Plant Biotechnology for Biofuels

Markus Pauly

Energy Biosciences Institute

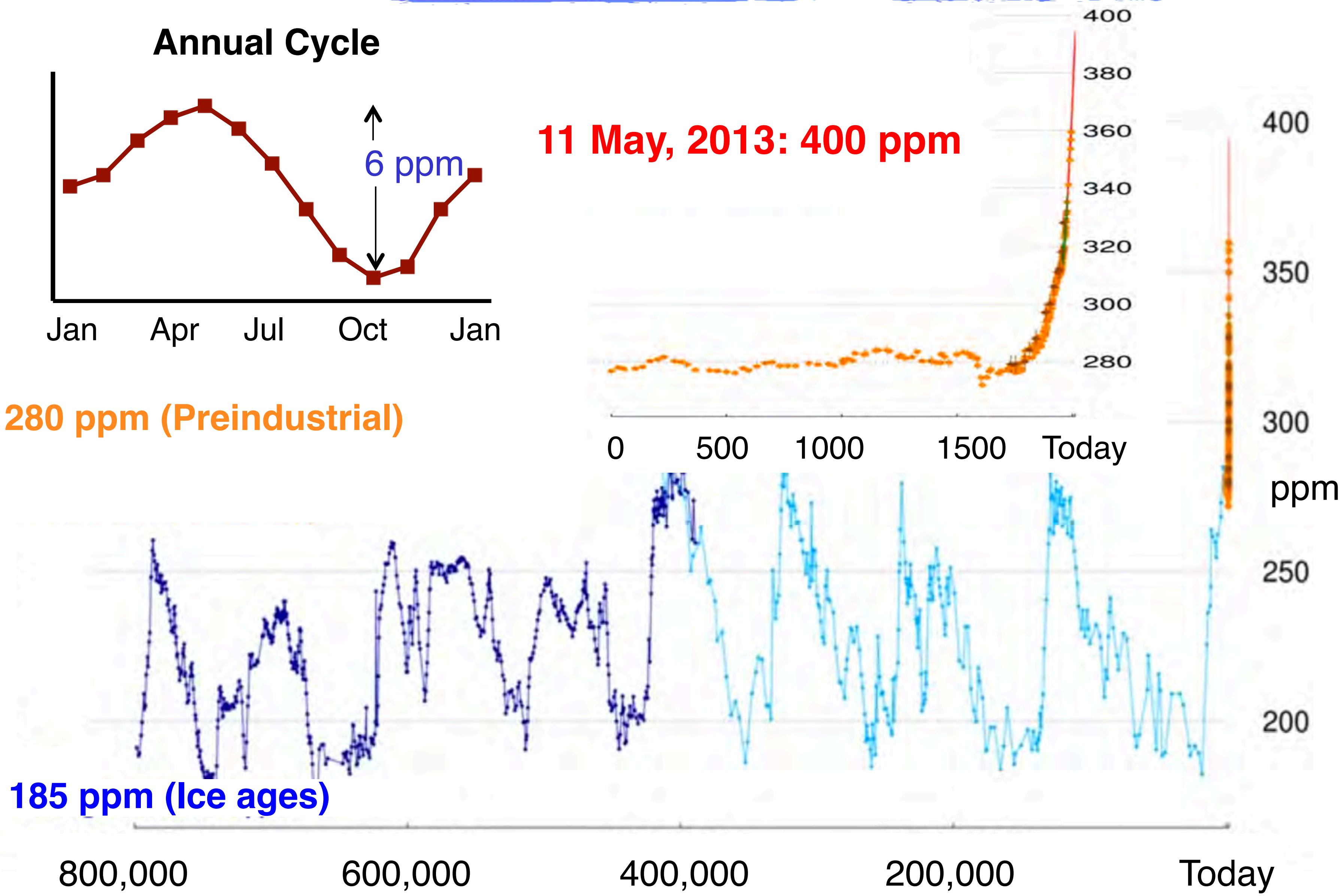
Department of Plant and Microbial Biology

