# Lignin valorization to chemicals

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# Lignin from 2G biorefineries will be quite abundant

POET | DSM
Advanced Biofuels

raízen

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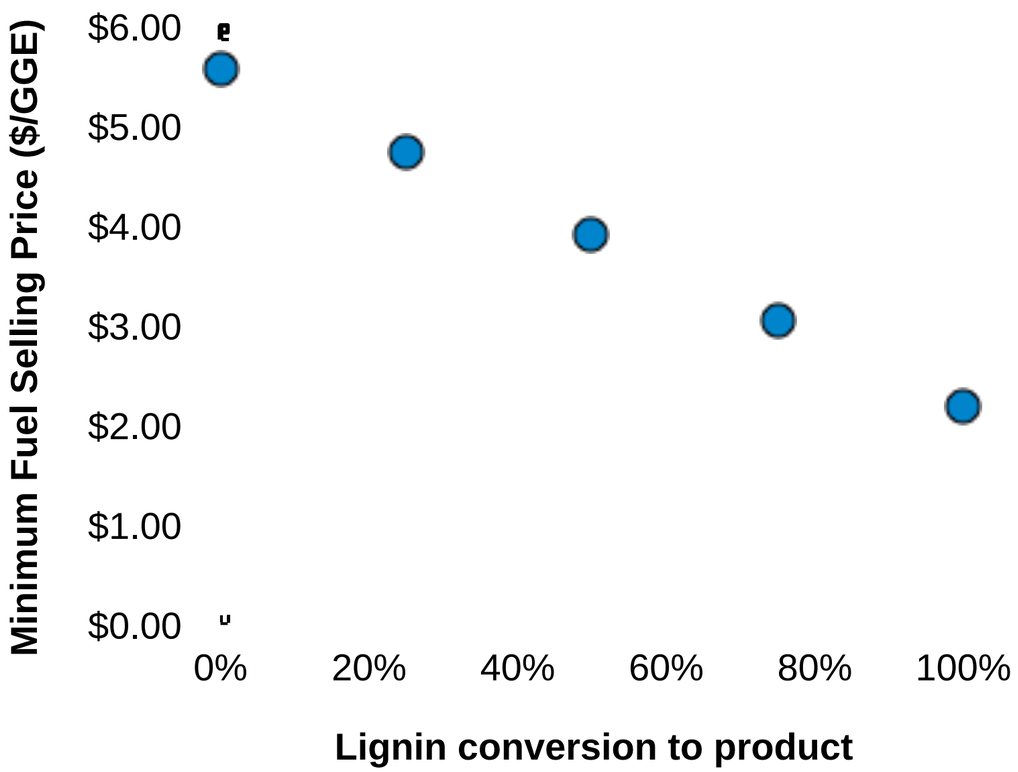
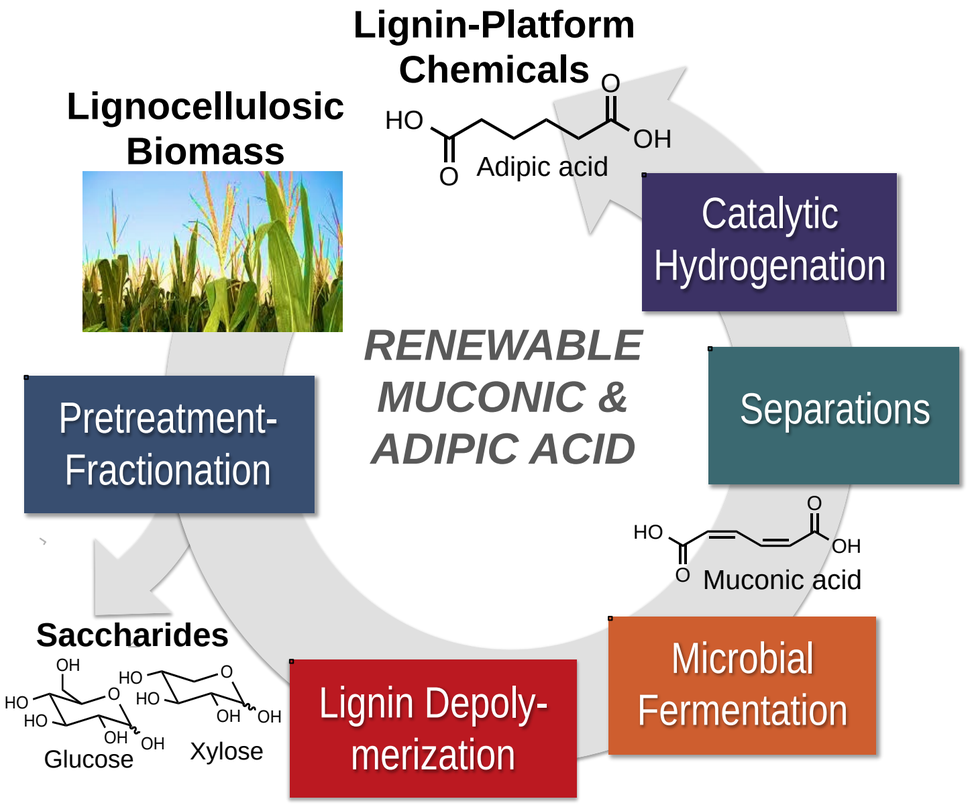
At a high capacity factor, each plant could process up to 400 tons/day of lignin

# Lignin can offer economic and sustainability value to biorefineries

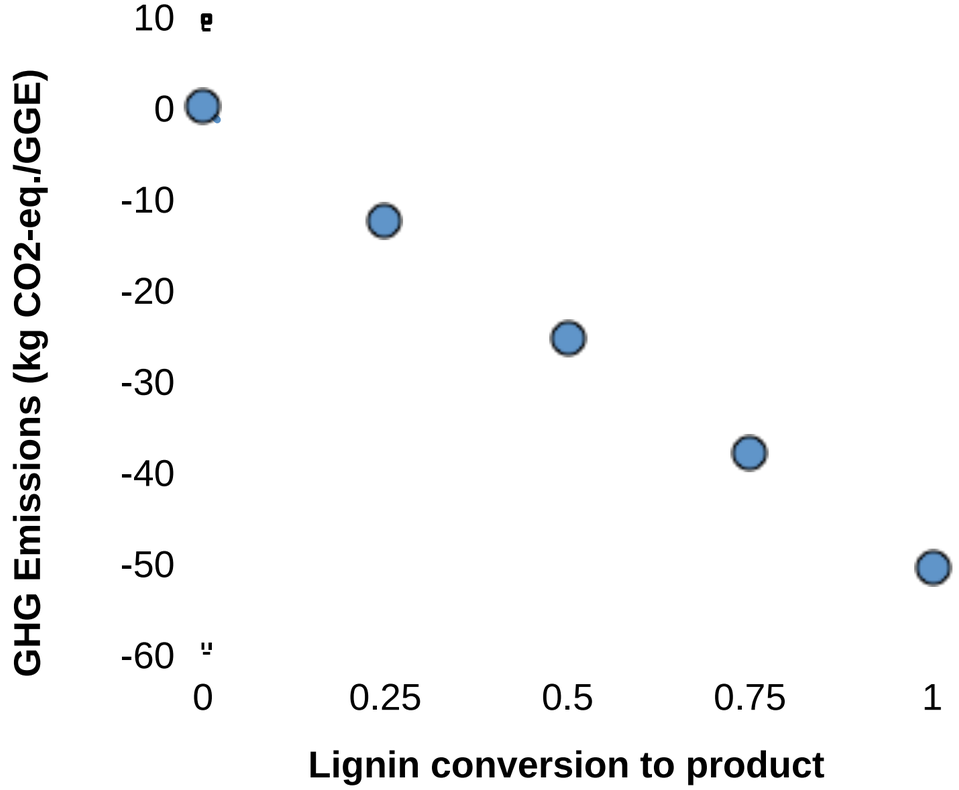

**Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons:**
**Dilute-Acid and Enzymatic Deconstruction of Biomass to Sugars and Biological Conversion of Sugars to Hydrocarbons**

