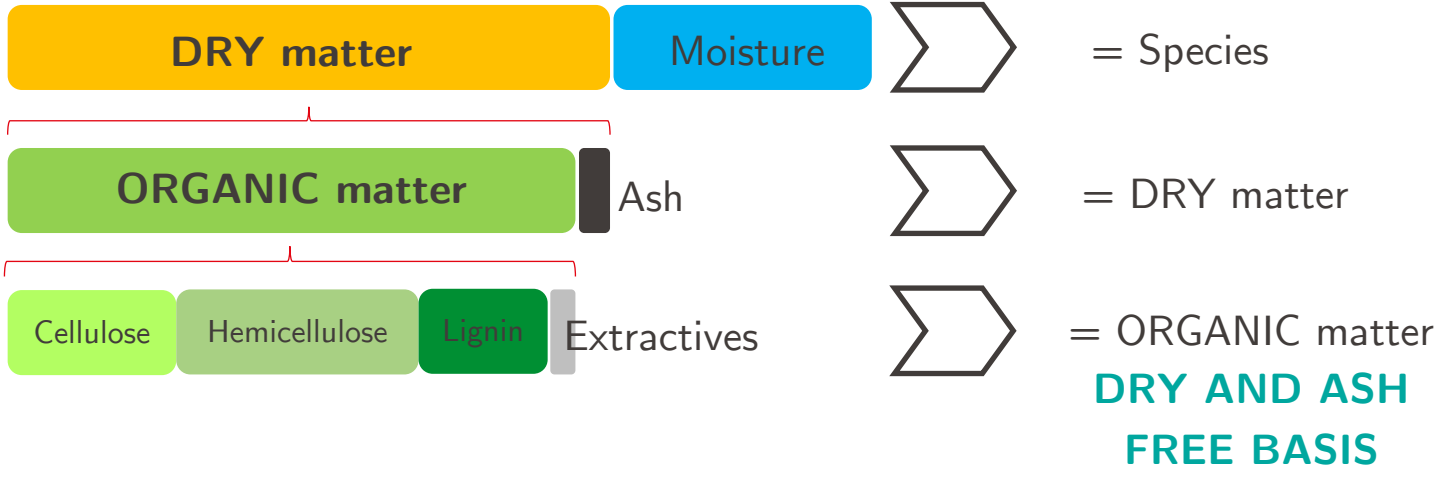
The structure of biomass



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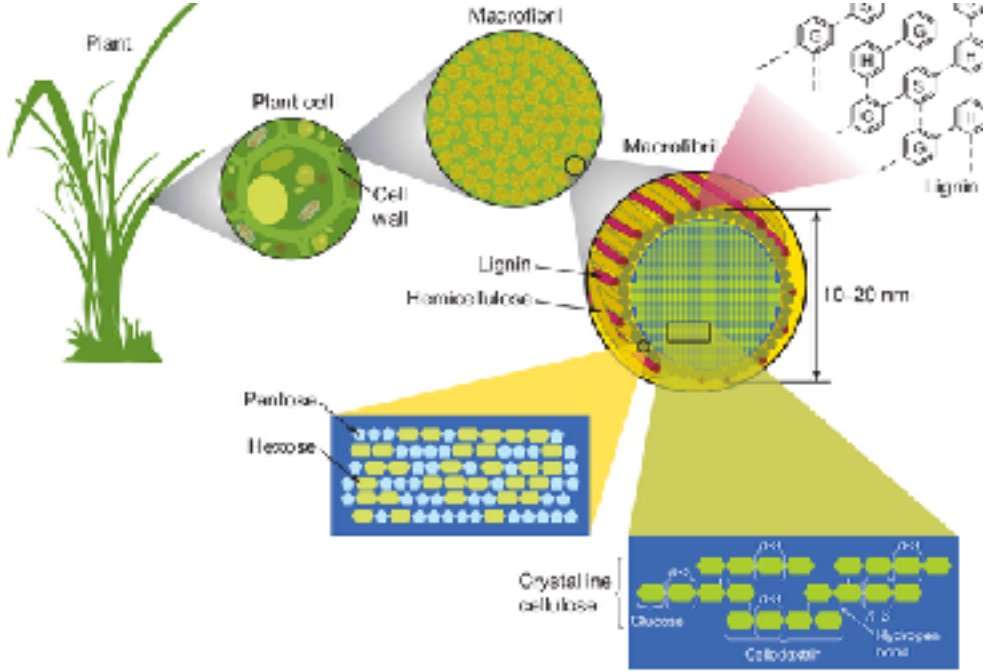
The structure of biomass