UC Berkeley

Princeton University, October 14, 2013

CO_2-concentration in the atmosphere

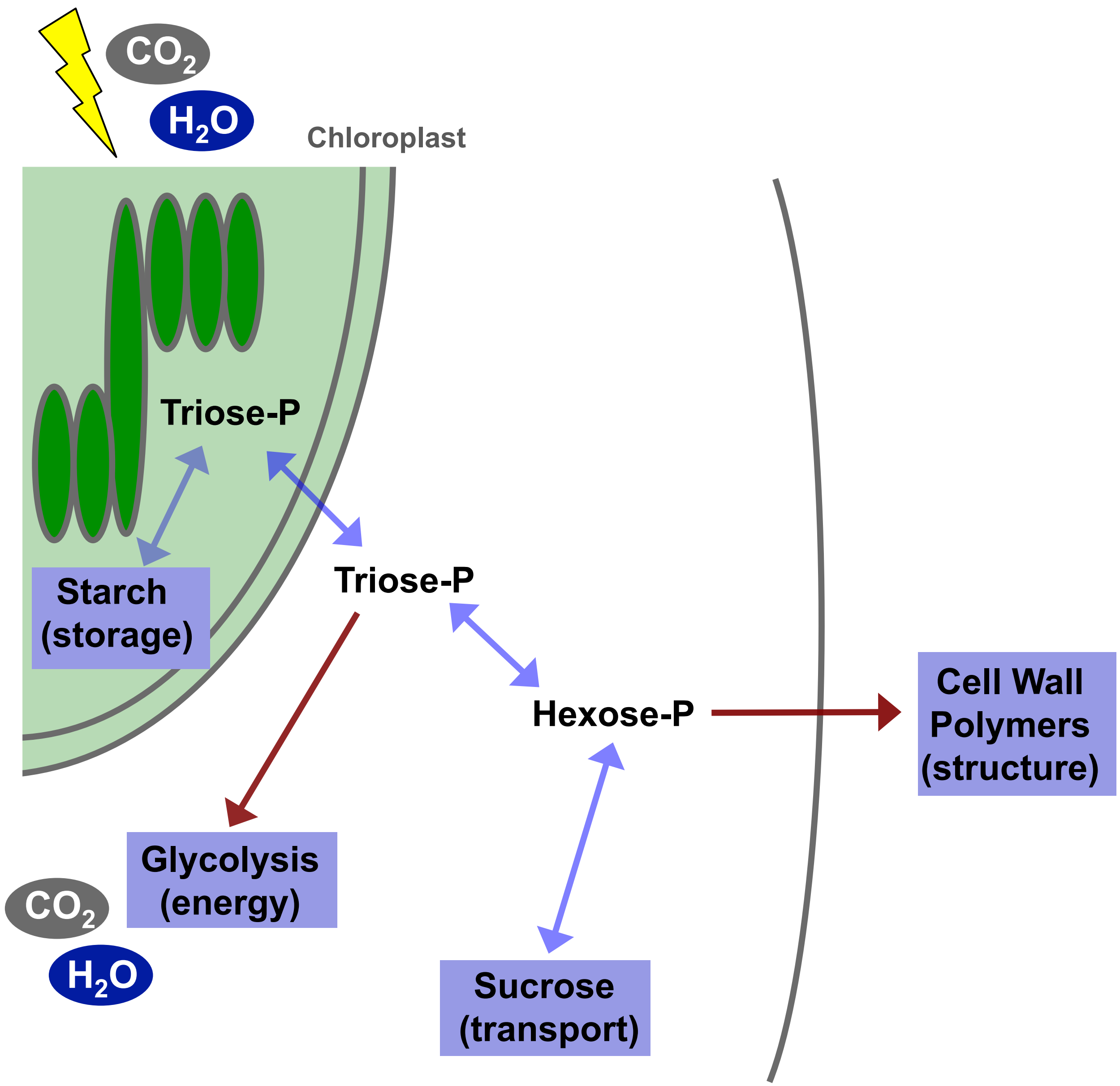
© Markus Pauly



Scripps Institute of Oceanography; National Climatic Data Center

Carbon fixation in plants

© Markus Pauly



Plant cell walls and Carbon Cycle

© Markus Pauly

Assimilated CO_2	**55 x10^9 t / a**
Plant Biomass (land, worldwide)	**170 – 200 x 10^9 t / a**
Cell walls (land, worldwide)	**120 – 170 x 10^9 t / a**

Field et al., 1998; Porter and Vilar, 1997; Pauly and Keegstra 2008

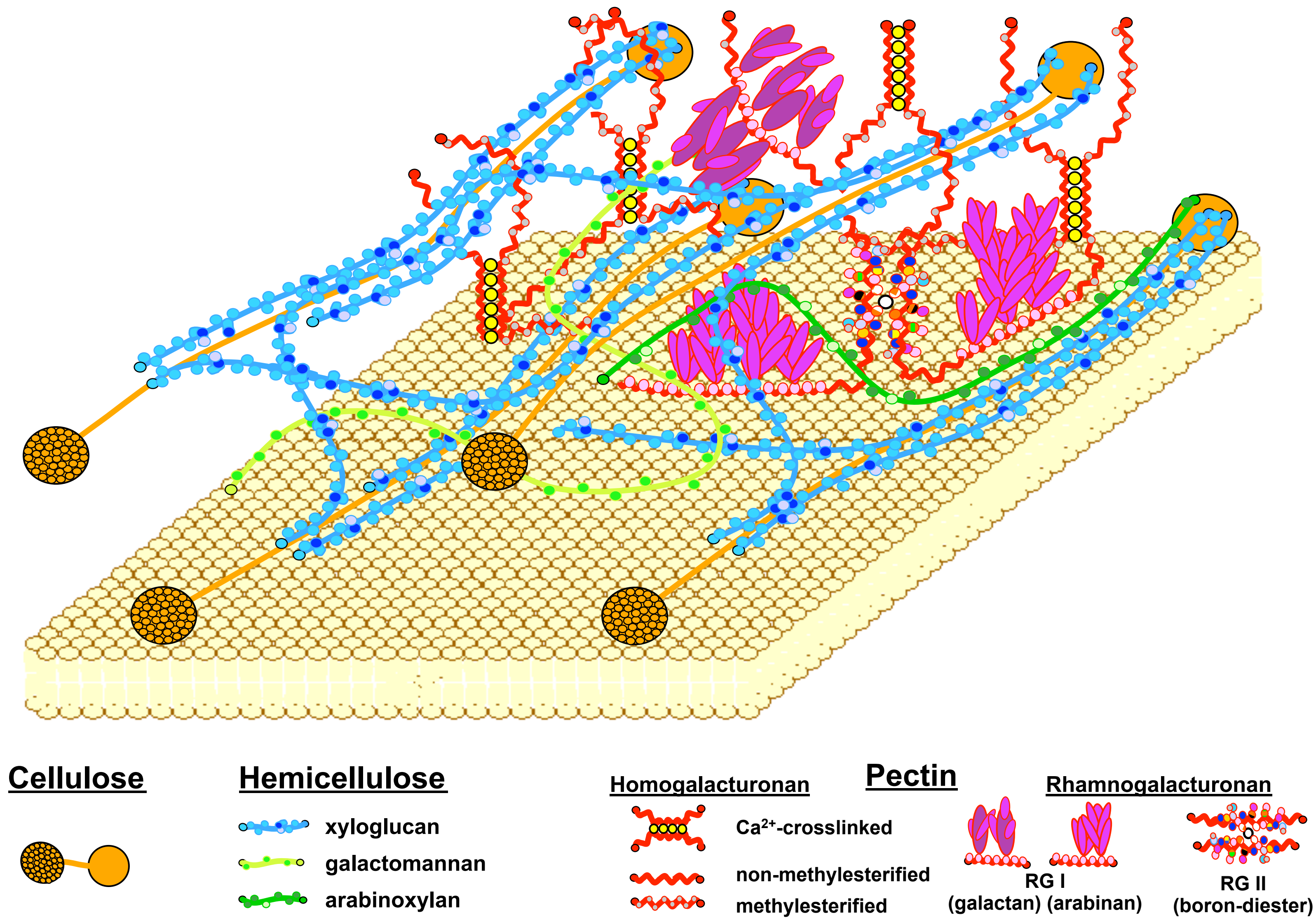
Annual global production of chemicals 2010 (without pharmaceuticals) **1.2 x 10^9 t**