R. Davis, M.J. Biddy, *et al.*, 2013



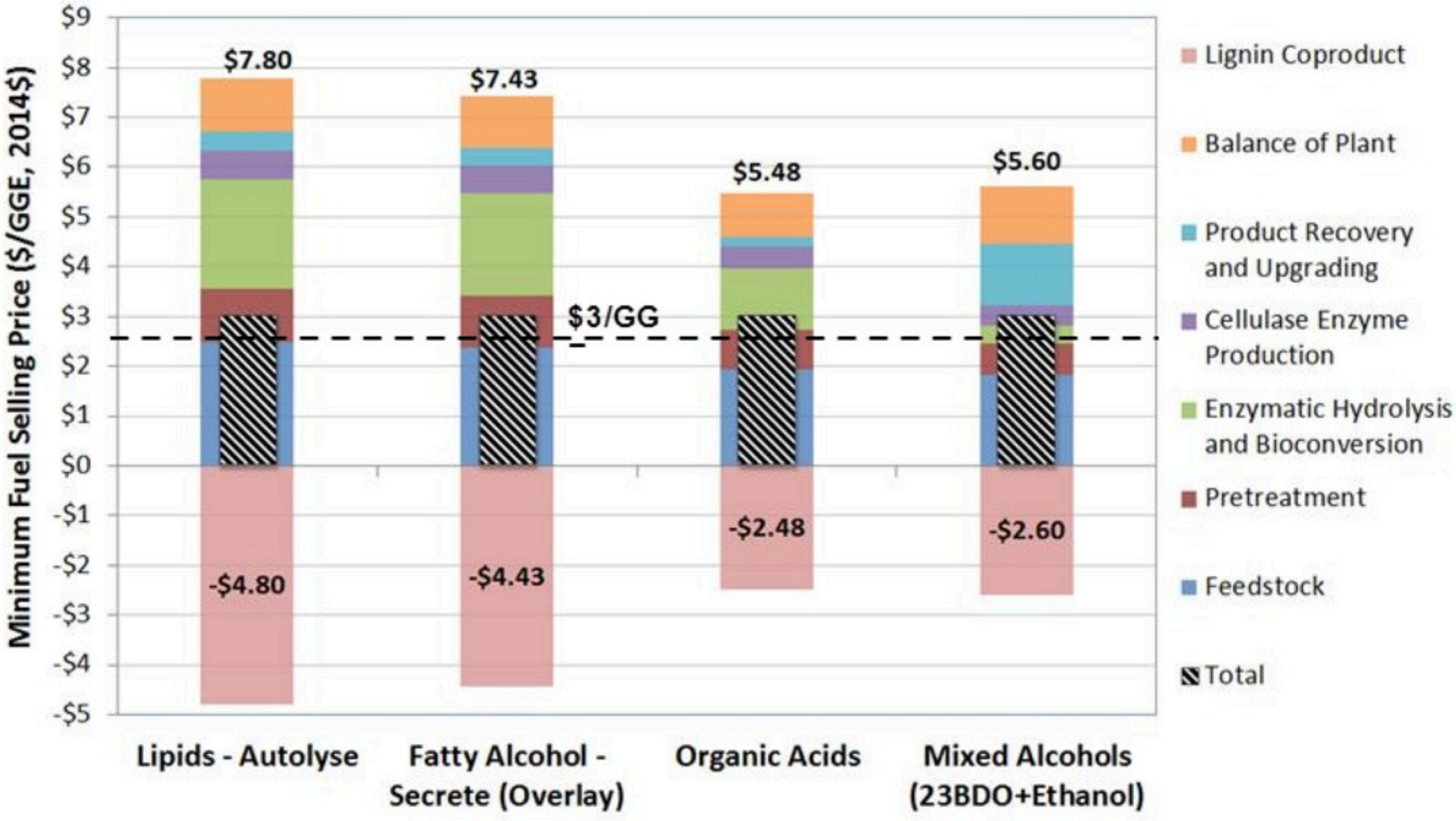




Vardon *et al., EES* 2015



# Lignin valorization is essential for biochemical conversion

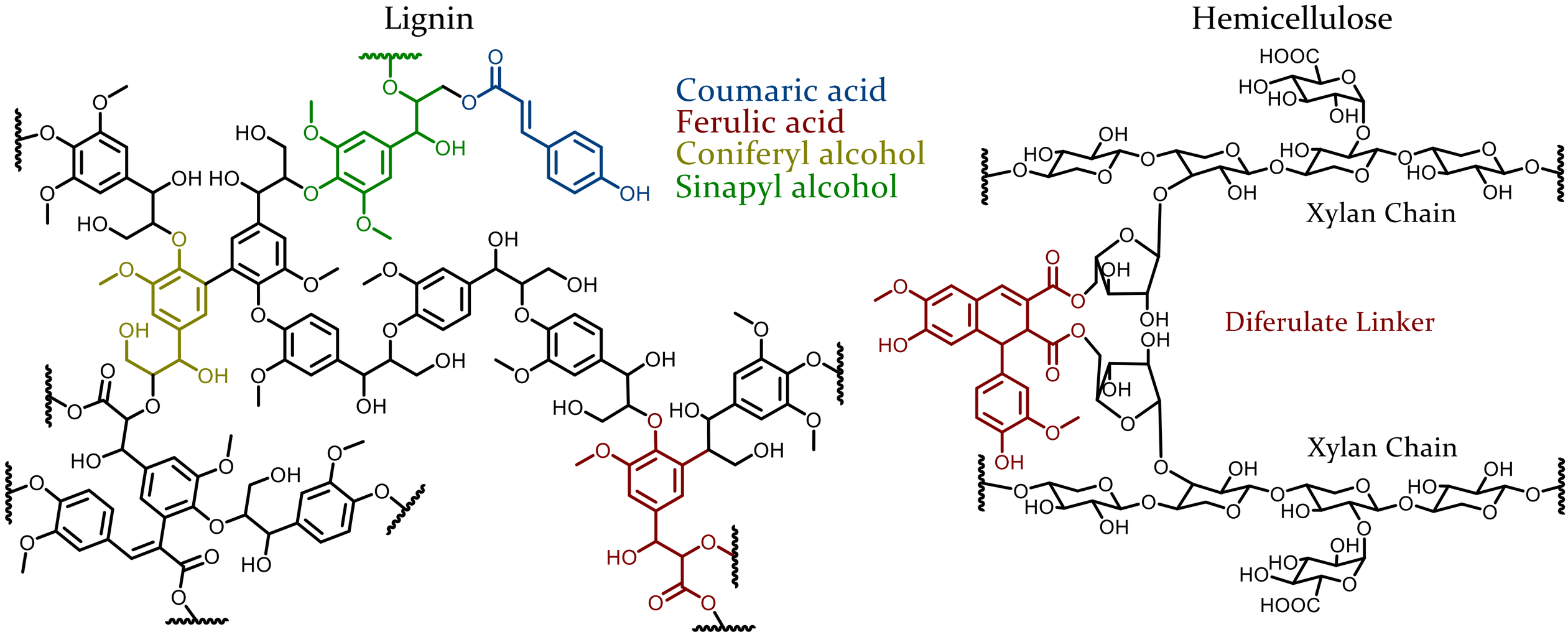
R. Davis, M.J. Biddy, *et al.*, 2013




| Metric | Lipids | Fatty Alcohols | Organic Acids | BDO + EtOH |
|---|---|---|---|---|
| MFSP ($/GGE, 2014$) —Prior to coproducts | $7.80 | $7.43 | $5.48 | $5.60 |
| Fuel C efficiency from biomass (%) | 20% | 21% | 25% | 27% |
| Fuel yield (GGE/ton) | 34.2 | 35.7 | 43.5 | 46.5 |
| TCI ($MM) —Prior to coproducts | $640 | $628 | $520 | $527 |
| Fuel-carbon chain length | ~9–20 | ~16–20 | 11 | ~8–18 |
| Carbon efficiency through lignin-to-coproduct train required to achieve $3/GGE (C in adipic acid vs C available in residual biomass) | 59% | 56% | 40% | 46% |