Cellulose | Hemicellulose | Lignin | Extractives

ORGANIC matter



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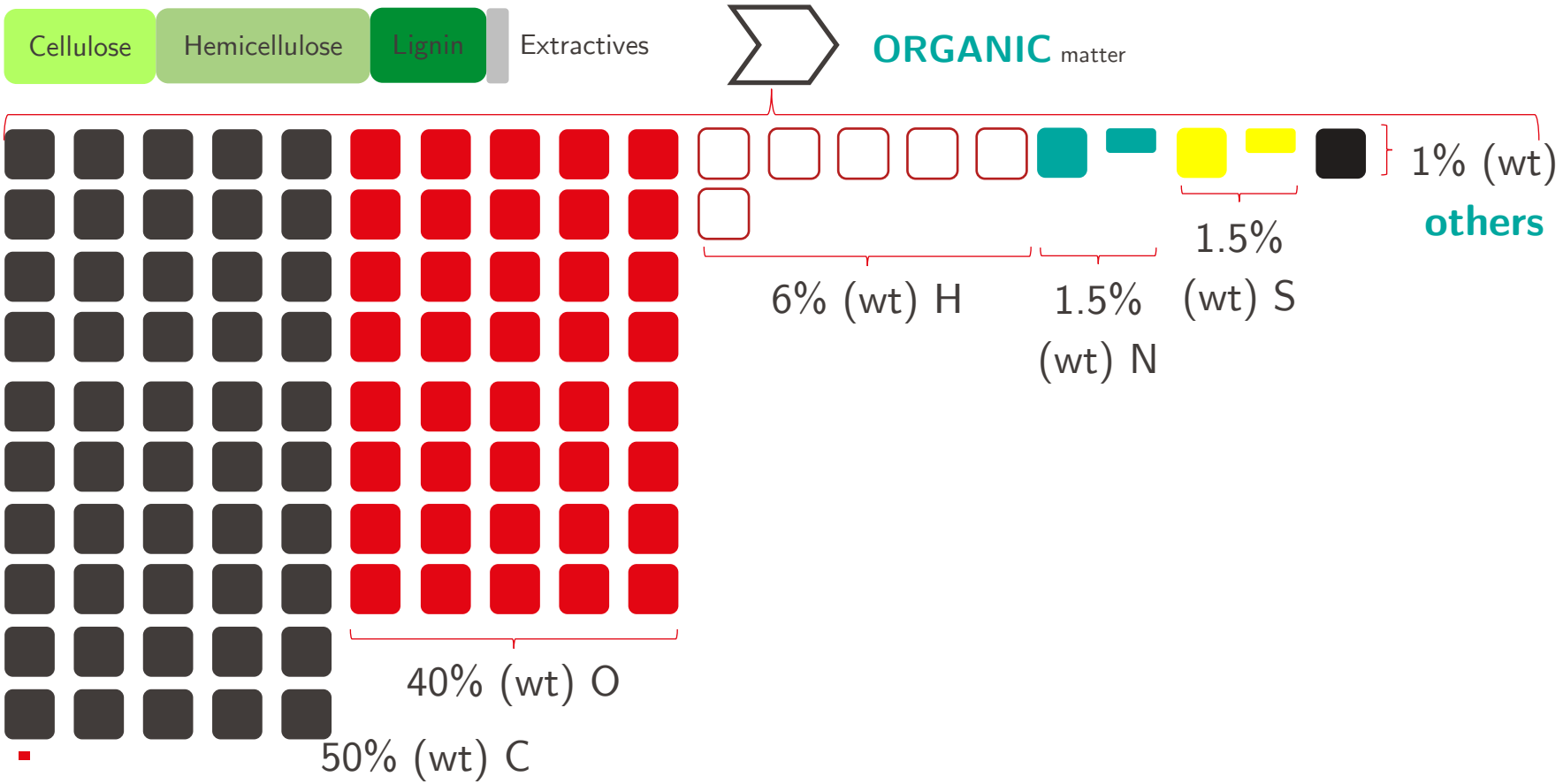
The structure of biomass



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Biomass resource classification

DRY BIOMASS

= "lignocellulosic", most abundant

- **Wood and co-products** (*pellets*)
- **Agricultural co-products** (*straw*)
- **Energy crops** (*switchgrass*)



WET BIOMASS

= more than 50% moisture

- **Agricultural products** (*sugar beet*)
- **Industry co-products (***pulping residues*)
- **Organic waste** (*manure, sludge*)