BASF report 2010 – Trends in the chemical industry

► Cell walls represent the dominant biological carbon sequestration system

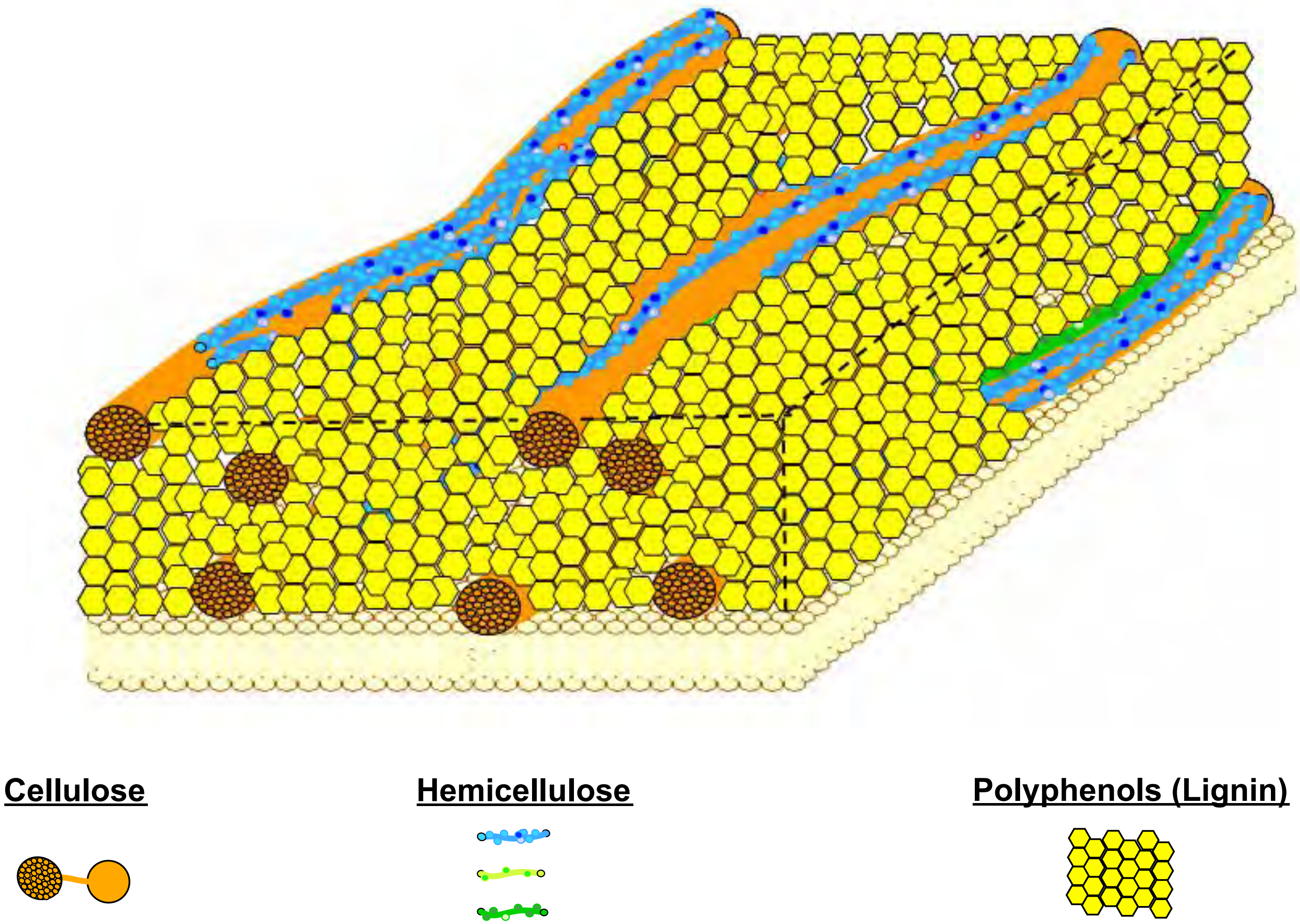
The Plant Cell Wall

© Markus Pauly



The mature Plant Cell Wall

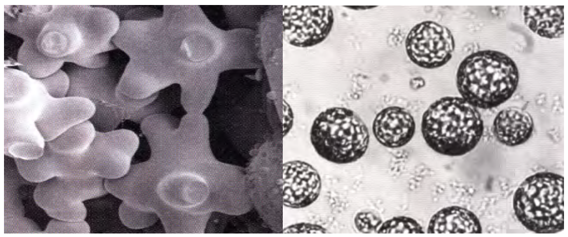
© Markus Pauly



Function of plant cell walls

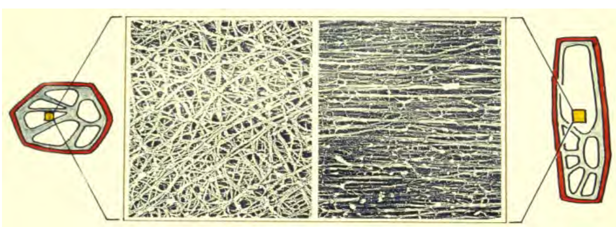
© Markus Pauly

- structural integrity of cell/ tissue/ plant
  - cell shape/ plant morphology
  - cell adhesion
  - barrier (mechanical/ path. defense)



Buchanan, 1999

- dynamic entity of the cell
  - cell expansion



Keith Roberts

- reposit for signaling molecules
  - pathogen attack

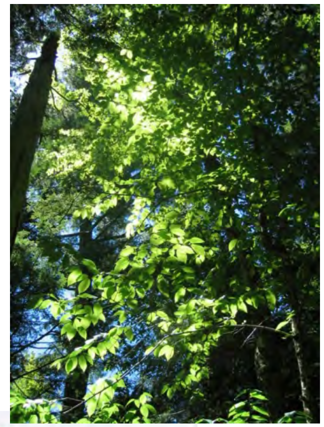
Redwoods:

up to 379 feet high, up to 2200 y old

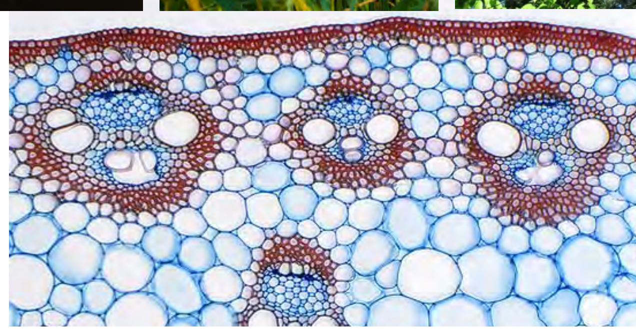
The Plant Cell Wall: Diversity

© Markus Pauly

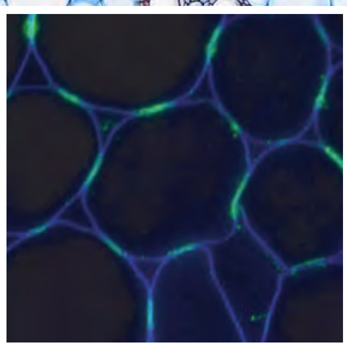
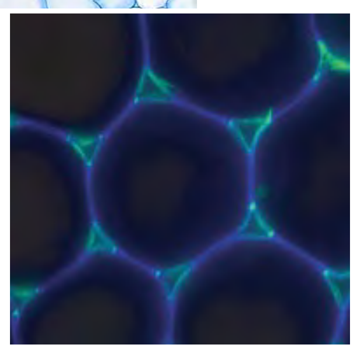




