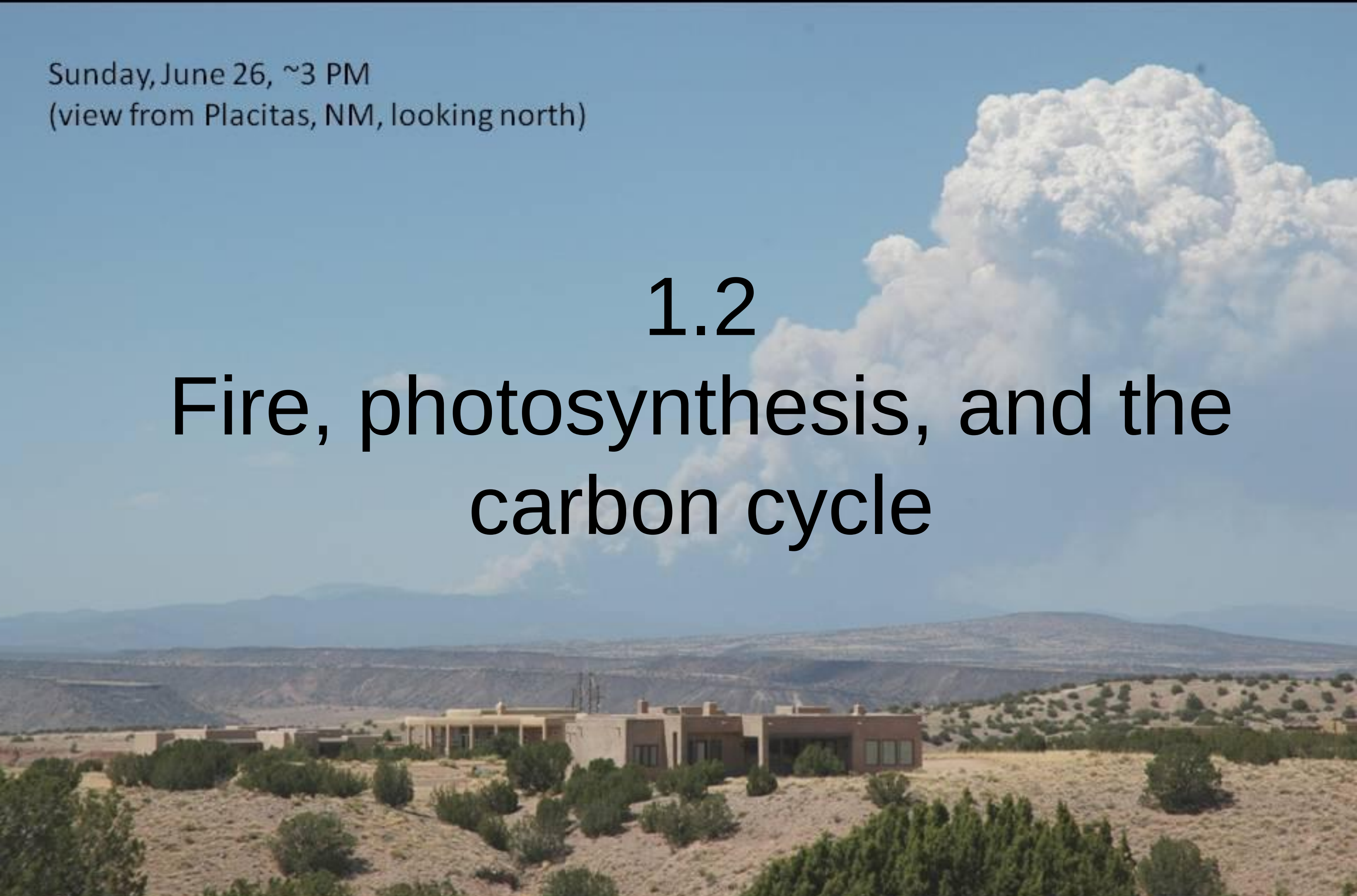
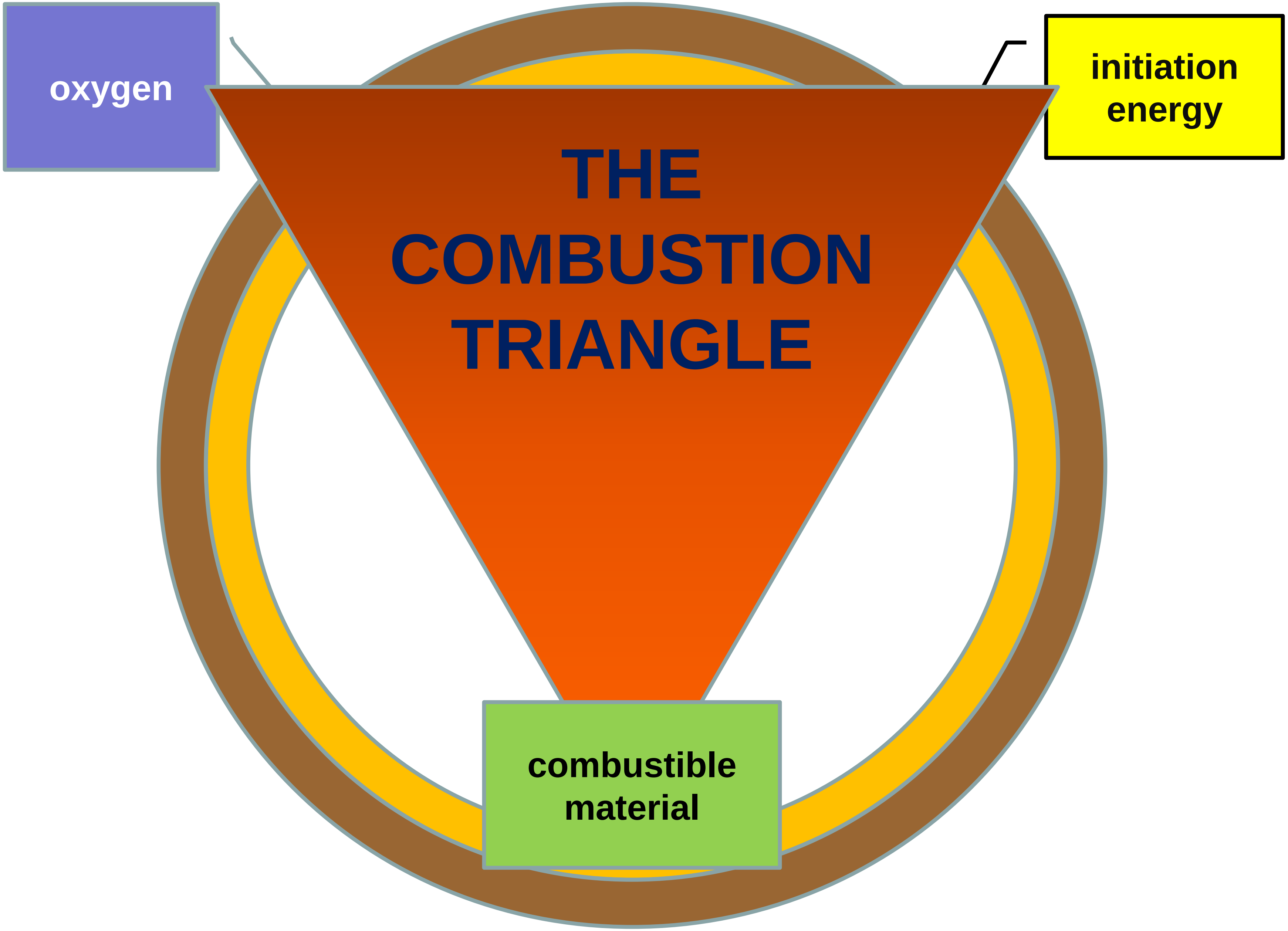
1.2
Fire, photosynthesis, and the carbon cycle