MARINE BIOMASS

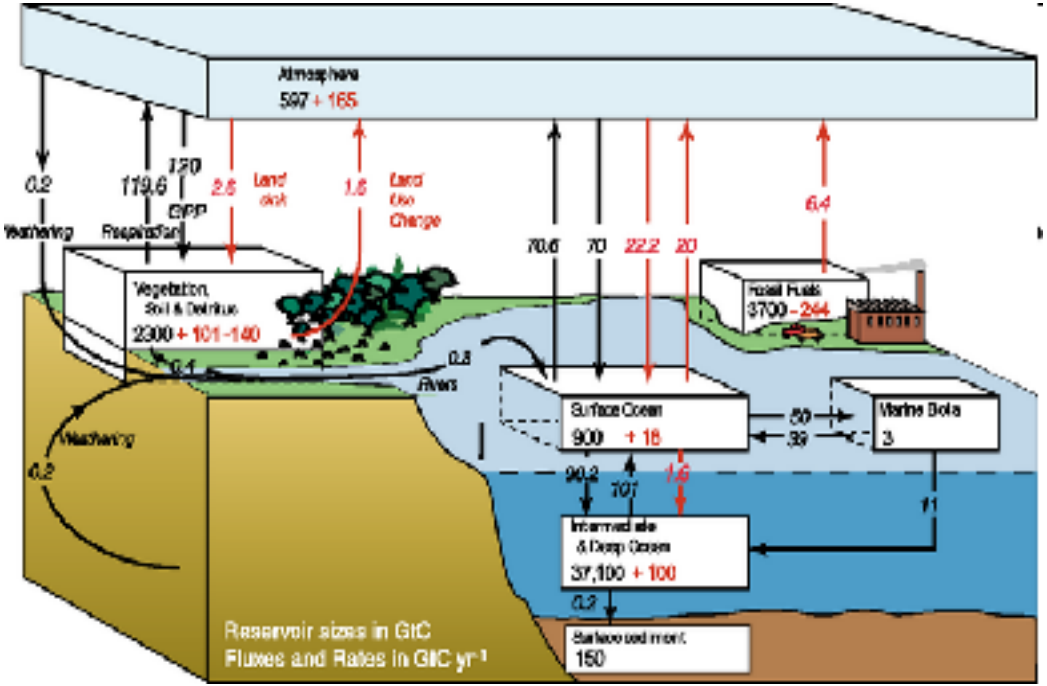
= extracted/produced from ocean sources

- **Algae** (*spirulina*)

The “carbon-neutral” aspect

- **The carbon cycle**
  - Pre-industrial “natural” fluxes (black)
  - The “anthropogenic” fluxes (red)

  - Vegetation – 2300 Gt**C**
  - Atmosphere – 600 Gt**C**



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The “carbon-neutral” aspect

- **Direct CO_2 emissions**
  - **Combustion** of biomass (process)
- **Indirect CO_2 emissions**
  - Land use change
  - Forest management
  - Harvesting/transportation

	Grassland	Young forest	Old forest
Stock (t C ha^{-1})	6 - 9	100 - 350	200 - 700
Sequestration (yrs)	1	25 - 100	100 - 350
NPP (t C ha^{-1} yr^{-1})	6 - 9	4 - 7	2 - 4
Biomass C/N	20 - 100	200 - 300	>300

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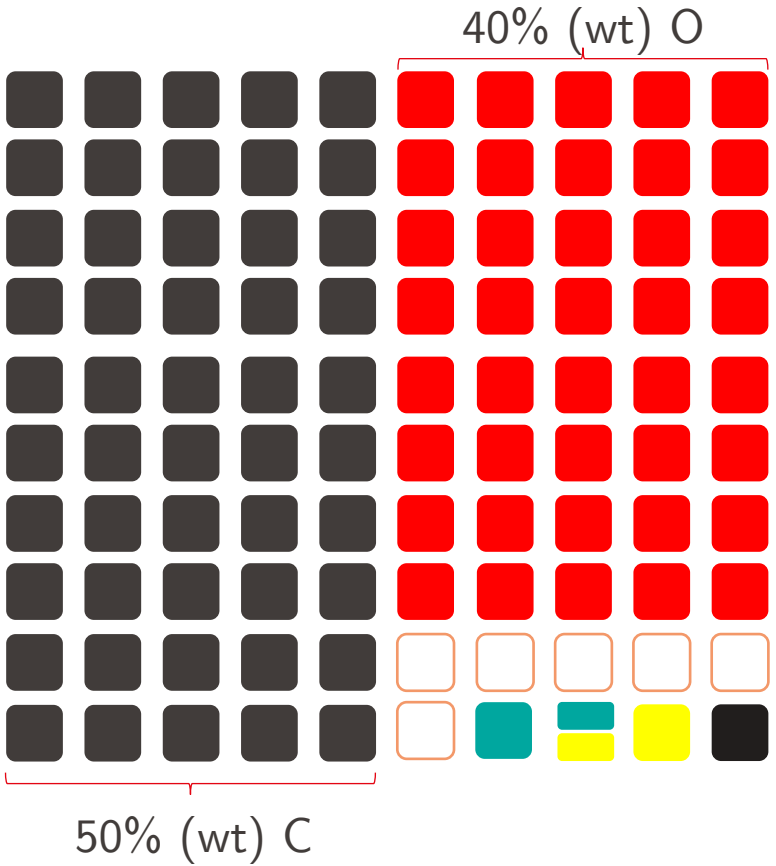
The energy content