# Native lignin structure (monocot)

Image from E.M. Anderson *et al.*, *ACS SusChemEng* 2016

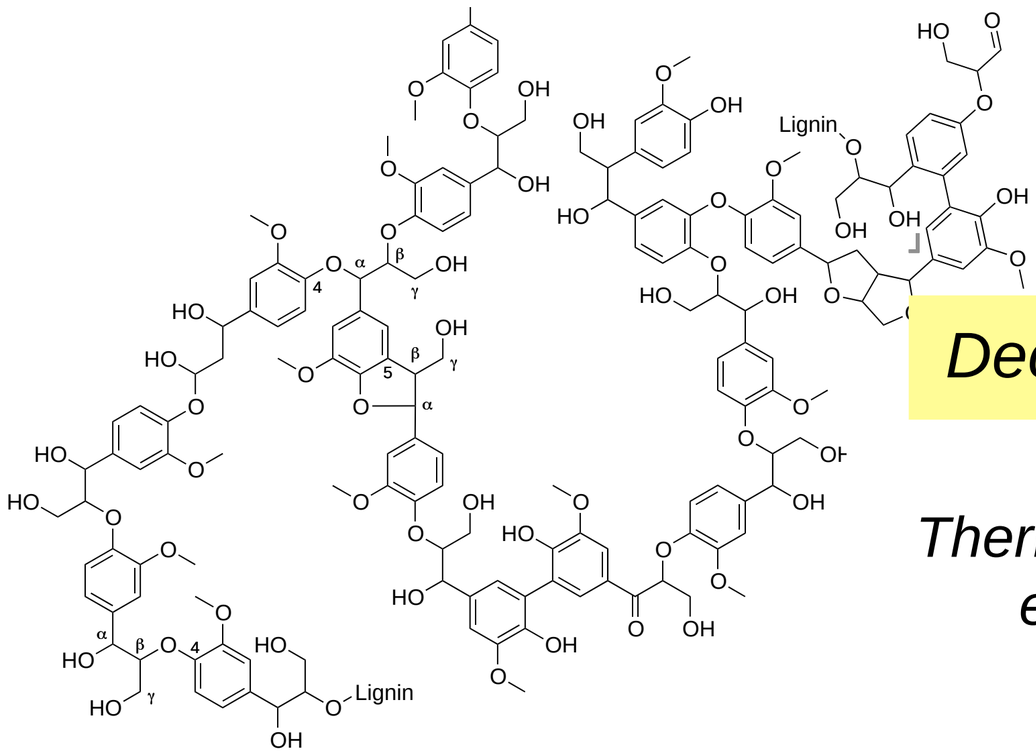



## Multiple bond types, multiple monomer types

- Common polysaccharide-centric treatments break labile C-O linkages and form more recalcitrant C-C linked structures
- More than a century of research in lignin depolymerization

# Heterogeneity is the main barrier for lignin upgrading to chemicals

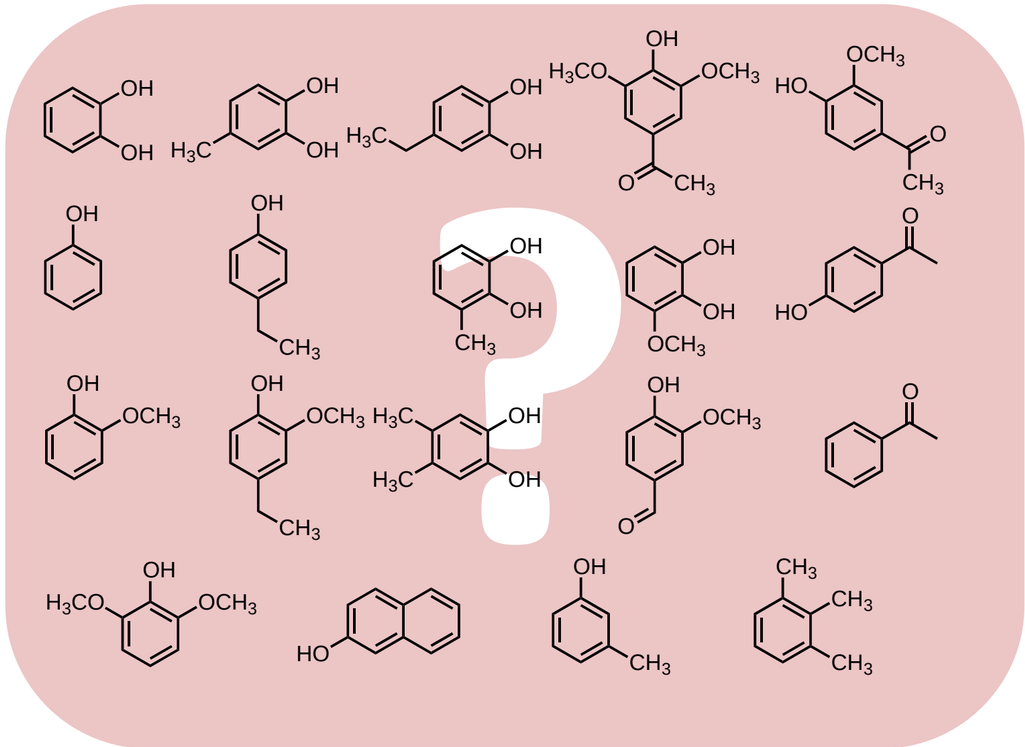
## Lignin's Alkyl Aromatic Structure




*Deconstruction*

*Thermal, catalytic, enzymatic*

## Depolymerization Product Slate



There is a world of difference between a valuable mixture of chemicals and a mixture of valuable chemicals (Art Power)

- Overcoming lignin heterogeneity is the key problem in lignin valorization to chemicals