► **plant species**



► **plant tissue**

Courtesy of Paul Knox, Univeristy of Leeds

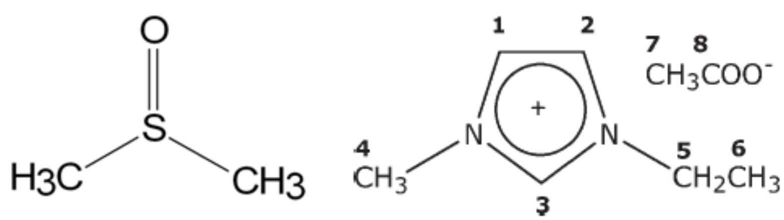
► **plant cell**

Assessment of plant cell wall structural diversity:
Whole lignocellulosic 2D-NMR

© Markus Pauly

Plant tissue (Lignocellulosics) → **Ball milling** → **Dissolution in organic solvent** → **2D-NMR spectroscopy**

10 mg (dry)



DMSO-d$_6$/[Emim]OAc-d$_{14}$

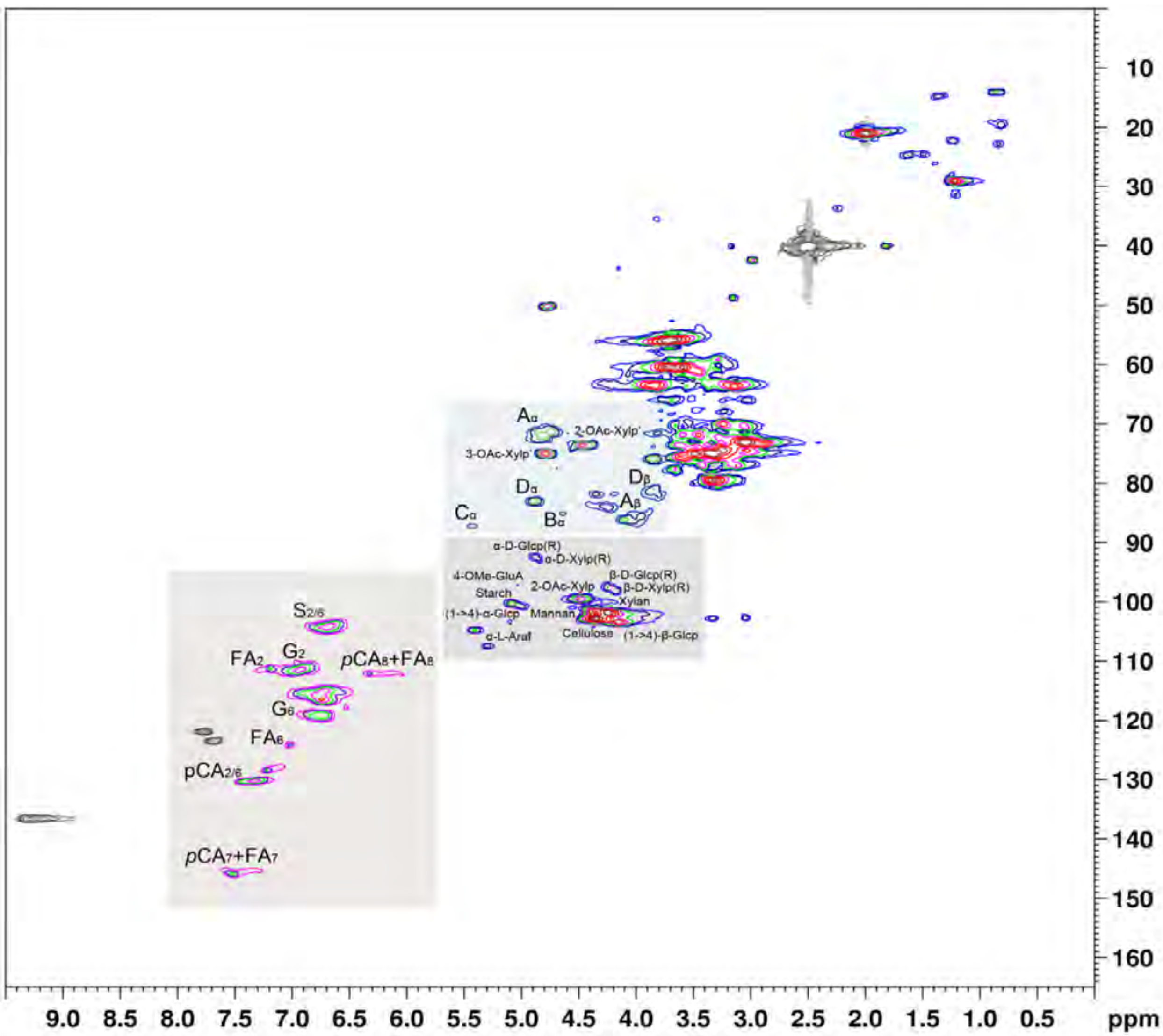
750 µl : 10 µl

Kun Cheng

Whole lignocellulosic 2D-NMR

© Markus Pauly

^{1}H-^{13}C HSQC

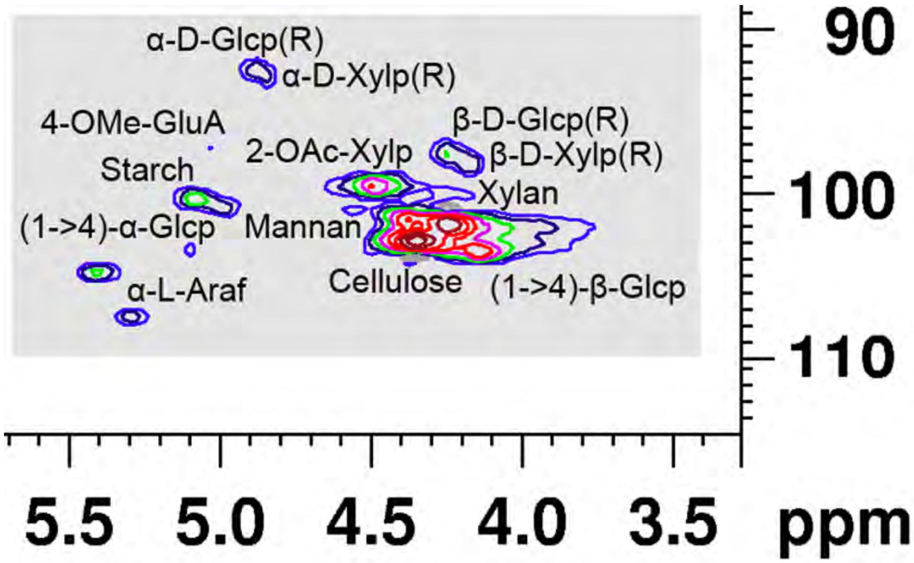


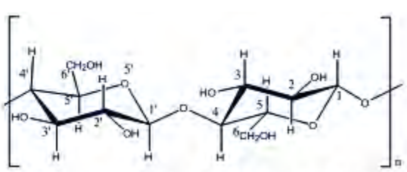
Kun Cheng

Whole lignocellulosic 2D-NMR

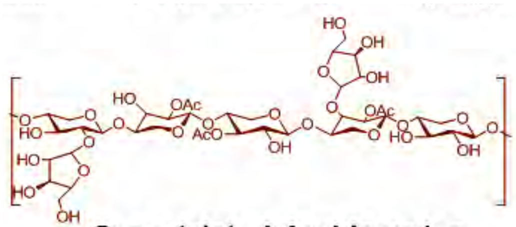
© Markus Pauly

Anomeric polysaccharides





Cellulose ((1→4)-β-D-Glc*p*)