Biomass contains about 33% to 60% less (weight basis) energy than fossil fuels

Because of the presence of O (partial oxidation) in the molecule



The energy content and composition



C, H, S, N can be oxidised (not O)

- Dry biomass

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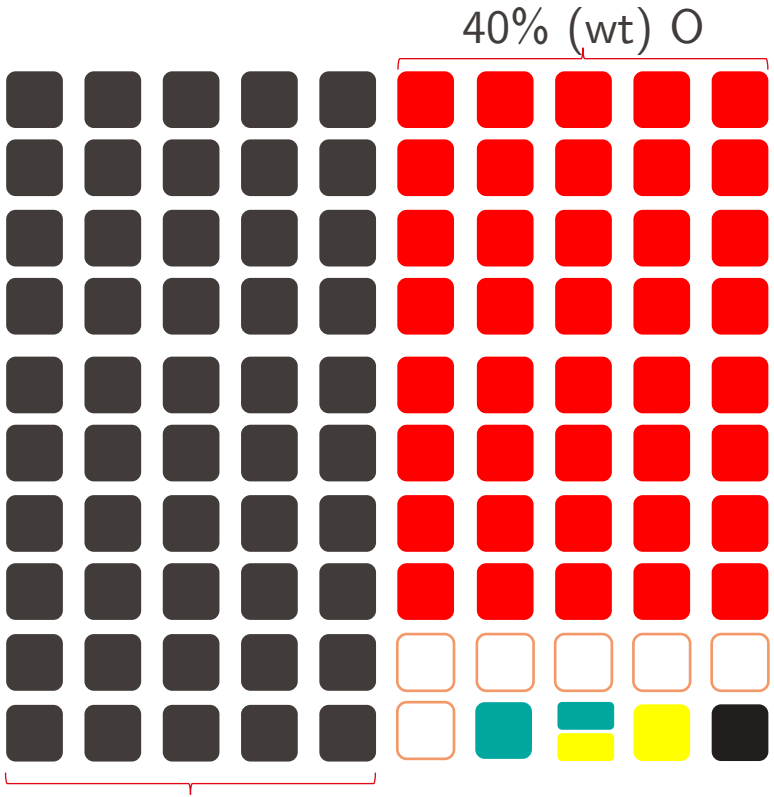
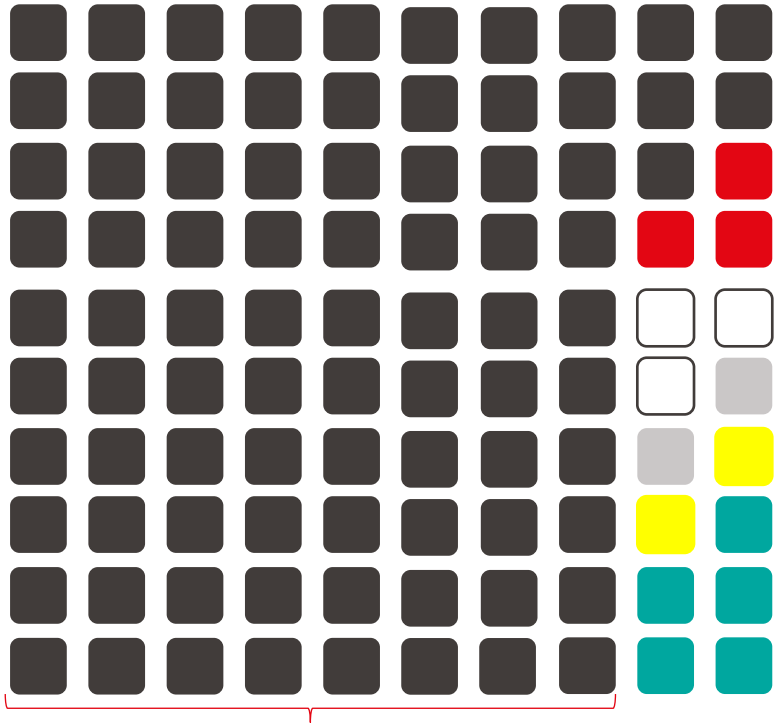
Coal vs biomass : composition