# Emerging routes to overcome lignin heterogeneity: Engineering plants

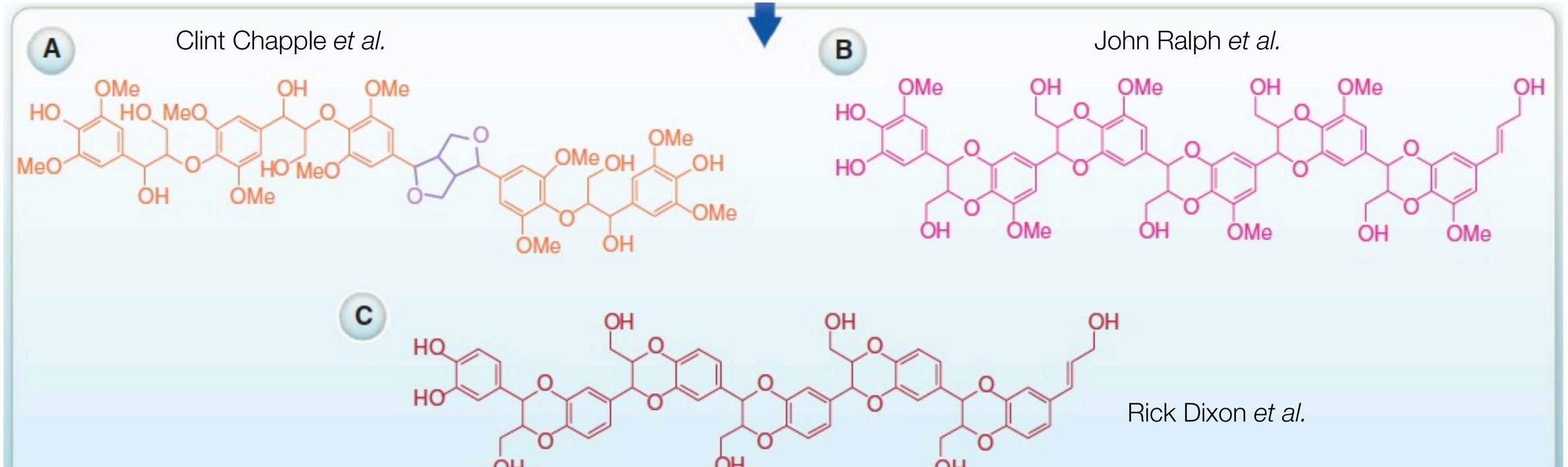
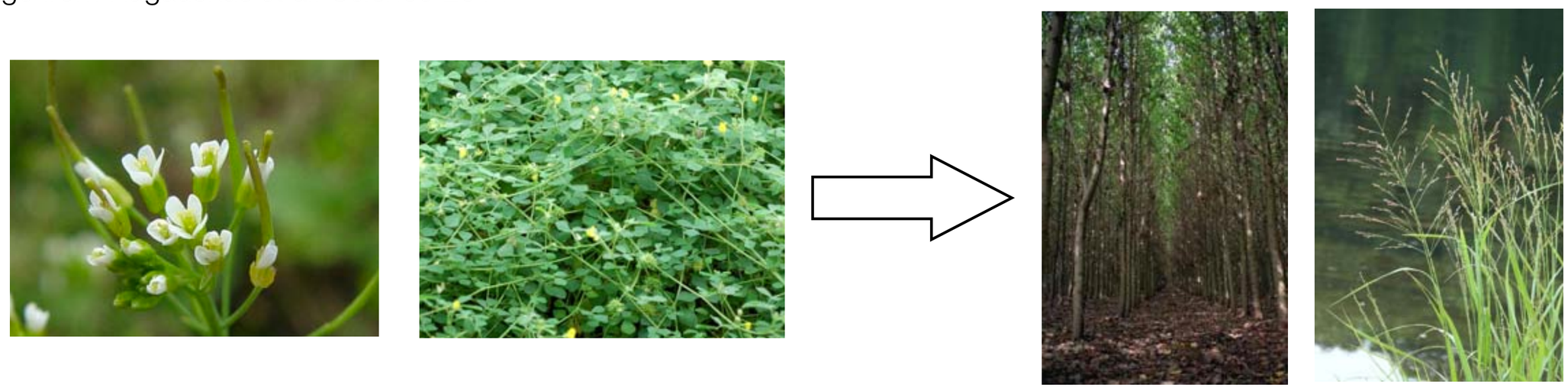



Image from Ragauskus *et al. Science* 2014



## Lignin biosynthesis is plastic and can be successfully manipulated

- The C-lignin discovery highlights that native lignin polymers remain to be discovered
- Work in model systems can be transitioned to energy crops via emerging genome editing