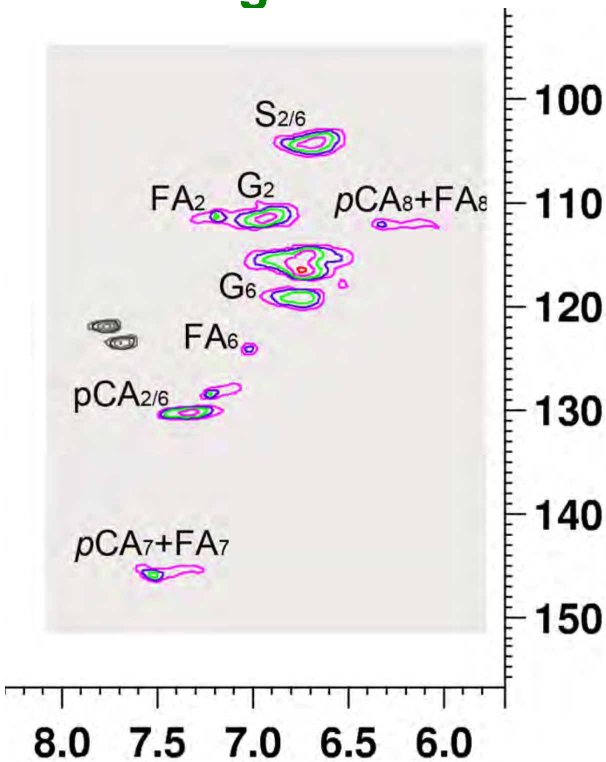


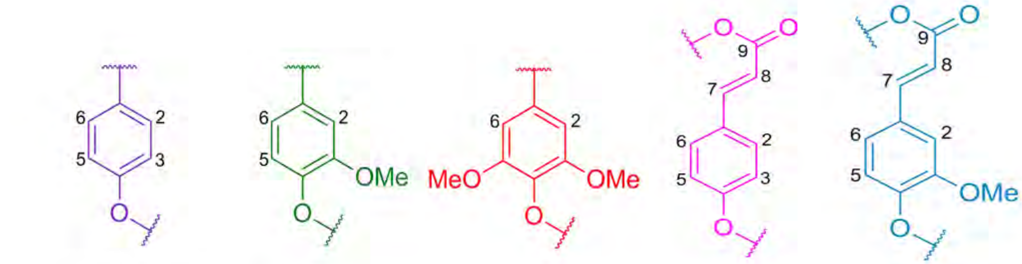
O-acetylated-Arabinoxylan

Whole lignocellulosic 2D-NMR

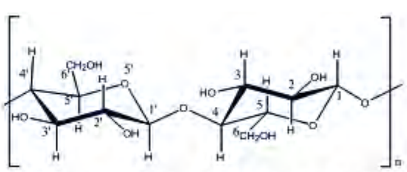
© Markus Pauly

Aromatic Lignin

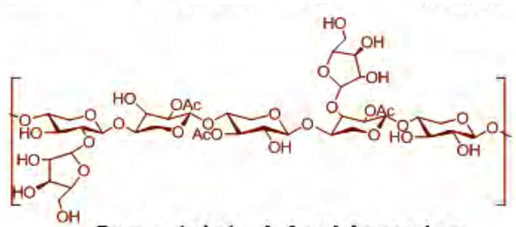




H p-hydroxyphenyl | **G** guaiacyl | **S** syringyl | ***p*CA** *p*-coumarate | **FA** ferulate



Cellulose ((1→4)-β-D-Glc*p*)

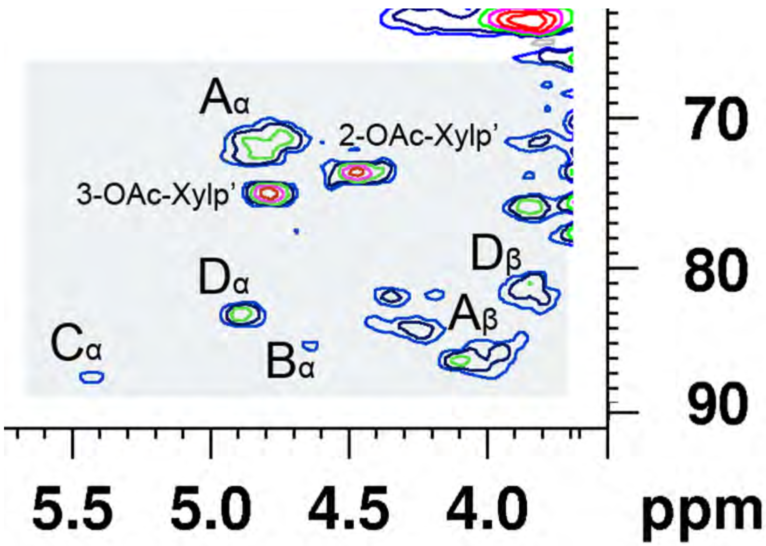


O-acetylated-Arabinoxylan

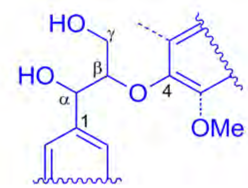
Whole lignocellulosic 2D-NMR

© Markus Pauly

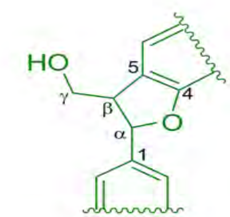
Aliphatic Lignin linkages



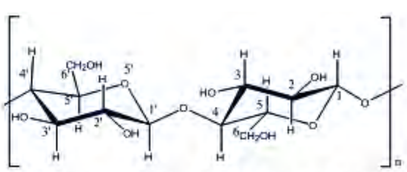
H *p*-hydroxyphenyl | **G** guaiacyl | **S** syringyl | ***p*CA** *p*-coumarate | **FA** ferulate