- **Dry biomass**

Dry coal

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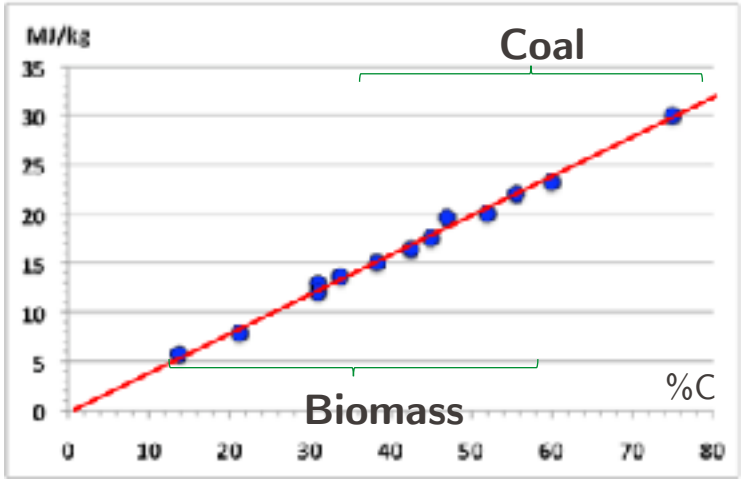
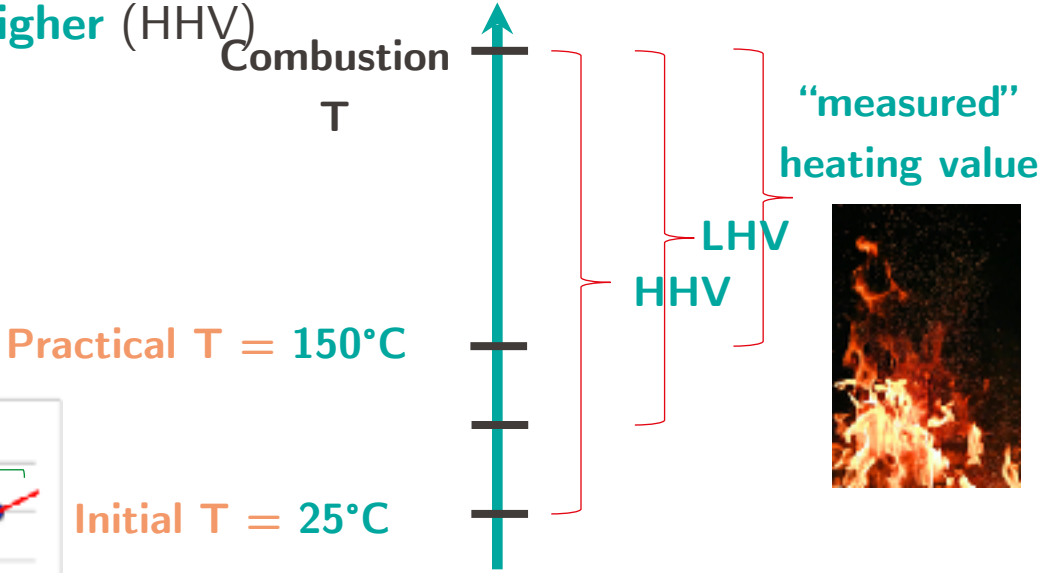
The energy content

Important properties:

- Heating value – **lower** (LHV) and **higher** (HHV)





Biomass : 15-20 MJ/kg Dry basis

Biomass biogenic carbon content

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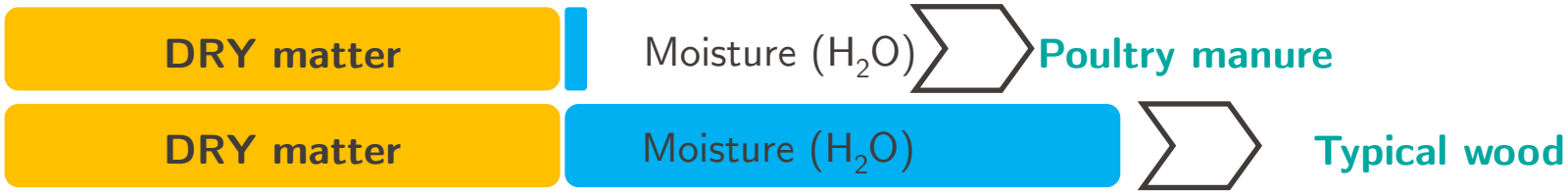
Importance of humidity content