Moving toward understanding wildland “fire” as a biophysical process


oxygen
initiation energy
THE COMBUSTION TRIANGLE
combustible material

Fire as a process

- Burning as oxidative respiration (O_2)
- What "burns" ("fuel")
- What starts fires: initiation energy (ignition)

The big picture: We want to understand the process of combustion in relation to bigger ecosystem processes

Final form for oxidation of glucose:

e_{in}

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O \quad + e_{out}$$

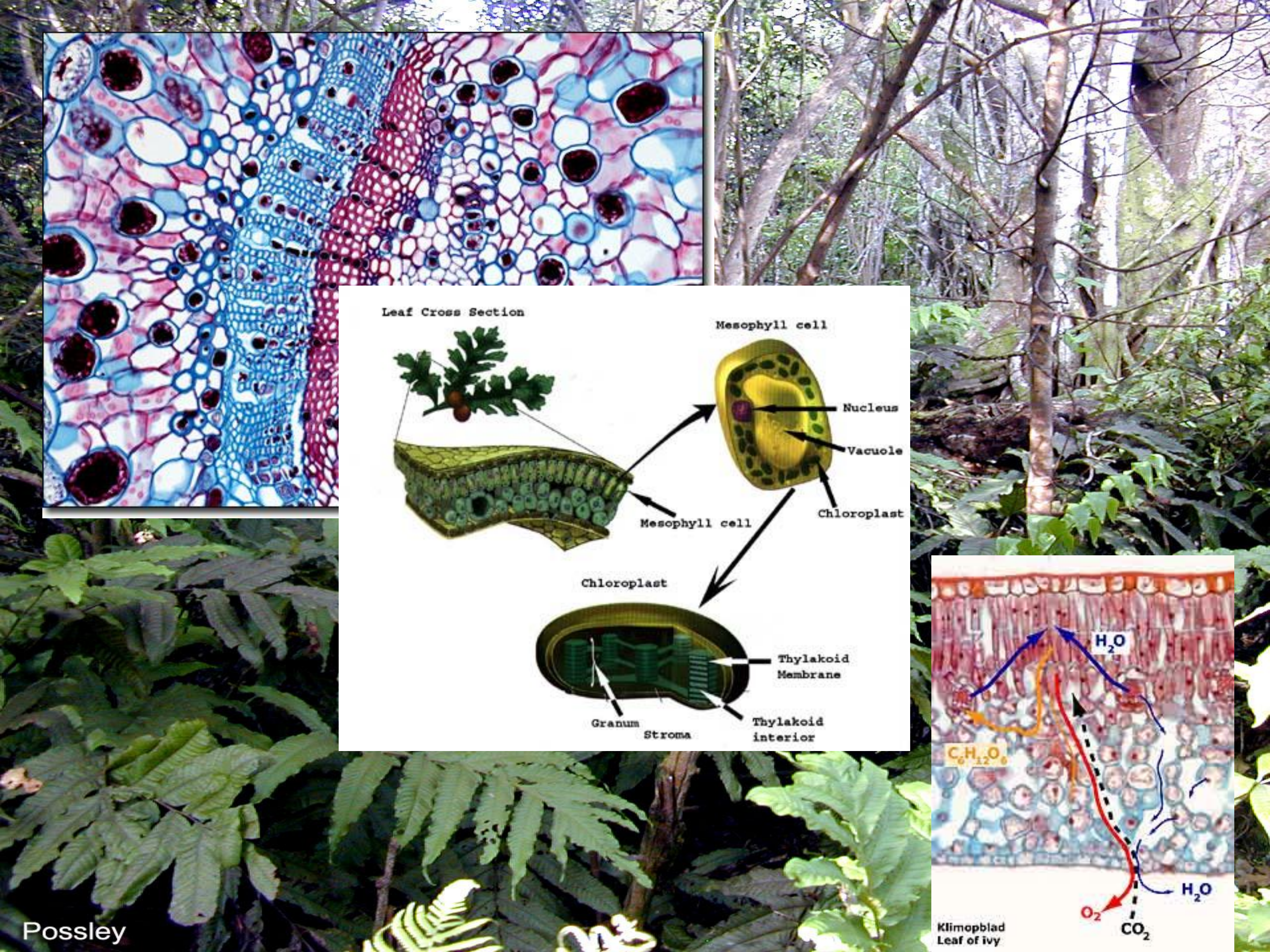
Where do these hydrocarbons come from?

- Presumably, they are products of **photosynthesis**, which is:

"…the conversion of light energy into chemical energy and biomass by living organisms. Its initial substrates are carbon dioxide and water; the energy source is light (electromagnetic radiation); and the end-products are oxygen and (energy-containing) carbohydrates, such as sucrose, glucose or starch." *

Hmmmmmm…………..this sounds familiar!

* *Wikipedia* 28.08.08


Leaf Cross Section
Mesophyll cell
Nucleus
Vacuole
Mesophyll cell
Chloroplast
Chloroplast
Thylakoid Membrane
Granum
Stroma
Thylakoid interior
H_2O
$C_6H_{12}O_6$
H_2O
O_2
CO_2
Klimopblad
Leaf of ivy
Possley

The fundamental photosynthesis equation:

e_{in}

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Look familiar?