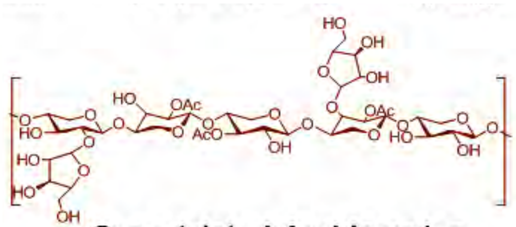
A
β-aryl ether



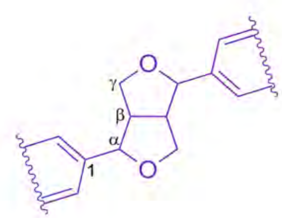
B
phenylcoumaran



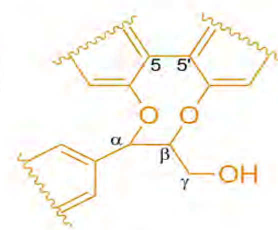
Cellulose ((1→4)-β-D-Glc*p*)



O-acetylated-Arabinoxylan



C
resinol



D
dibenzodioxocin

Whole lignocellulosic 2D-NMR

© Markus Pauly

	Molar percentage (Miscanthus)	
Glc	63	+/- 3
Xyl	32	+/- 1
Ara	3	+/- 0.5
Man	2	+/- 0.5
GlcA	>1	
Ac-xylan	53	+/- 2
Guaiacyl (G)	54	+/- 1
Syringyl (S)	40	+/- 1
P-hydroxyphenyl (H)	5	+/- 0.5
S/G ratio	>1	
Aryl-ether (A)	68	+/- 3
Phenylcoumaran (B)	1	
Resinol (C)	7	+/- 0.5
Dibenzodioxacin (D)	24	+/- 1