substance name	ID in [4]	humidity[a] %wt	composition C	H	O	N	S	ash (%wt)
municipal solid waste	1518	39	31.0	1.0	21.5	1.1	0.8	44.5
wet sewage sludge	2810	73	27.0	3.8	17.2	2.2	0.9	47.8
Fresh water biomass	2319	84	54.6	6.7	23.4	6.7	0.4	8.2
fruit/vegetable waste	2811	7	46.5	6.1	38.5	0.7	0.5	7.7
cattle manure	1885	13	13.0	1.5	10.1	1.5	0.3	73.6
pig manure	1366	92	35.4	4.5	21.5	2.8		35.8
poultry manure	1872	4	35.9	5.0	27.4	3.6	0.8	27.4
sugarbeet	417	77	44.5	5.9	42.8	1.8	0.1	4.8
bagasse	894	10	48.6	5.9	42.8	0.2		2.4
grass	568	40	46.0	5.5	41.1	0.5	0.1	4.8
vine shoots	1253		46.9	5.9	44.2	0.8		2.2
straw	2129	14	47.7	5.9	41.0	0.7	0.2	4.5
wood	own data	50	50.7	5.7	42.7	0.2		0.7
lignin	2000	75	62.1	5.9	31.1	0.2	0.1	0.6

The water in the resources will be evaporated by the heating value of the dry matter

Heat of evaporation 2,442 kJ/kg

5-92% (wt)

H_2O

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Biomass Ash content

municipal solid waste	1518	39	31.0	1.0	21.6	1.1	0.8	44.5
wet sewage sludge	2810	73	27.0	3.8	17.2	3.2	0.9	47.8
fresh water biomass	2319	84	54.6	6.7	23.4	6.7	0.4	8.2
fruit/vegetable waste	**2811**	**7**	**46.5**	**6.1**	**38.5**	**0.7**	**0.5**	**7.7**
cattle manure	**1885**	**13**	**13.0**	**1.5**	**10.1**	**1.8**	**0.2**	**73.6**
pig manure	**1366**	**92**	**35.4**	**4.5**	**21.5**	**2.8**		**35.8**
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vine shoots	1253		46.9	5.9	44.2	0.8		2.2
straw	**2129**	**14**	**47.7**	**5.9**	**41.8**	**0.7**	**0.2**	**4.5**
wood	own data	50	50.7	5.7	42.7	0.2		0.7
lignin	2000	75	62.1	5.9	31.1	0.2	0.1	0.6

0.6-73.6% (wt) ash

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Biomass potential

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The uses of biomass

In the world : about 66% (primary energy use) of the biomass is used for cooking and heating"

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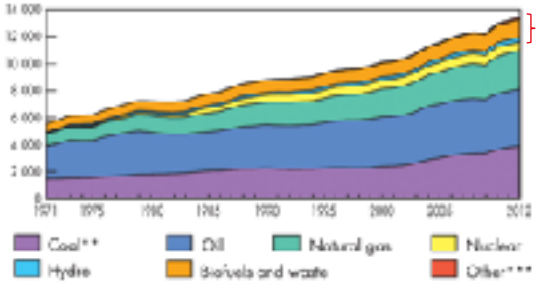
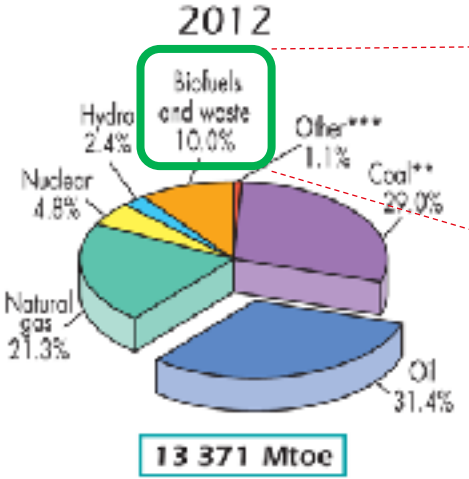
The uses of biomass



10%

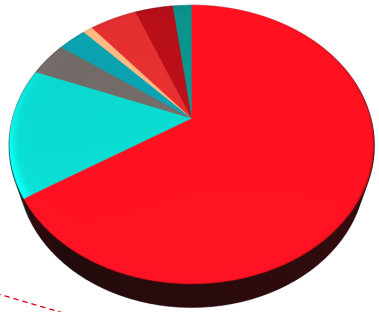


Residential – 66%

Transportation – 4%

Power plants – 4%

Industry – 15%



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The potential of biomass

- Today...