So…photosynthesis and oxidation are mirror images of each other:

e_{in}

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

(plants split water and fix CO_2 into carbohydrates, releasing oxygen)

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

$+ e_{out}$

(carbohydrates are oxidized, releasing CO_2 and H_2O)

Hence, the entire cycle of carbon and energy can be expressed as a <u>single equation</u>*

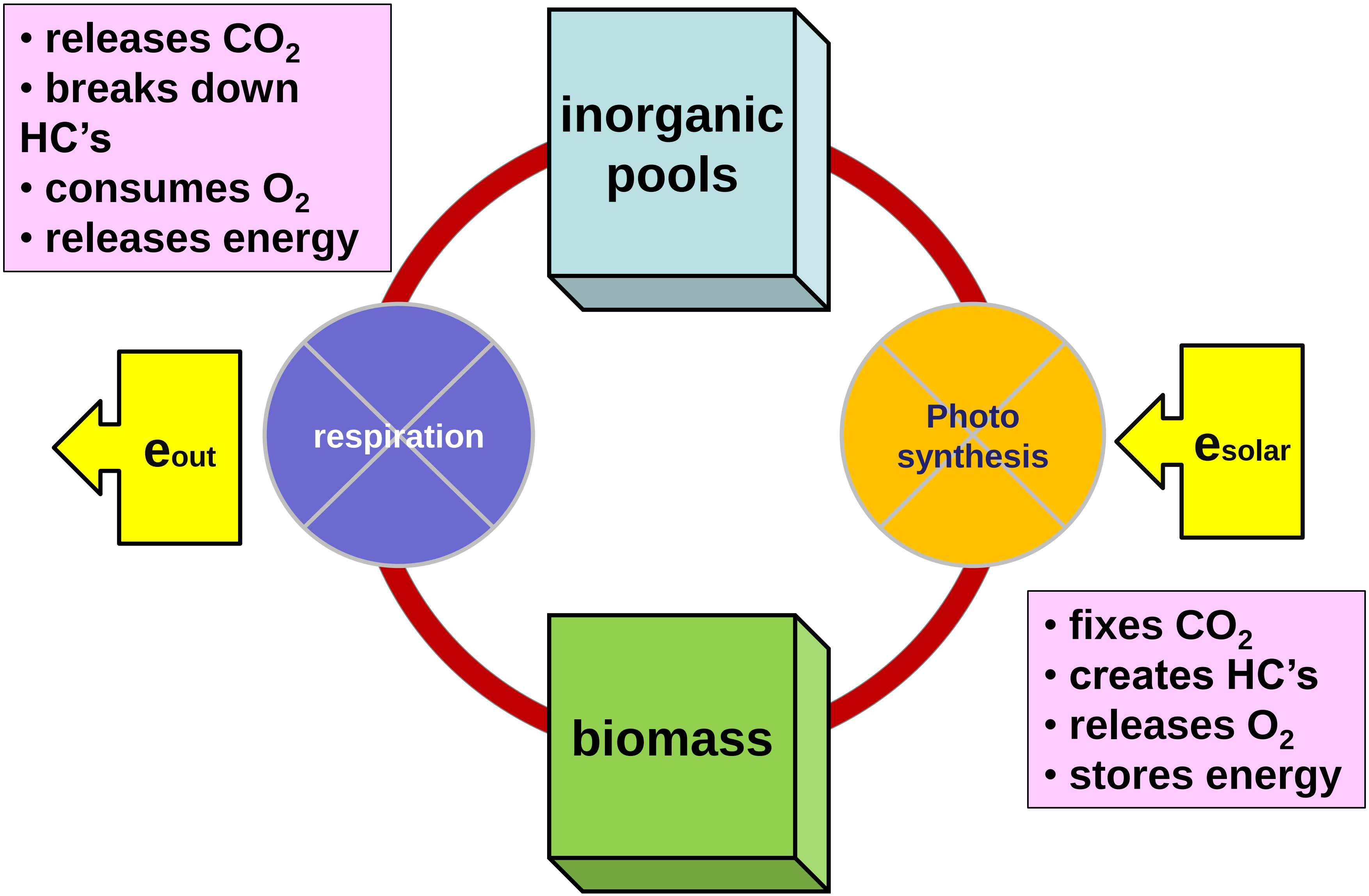
The Biomass-Energy Cycle

$$e_{in}$$

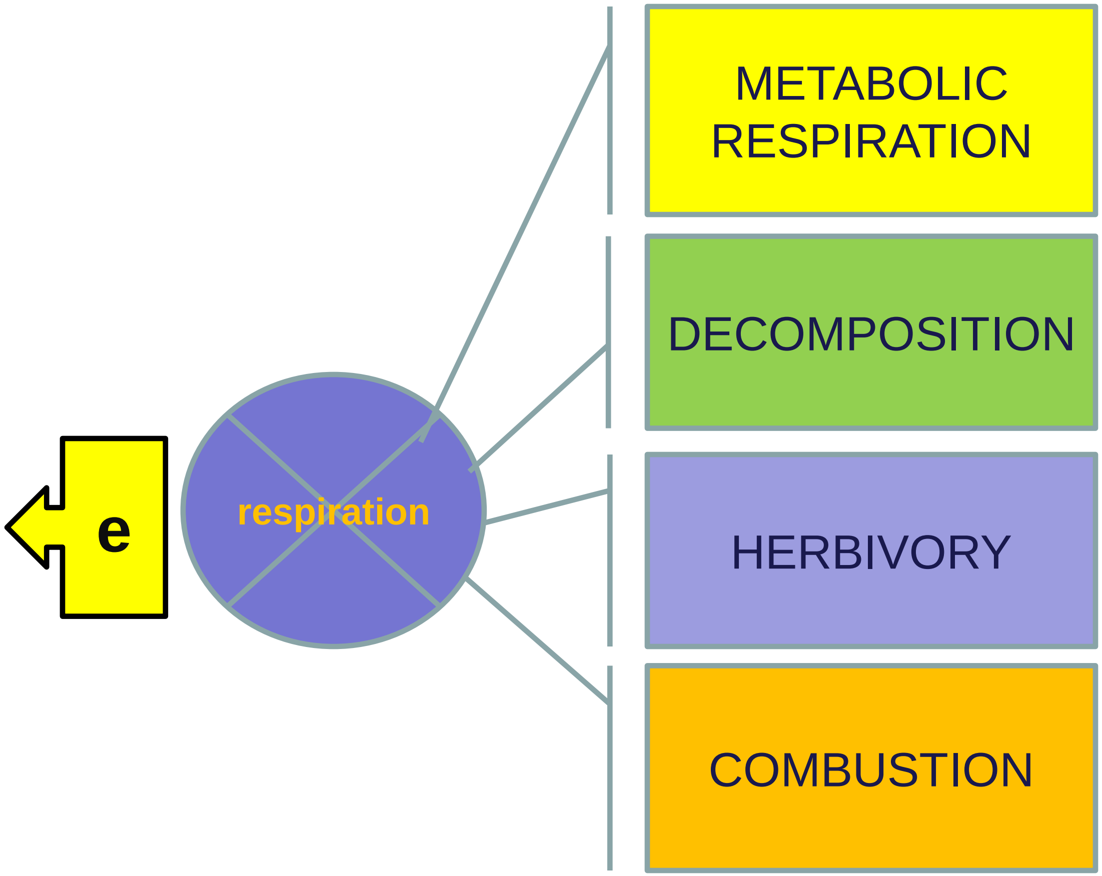
$$CO_2 + H_2O \leftrightarrow C_nH_mO_n + O_2$$