# Emerging routes to overcome lignin heterogeneity: Plant diversity

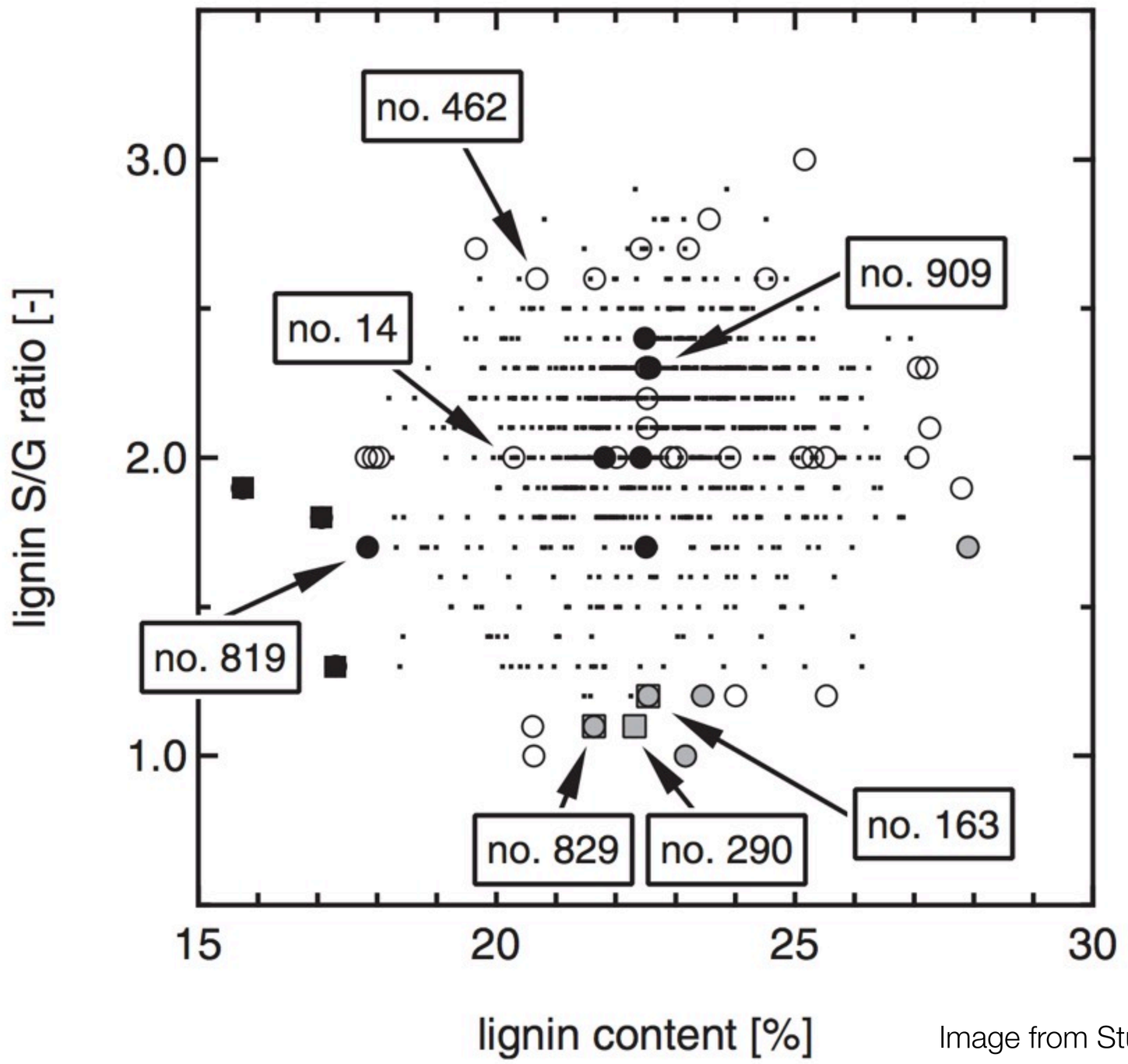



Image from Studer *et al. PNAS* 2011

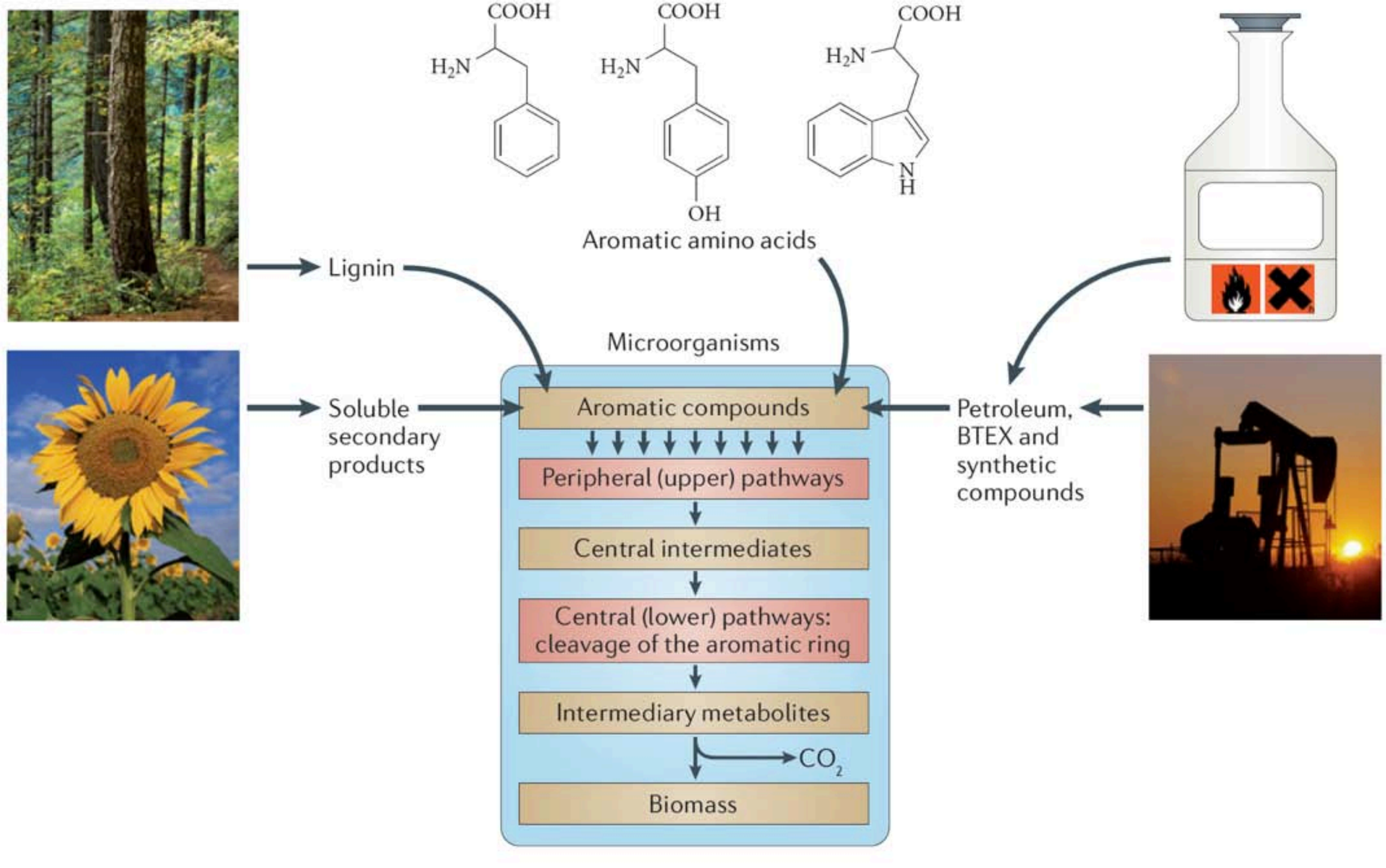
## Lignin in many species can be quite diverse

# Emerging routes to overcome lignin heterogeneity: Biological funneling

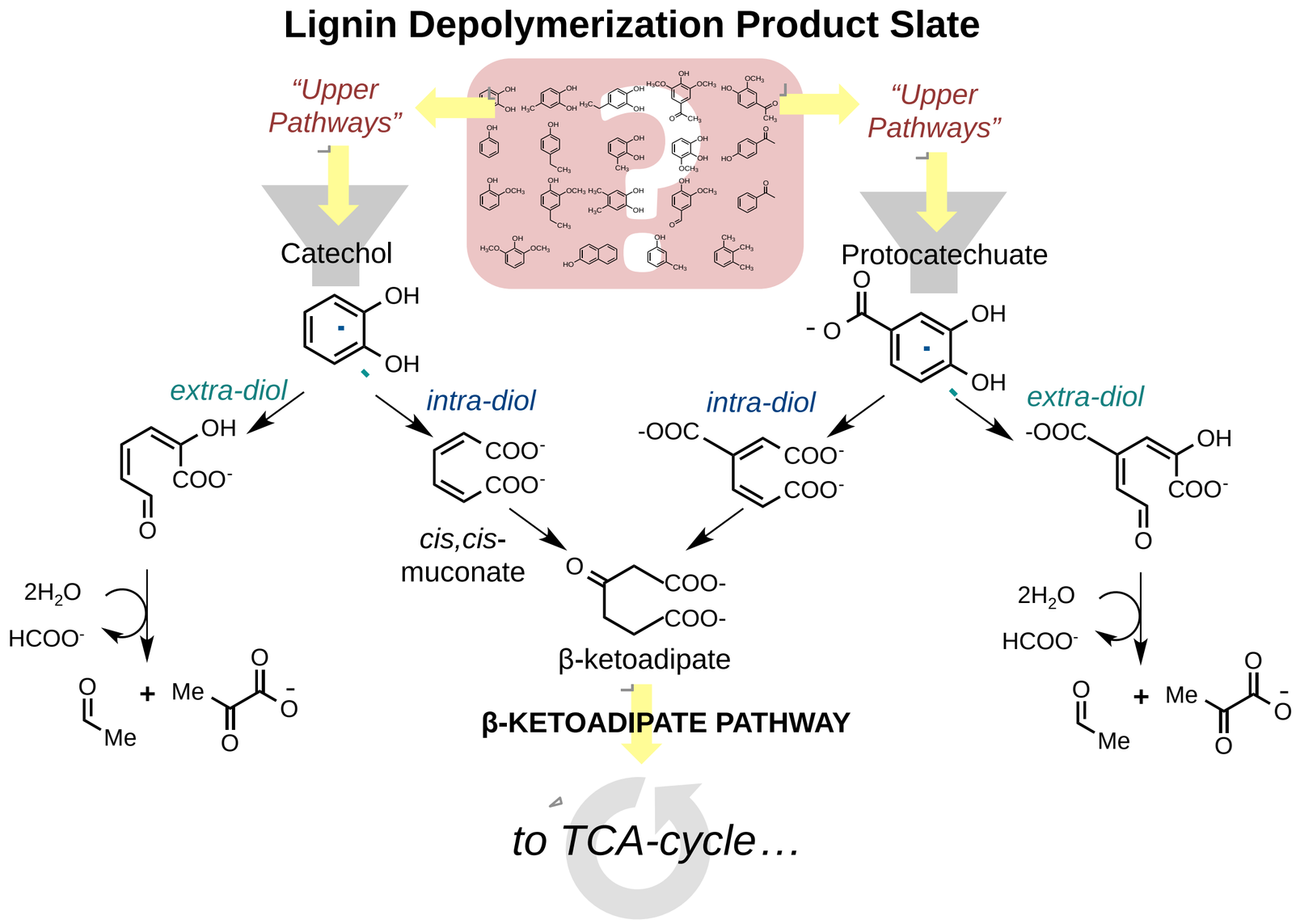
## Microbial degradation of aromatic compounds — from one strategy to four