Primary Energy = 516 EJ/yr

Transport = 104 EJ/yr

Biomass supply = 54 EJ/yr

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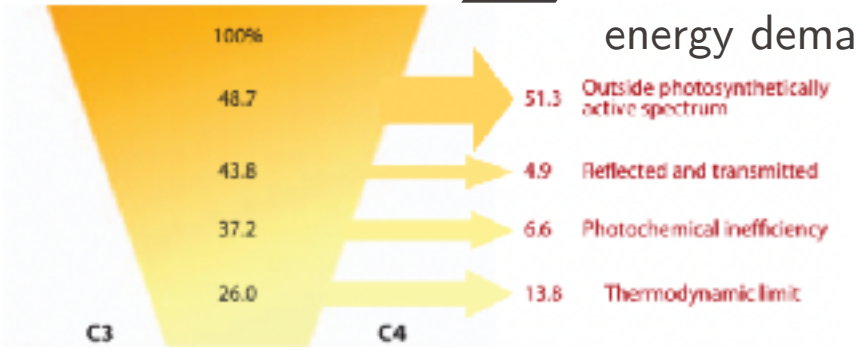
The potential of biomass

Solar radiation
(5.5 10^6 EJ/yr)

= **968 times** the primary energy demand



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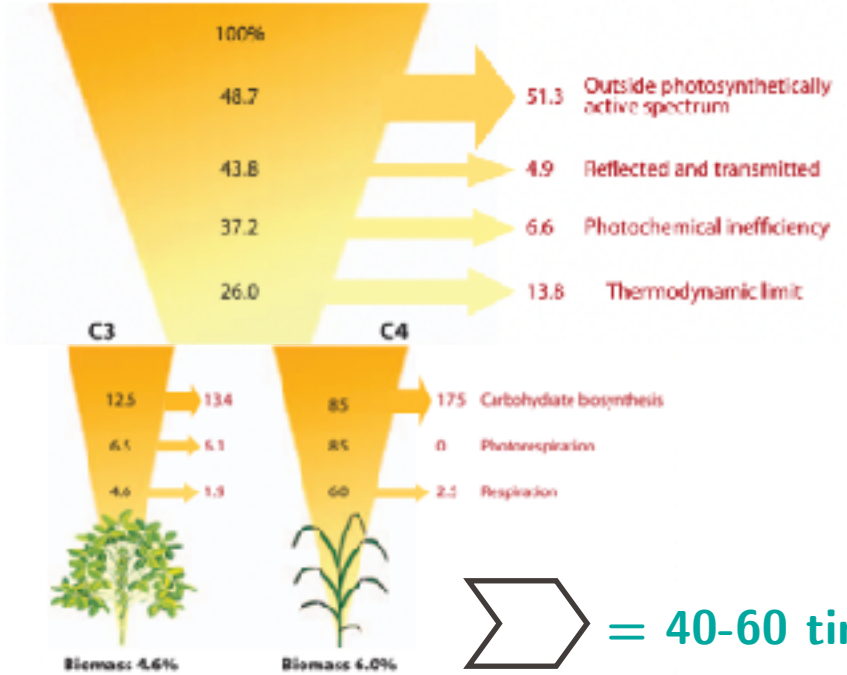
The potential of biomass

Solar radiation
(5.5 10^6 EJ/yr)

Theoretical conversion from solar radiation to biomass production **(10.6%)**



= 40-60 times the primary energy demand

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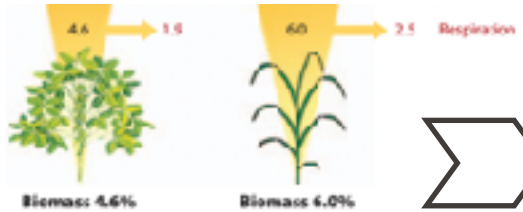
The potential of biomass

"Real" conversion from solar radiation to biomass production

4500 EJ/yr (0.8%)



= **8 times** the primary energy demand

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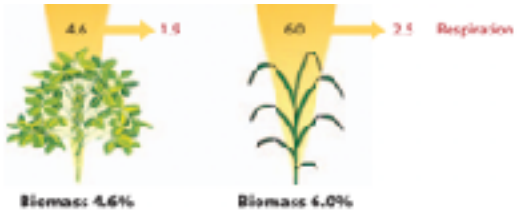
The potential of biomass

Theoretically harvestable

2900 EJ/yr



= **5.4 times** the primary energy demand

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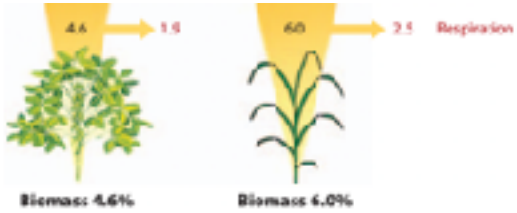
The potential of biomass