$$e_{out}$$

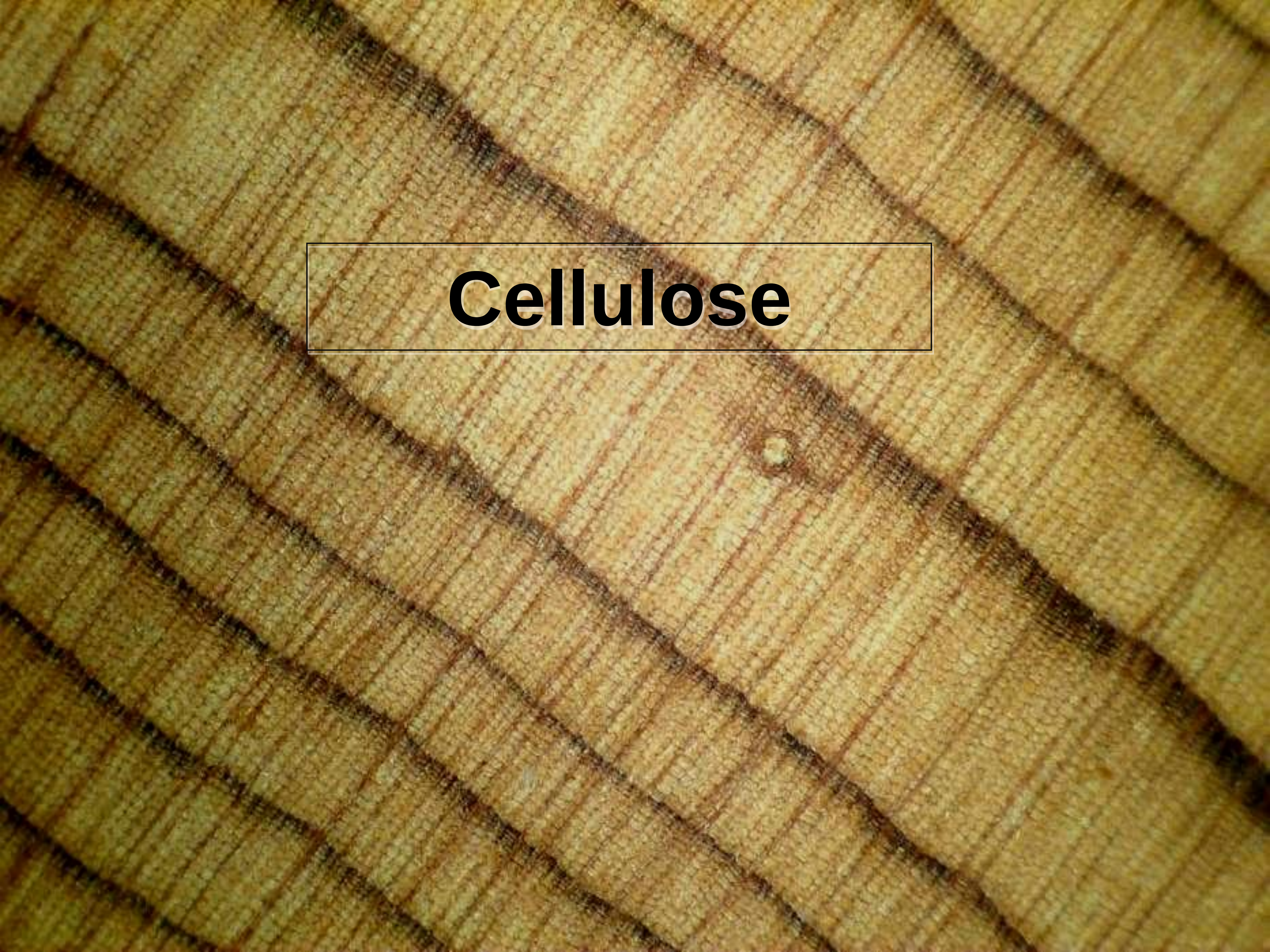
* Leaving aside the stoichiometry for the moment


• releases CO_2
• breaks down HC's
• consumes O_2
• releases energy
inorganic pools
respiration
Photo synthesis
e_{out}
e_{solar}
biomass
• fixes CO_2
• creates HC's
• releases O_2
• stores energy

Inside the “respiration” box: what ecological processes break down organic molecules, release energy, and process carbon?



Cellulose



Cellulose factoids:

- Cellulose is a form of carbohydrate made of chains of as many as 1500 glucose rings;
- Cellulose molecules tend to be straight chains, so fibers made of cellulose molecules have the strength to form the supporting structures of plants;
- Wood is largely cellulose, making cellulose the **most abundant organic compound** on the Earth.

Composition of vegetative biomass (e.g. wood and grasses)

- Live, sound wood is 35-55% cellulose
- With smaller fractions of:
  - hemicellulose (20-35%)
  - lignin (10-25%)
  - extractives (10-45%)
  - water
  - other minor components

http://genomicscience.energy.gov/benefits/cellulosicethanol.shtml

Cellulose:

- Long polymer chains of hexose (d-glucose)
- Form bundles or fibers

Hemicellulose:

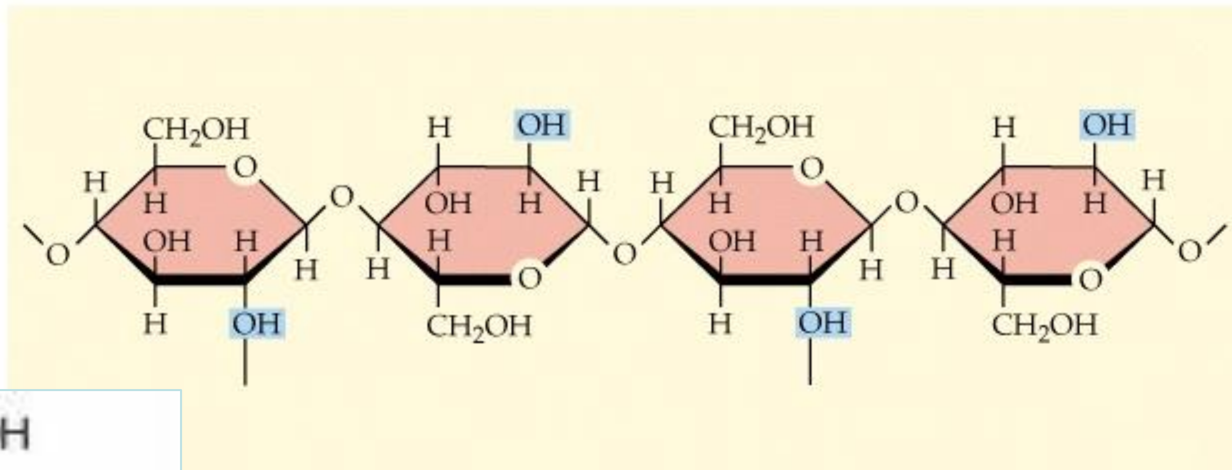
- Also polysaccharides, but shorter than cellulose