Cheng, Sorek, Zimmermann, Wemmer, Pauly (2013) Analytical chemistry

„Structural Space" of lignocellulosics

© Markus Pauly

Plant species

Model plant

Arabidopsis

Energy Grass

Switchgrass

Miscanthus

Agriculture residues

Rice

Sorghum

Sugarcane

Maize

Forestry resources

Pine

Maple

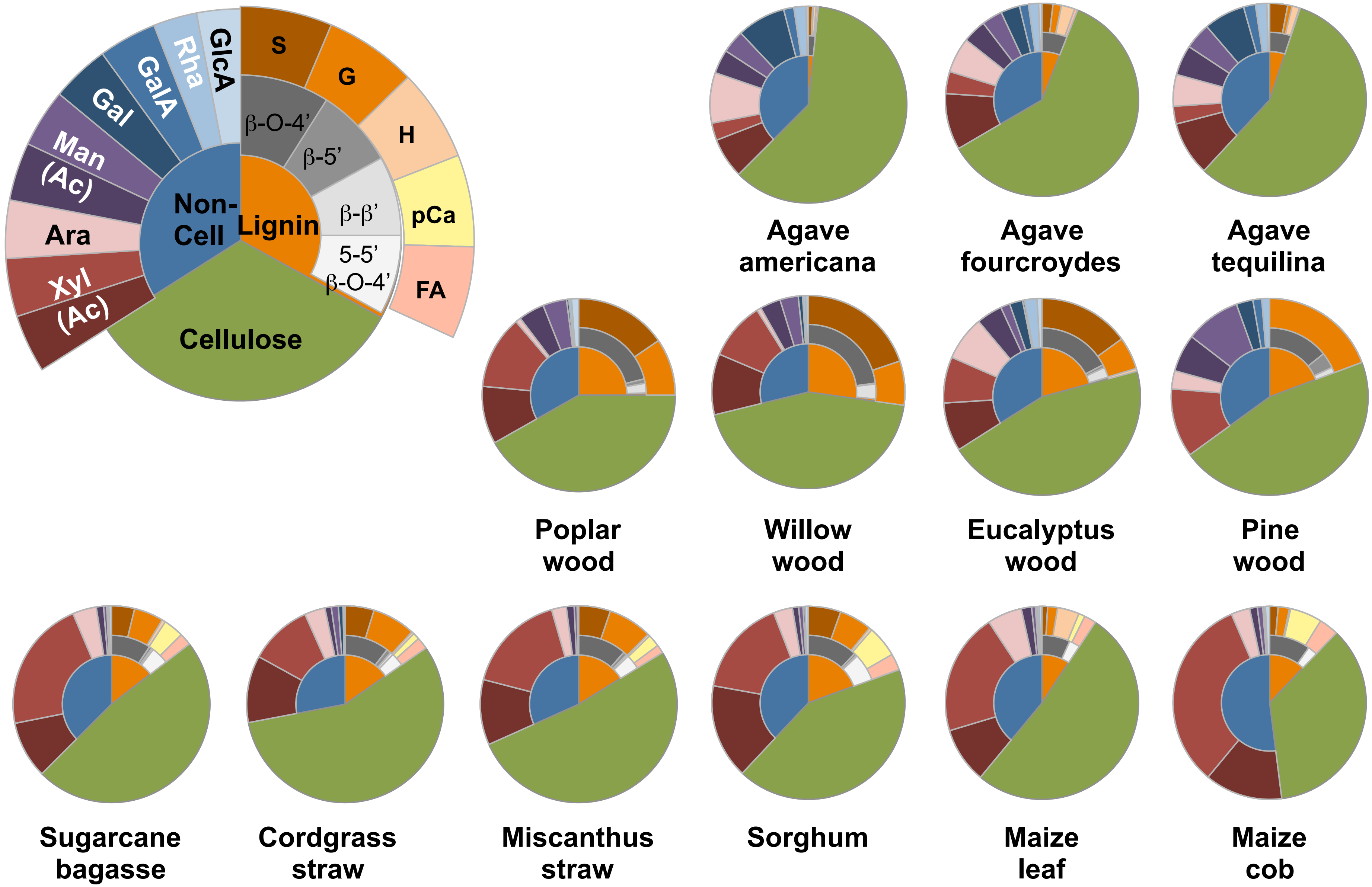
Willow

Poplar

Eucalyptus

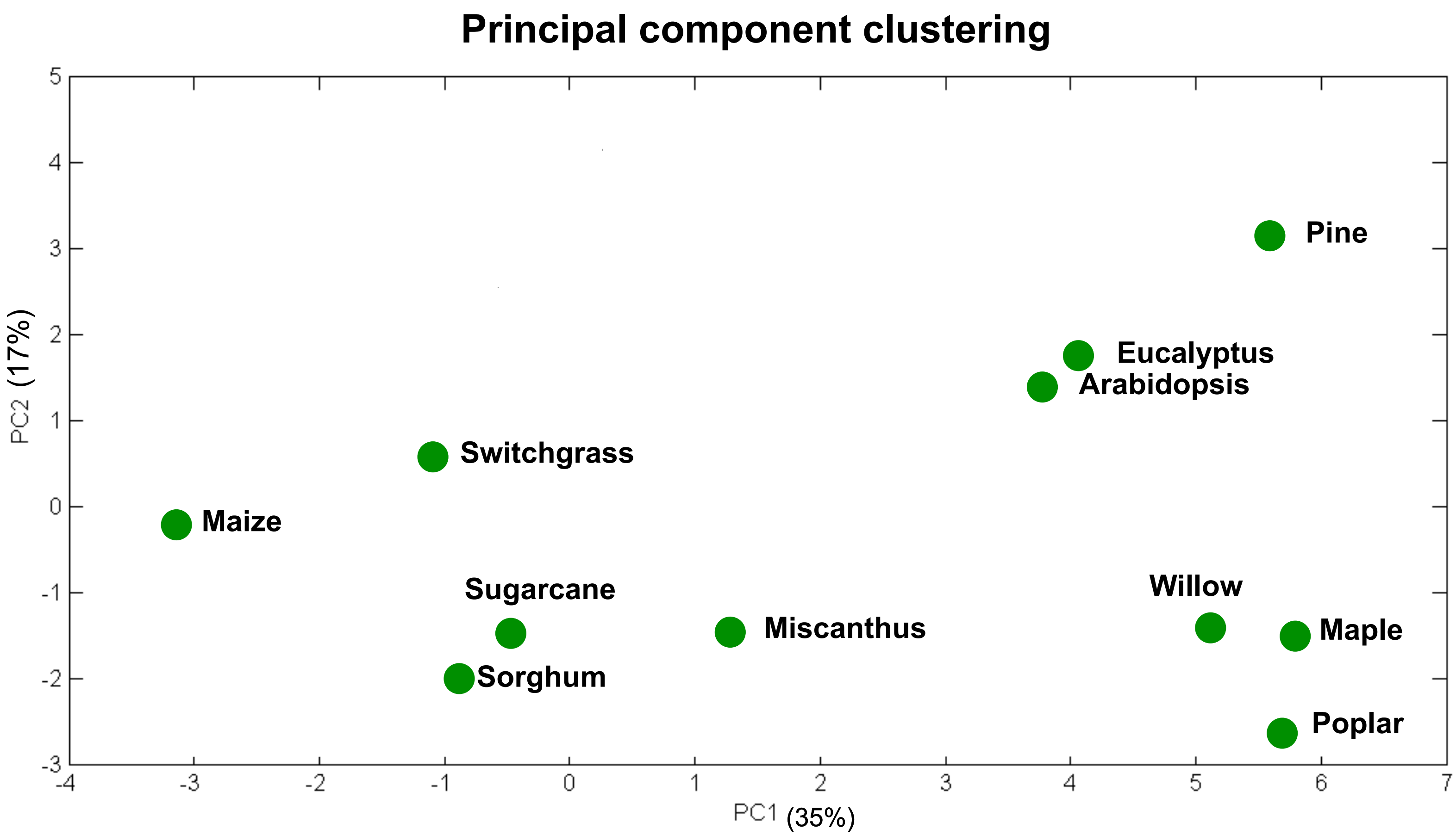
Lignocellulosic structural diversity

© Markus Pauly



„Structural Space“ of lignocellulosics

© Markus Pauly

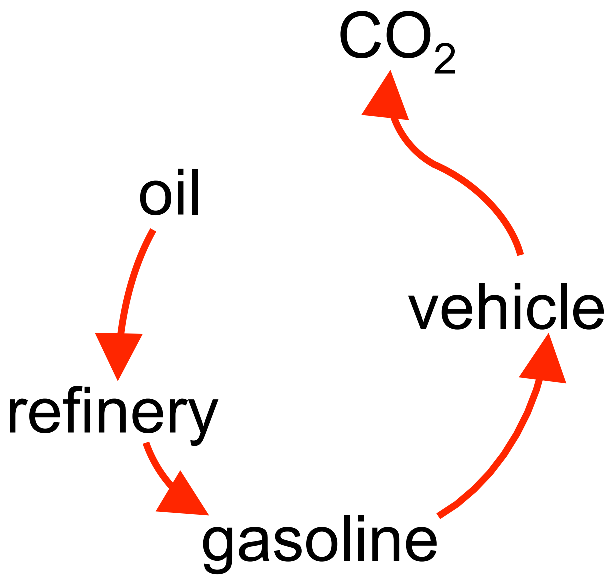


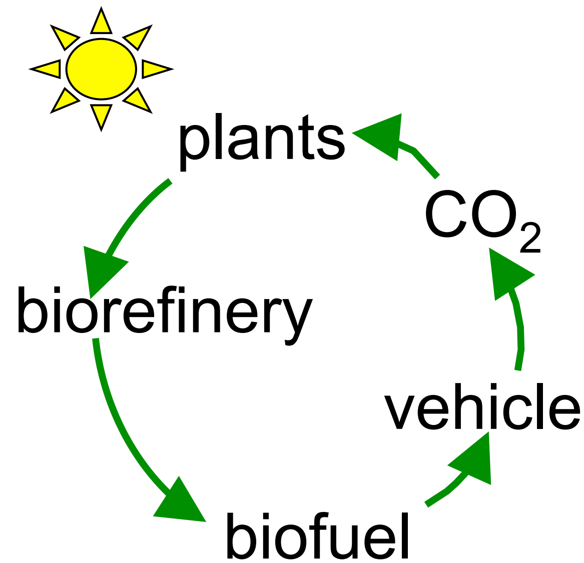
Plant species

► **Grasses ≠ Wood (Hardwood ≠ Softwood)**

Alternative to fossil fuels: Plant biomass

© Markus Pauly





- **Plants capture energy from the sun**
- **Plants convert energy into durable chemicals**
- **Plants sequester CO_2 from the atmosphere**