Sustainably exploitable

270 EJ/yr

= **0.5 times** the primary energy demand

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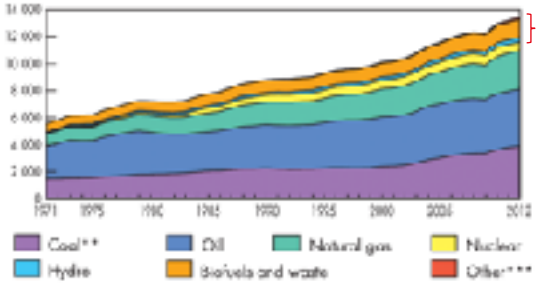
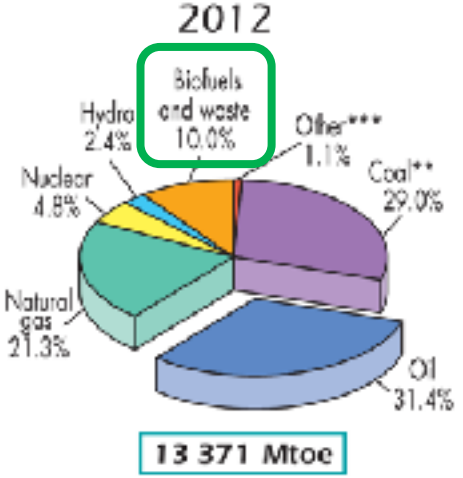
The potential of biomass

- Today…



10%



Biomass potential	North Amer.	Latin Amer.	Asia	Africa	Europe	Middle East	Former USSR	World
Woody biomass	12.6	5.9	7.7	5.4	4.0	0.4	5.4	41.6
Energy crops	8.1	12.1	1.1	13.9	2.6	0.0	3.6	37.4
Straw	2.2	1.7	9.9	0.9	1.6	0.2	0.7	17.2
Other	0.8	1.8	2.9	1.2	0.7	0.1	0.3	7.8
= Potential, Sum (EJ/a)	13.5	21.5	21.6	21.4	8.9	0.7	10.0	103.8
Use (EJ/a)	3.1	2.6	23.2	8.3	2.0	0.0	0.5	39.7
Use/potential (%)	15	12	108	39	22	7	5	38

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What's next for biomass?

Role in the Energy System

Biomass as a gamechanger

IPCC – Extract from the article D.4.3

1.5°C and 2°C modelled pathways often rely on the deployment of large-scale land-related measures like afforestation and **bioenergy supply**.

The key usage of biomass is in the concept of **BECCS:**

Biomass Energy Carbon Capture and Sequestration

1. Convert the energy value
2. Capture biogenic carbon
3. Sequestrate the captured carbon

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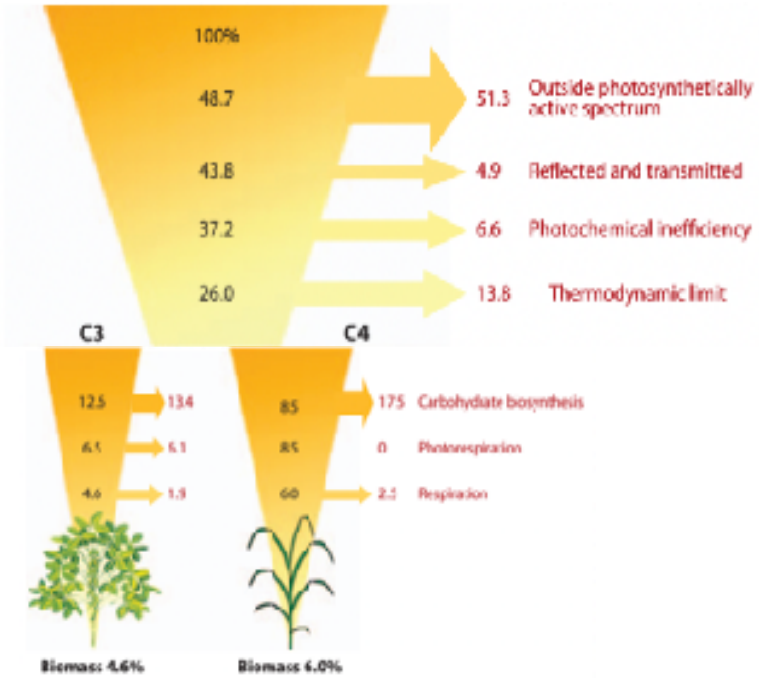
Take-home message



Take-home message

- Three types of **biomass**: **dry, wet and marine**
- "**Renewable**" resource
- Direct Air Capture by Nature :
  Solar Energy Harvesting + Atmospheric Carbon Capture
- Biomass ($C(H_2O)_n$) – Polymer + Biogenic Carbon + Energy
- **Lower energy content** than fossil fuels (< 20 MJ/kg)
- Biomass – a **role in the future with BECCS**
  - **Negative emissions**
  - **Energy supply 50-500 EJ/yr**
  - **Biogenic Energy Storage**

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Questions ?

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