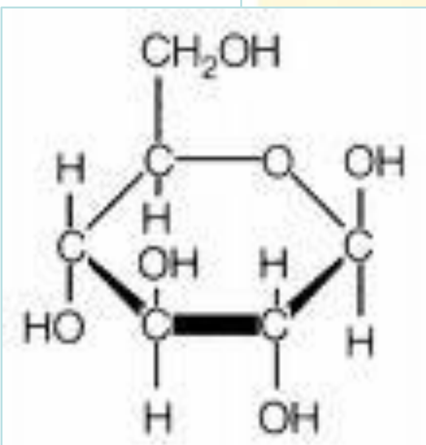
Lignin:

- Denser, complex organics
- Helps make wood hard and decay-resistant

(*a*) **Molecular structure**

Cellulose





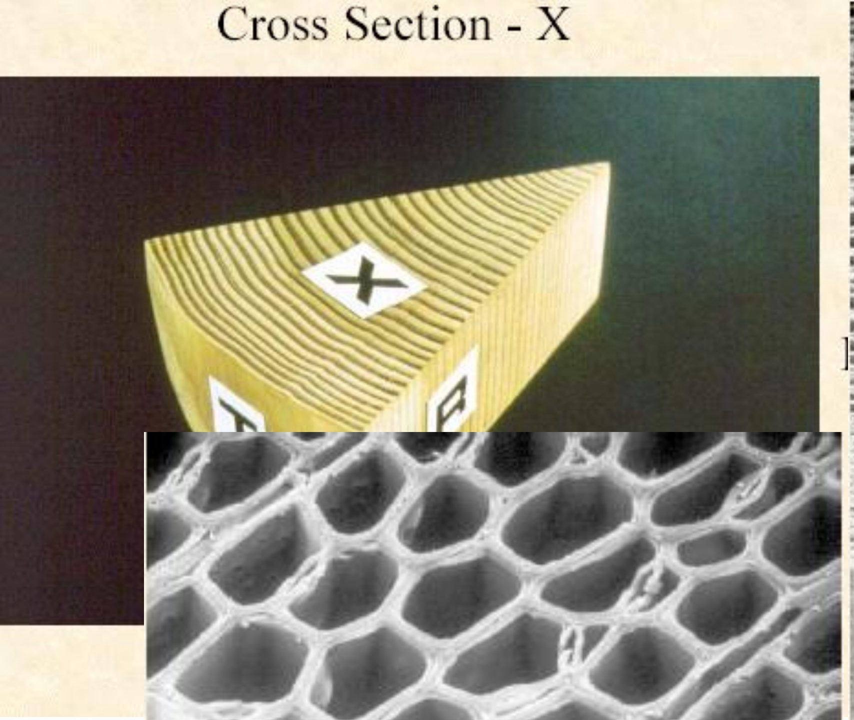
Elemental composition of wood (dry weight):