Lignocellulosics as renewable resource

© Markus Pauly

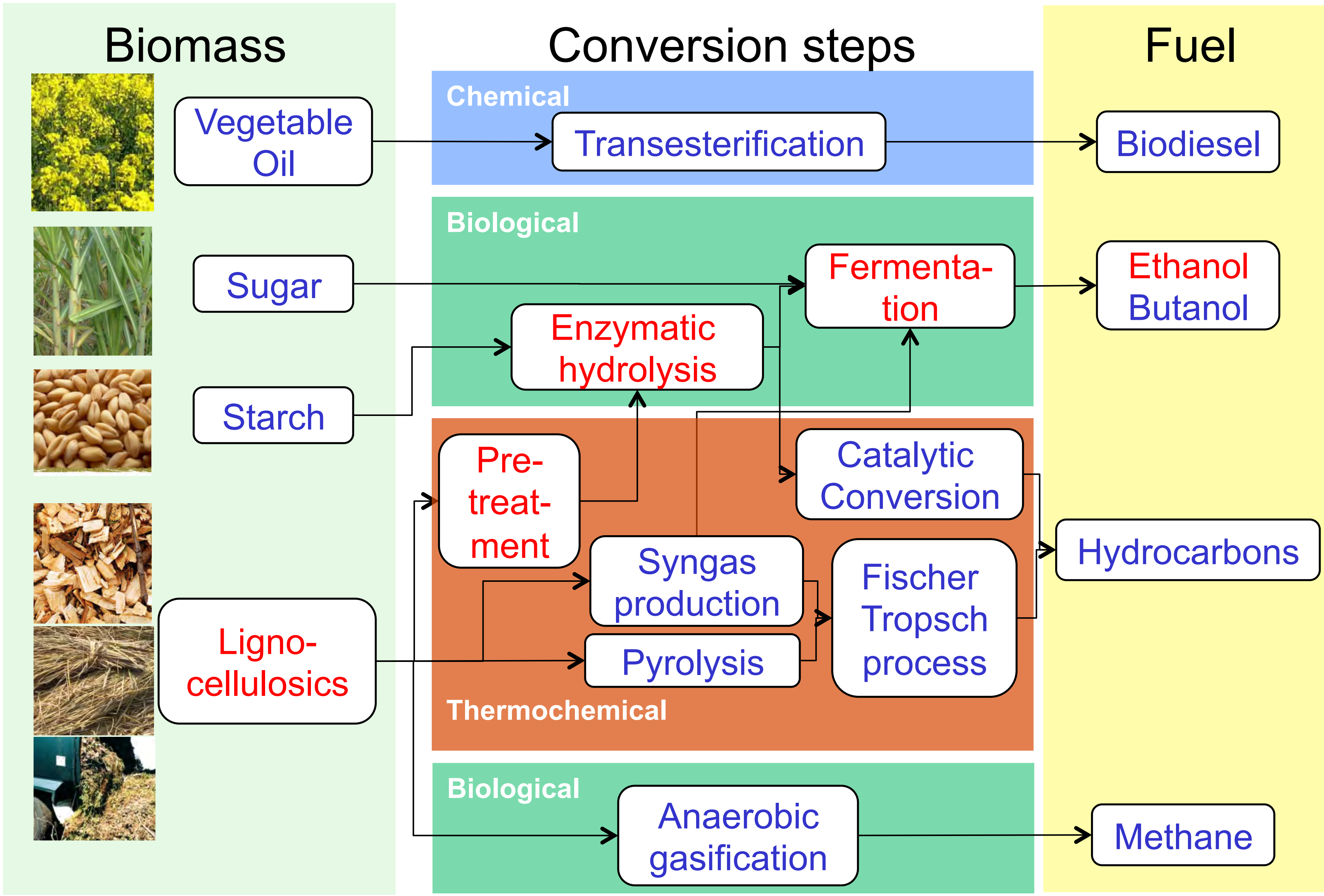
- ► **Cell walls (lignocellulosics) are non-food components**
- ► **Lignocellulosics are highly abundant**

    Dominant biological carbon sequestration system

- ► **The conversion of lignocellulosics is energy and cost-intensive**

Biomass to Biofuels

© Markus Pauly

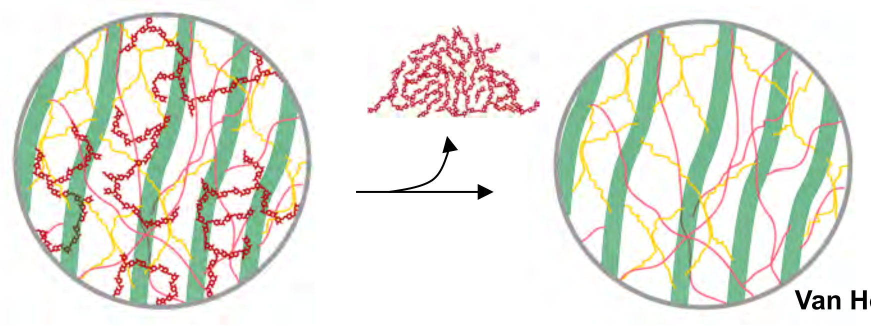


Challenges: Plant biology – 2nd Gen Biofuels

© Markus Pauly

- ► **Increase plant biomass/ ha**
  - ► Choice of crops
  - ► Increase resource efficiency (water, fertilizer)
  - ► Delayed flowering (energy maize: www.kws.com)

- ► **Increase the yield of fermentable sugars**
  - ► Create a more open wall architecture (reduce, alter lignin)
  - ► Reduce process inhibitors
  - ► Increase cellulose (amorphous), hemicelluloses (hexoses)



Van Holme, 2007

Acknowledgements

Pauly lab

Lifeng Liu
Jonathan Paulitz
Guangyan Xiong
Amancio Souza
Nasim Mansoori
Alex Schultink
Julia Schulbert
Dan Naylor

Collaborators:

Sarah Hake,
USDA Albany
Patrick Brown,
UIUC
ISU transformation
facility