*Georg Fuchs*, Matthias Boll‡ and Johann Heider§*

NATURE REVIEWS | MICROBIOLOGY



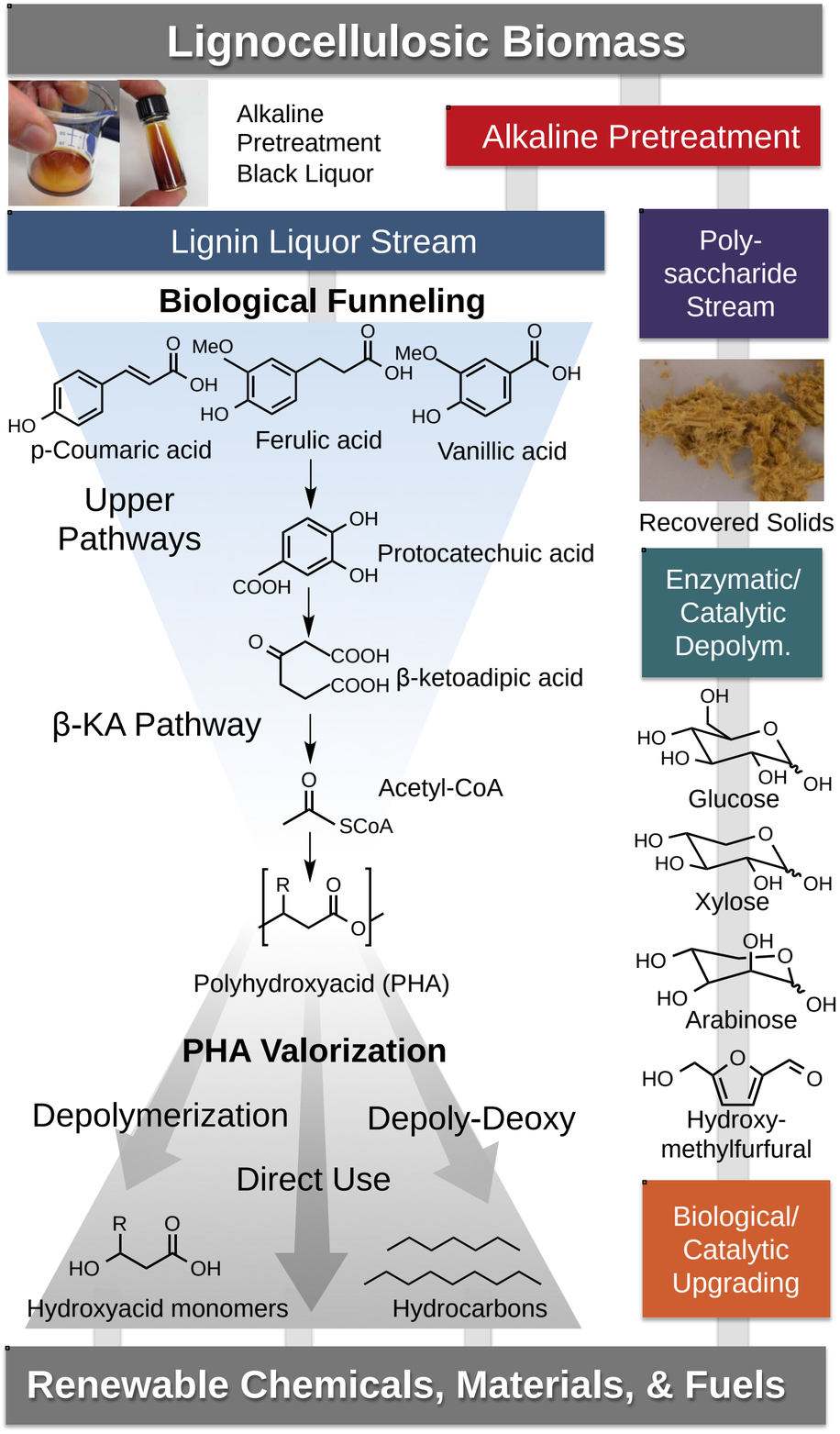
# Biological funneling enables metabolism of heterogeneous aromatics