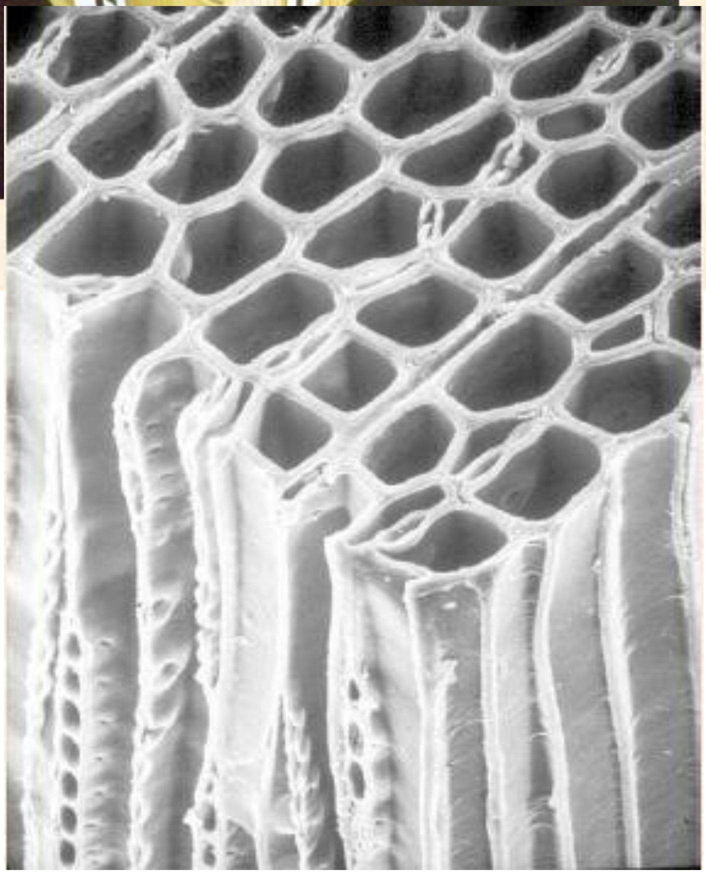
~ 50% C

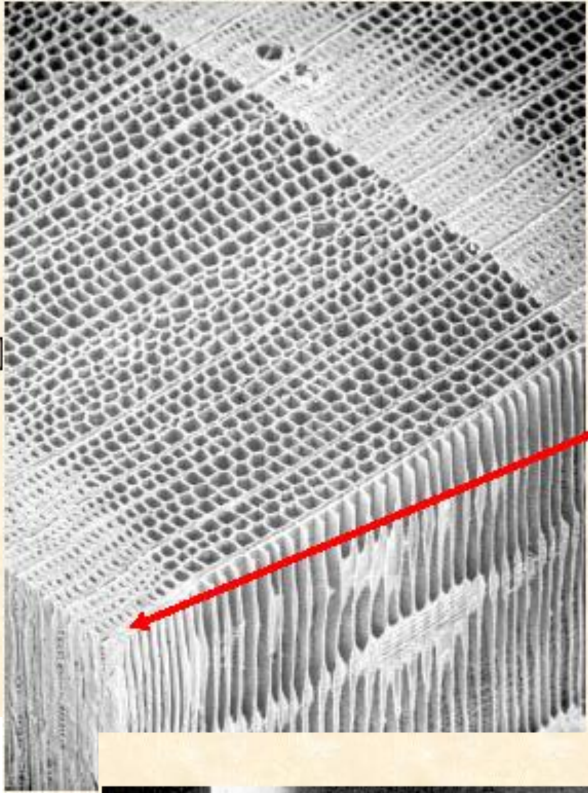
~ 44% O

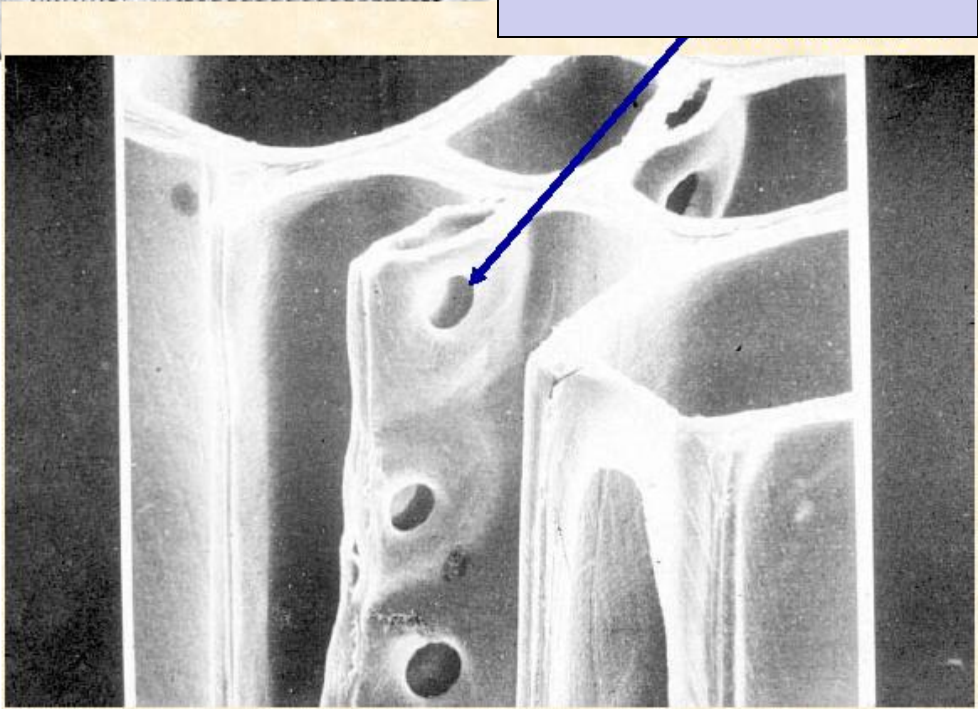
~ 5% H

~ 1% other elements (N, S)