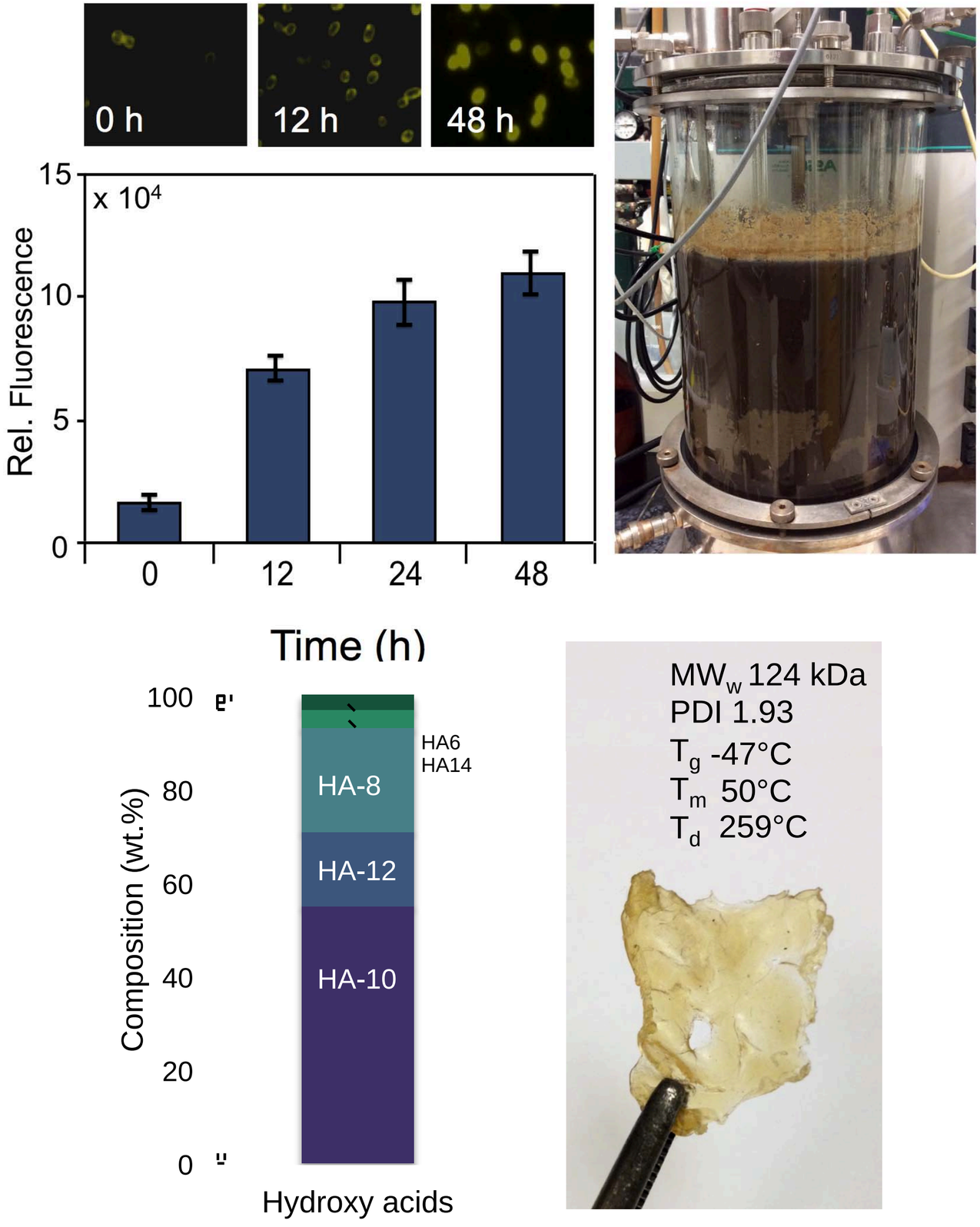



## Microbes can funnel lignin-derived aromatics to central metabolism

Significant body of work going into process development around this concept to optimize biocatalysts, biological cultivation processes, separations, and chemical catalysis