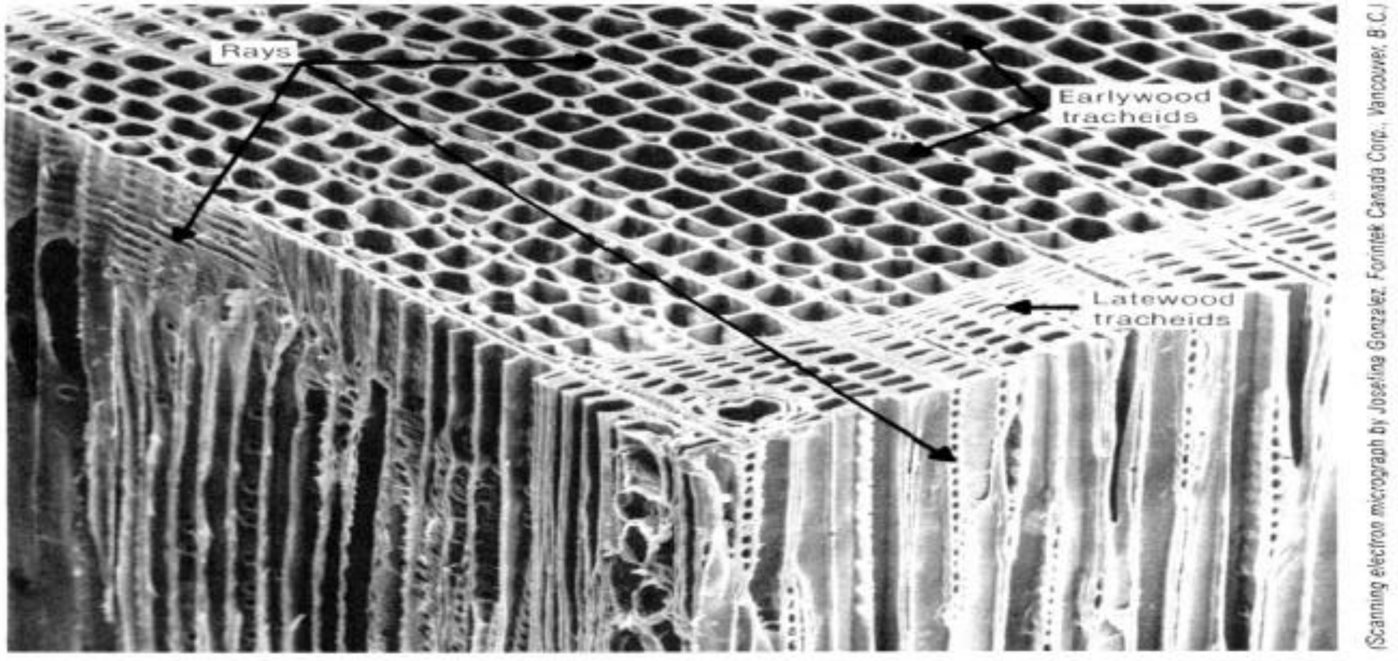






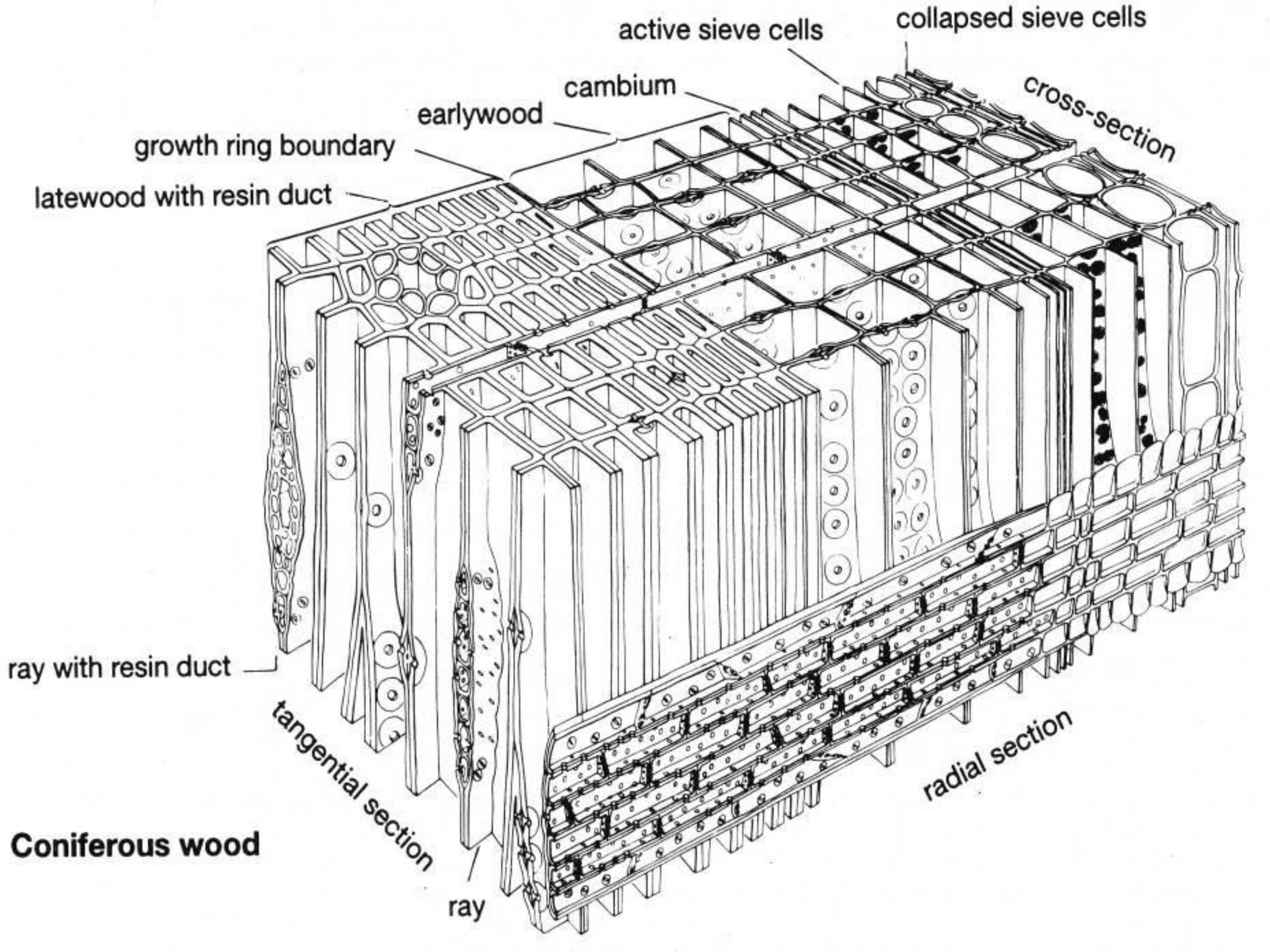
Where is the cellulose?

Mostly in **cell walls**



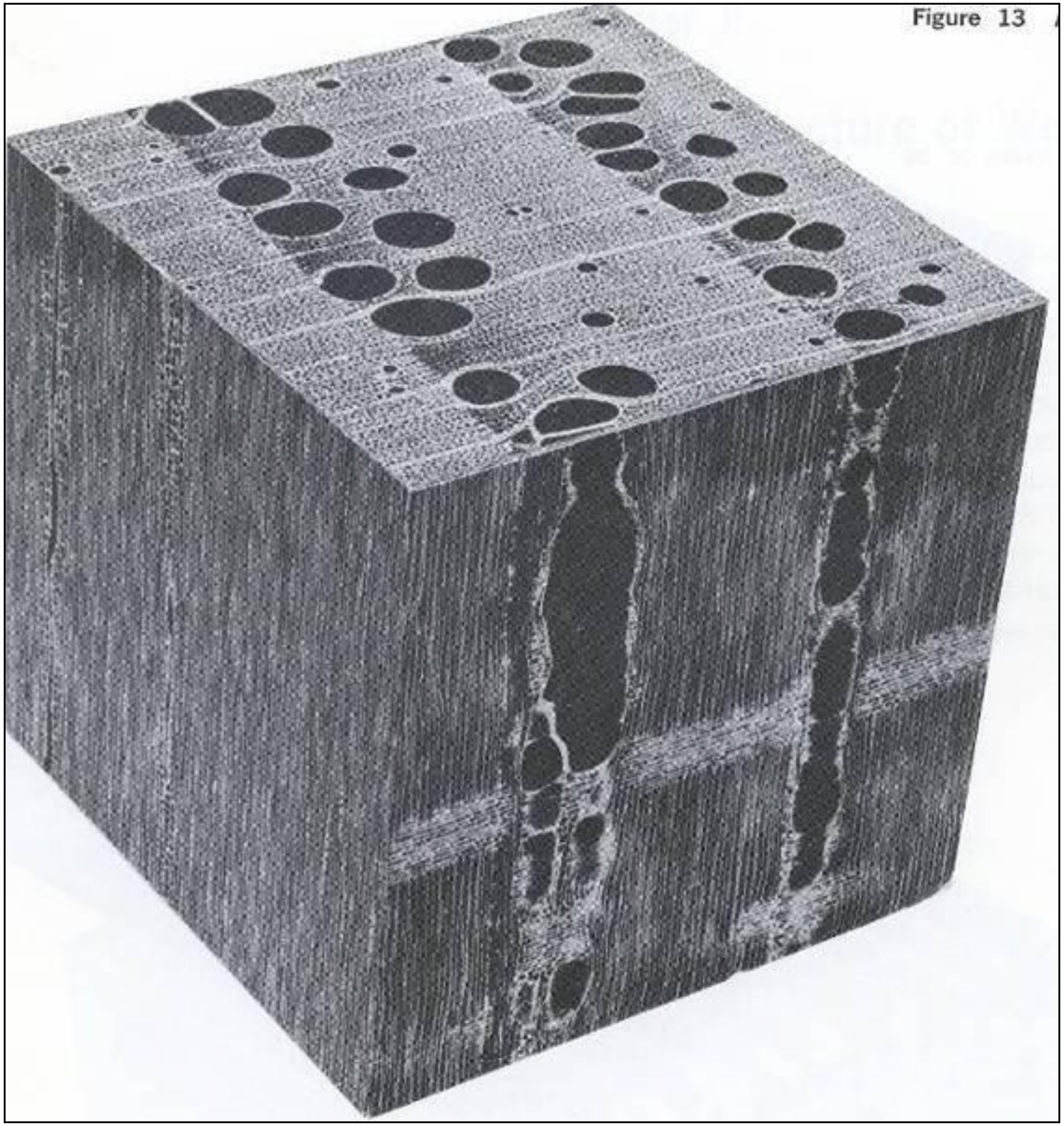
A. Softwood: Sitka spruce (*Picea sitchensis*). ×75