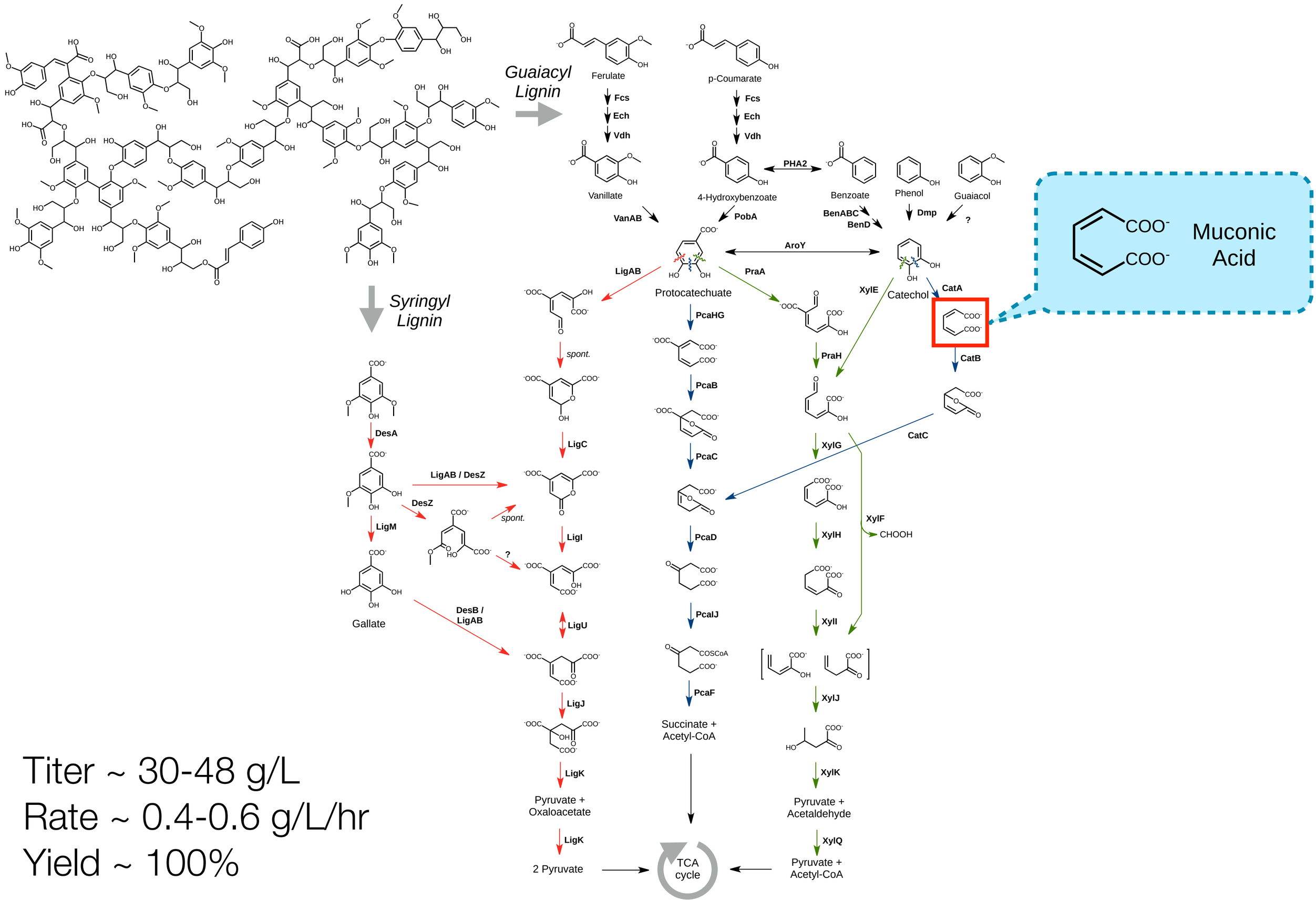
# Biopolymer production from lignin




Linger, Vardon, Guarnieri, Karp, *et al. Proc. Natl. Acad. Sci.*, 2014

# Atom-efficient intermediates from lignin



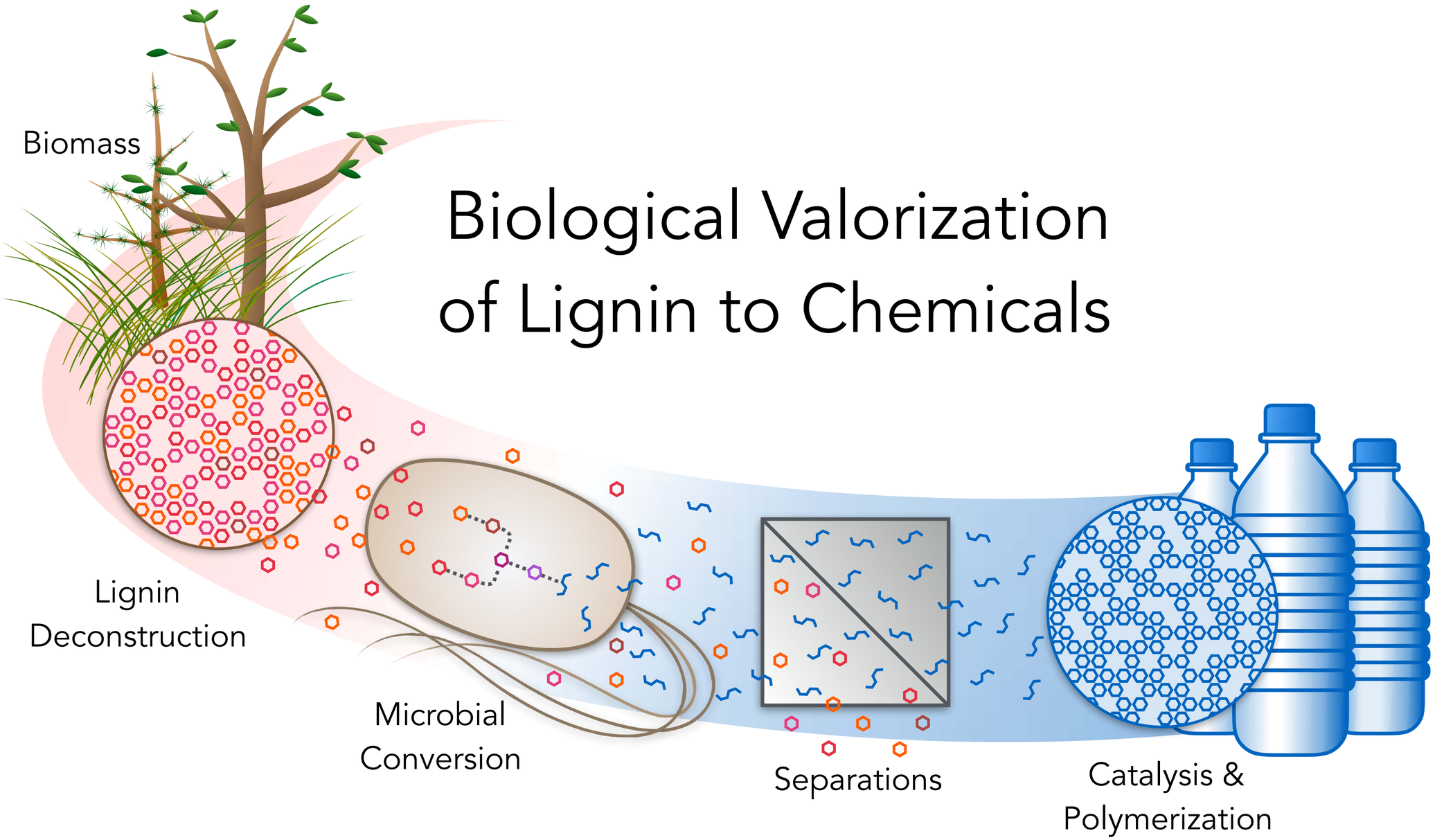

Titer ~ 30-48 g/L

Rate ~ 0.4-0.6 g/L/hr

Yield ~ 100%

# Towards selective lignin valorization

Beckham, Johnson, Karp, Salvachua, Vardon,
*Current Opinion in Biotechnology*, 2016




## Biological funneling (along with other emerging techniques) may enable a solution to overcome lignin heterogeneity

- Significant opportunity in co-designing *in planta* lignin with biological and catalytic conversion
- Emerging 2G biorefineries offer space for new lignin valorization processes

# Conference announcement!

Gordon Research Conferences

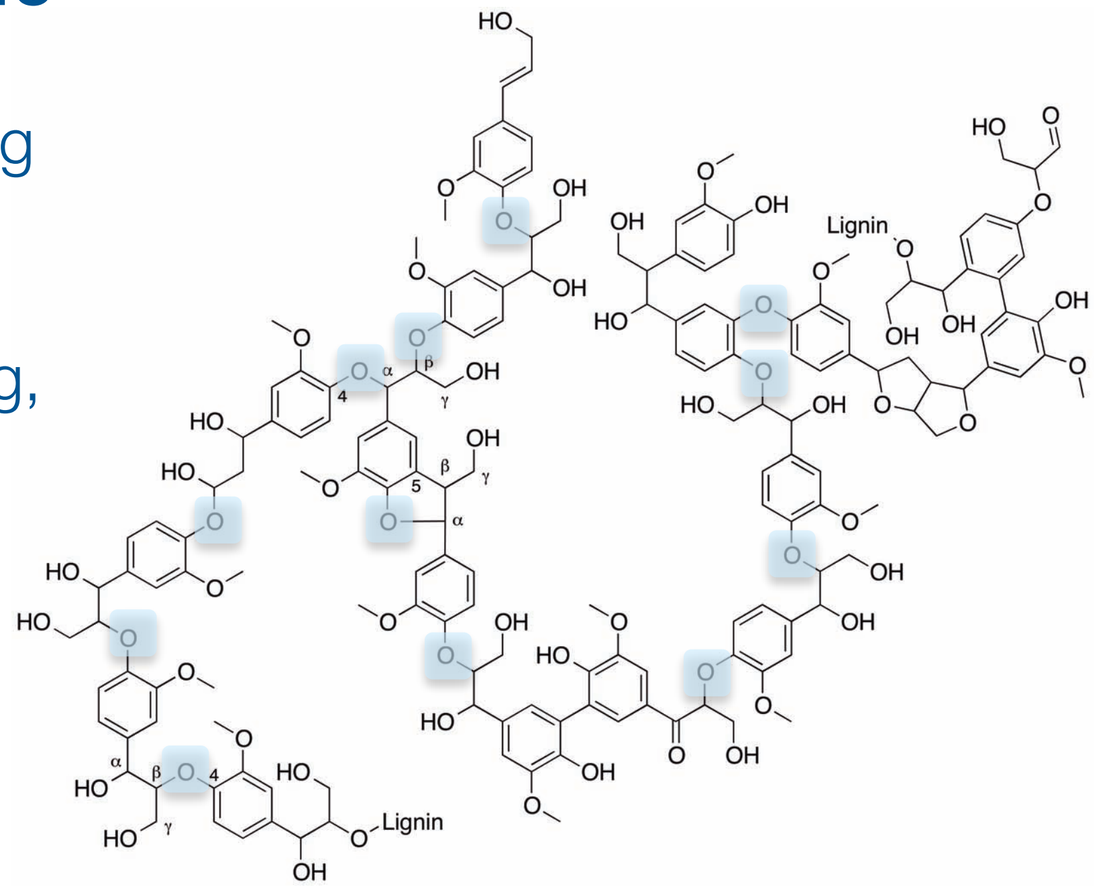
frontiers of science

**For your calendars!**

The inaugural **Lignin Gordon Research Conference** will be held in the **August 5-10, 2018**

The goal of this proposed GRC on lignin is to bring together leading researchers, postdocs, and students involved in multiple aspects of lignin including its characterization, *in planta* engineering, depolymerization and upgrading, and material science.

Interaction and discussion between plant researchers, chemists, engineers, and material scientists working on this recalcitrant polymer is critical to move the field forward.



# Acknowledgements

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Thank you for your attention!

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