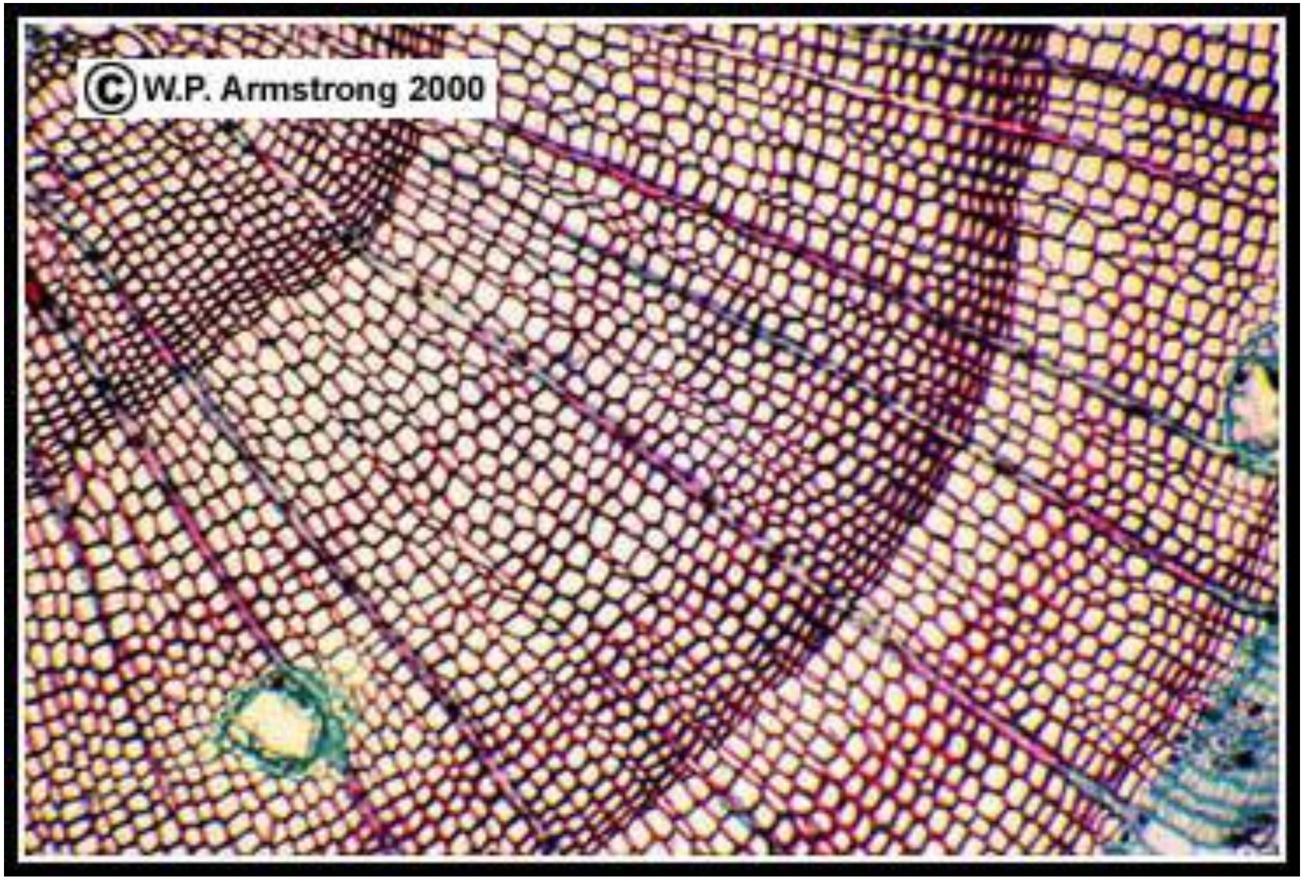
- In softwood (most conifer) trees such as pine, wood is composed of long (3 to 5 millimeters) tracheid cells that allow movement of the sap.



Coniferous wood

Hardwood (angiosperm) wood structure





Microscopic view of a 3-year-old pine stem (**Pinus**) showing resin ducts, rays and three years of xylem growth (annual rings). Magnified ~200X.

If we just count the cellulose component, which is mainly what burns:

$2C_6H_{10}O_5 + 12O_2 \rightarrow 12CO_2 + 10H_2O +$ -17.47 MJ/kg energy released*

1 J = 0.239 cal, so 1 MJ = 10^6 J x 0.239 cal/J = 239,063 cal/MJ

* By convention, a “-” sign indicates a net exothermic reaction

So the heat released by burning 2 kg (about 4.4 lbs, a medium size piece of firewood) of cellulose is:

-17.47 MJ/kg x 2 kg = -34.74 MJ

-34,740,000 J x 0.239 cal/J = 8,302,860 cal

That's a lot of energy!

But wait…fire is combustion in free air, not pure oxygen

- What are the constituents of air (*i.e.*, what are you breathing right now)?

Roughly:
78.08% N_2
20.95% O_2
0.93% Ar
0.03% CO_2
0.01% everything else (Ne, He, Kr, SO_2, CH_4, H_2, N_2O)

So, don't all these other elements change the combustion equation?

Not really! Recall combustion of methane in a pure oxygen environment:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Now do the same reaction in free air (78% N_2, 20.9% O_2, etc.) :

$$CH_4 + 2O_2 + 3.9N_2 \rightarrow CO_2 + 2H_2O + 3.9N_2$$

So: nitrogen gas is not part of the combustion equation! However, some N_2 is oxidized by another pathway into nitrous oxides (No_x) which become part of the gases emitted from combustion. More on that later.

Foliage (leaves) also contains secondary compounds: "extractives":

- Aromatic hydrocarbons
- Alcohols
- Aldehydes
- Gums
- Terpenes
- Waxes

These are <u>very</u> important in the combustion of foliage, and thus fire behavior

Take-home ideas:

1. Combustion is the reverse process of photosynthesis.
2. Combustion is a member of a family of processes (decomposition, cellular respiration) that break down complex molecules.
3. All of the energy in a fire has been fixed by photosynthesis.
4. The main components of woody vegetation (esp. cellulose) store a *lot* of energy.

Next time: Stages of combustion and modes of energy transfer