Exploring How Biomass Can Help on the Path to Industrial Decarbonization: Biomass Preprocessing

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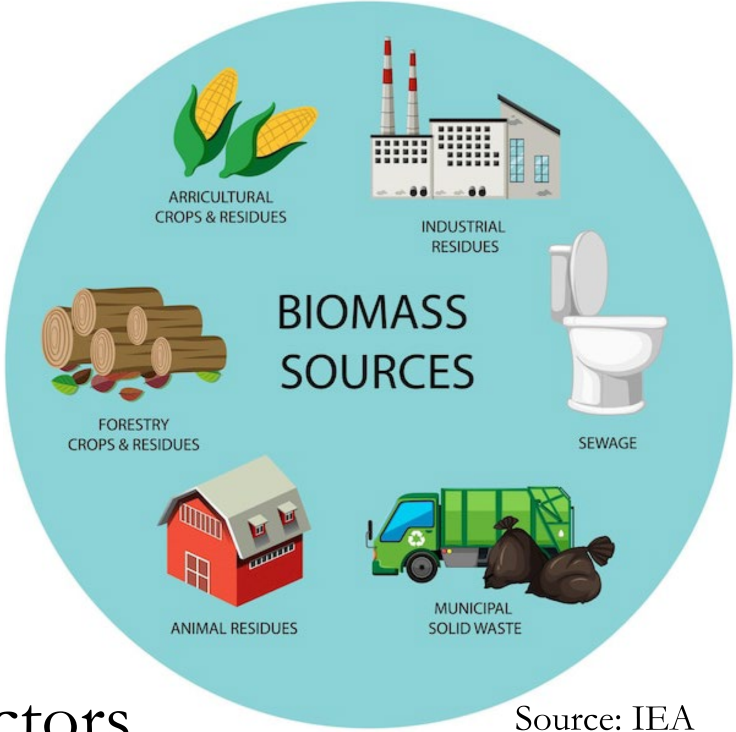
Outline

- The "billion-ton" potential
- Biomass preprocessing: necessity, approaches, and challenges
- Current efforts and outlook

Credit: U.S. DOE

Why is biomass important?

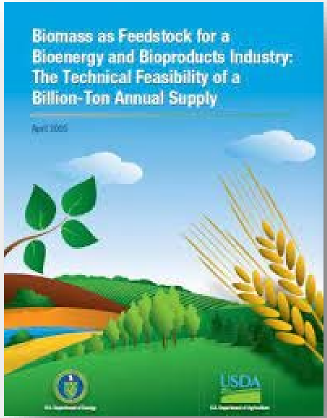
- (Only) sustainable carbon carrier
  - The largest source of renewable energy globally (55% all renewable, 6% total)
  - 5X higher than wind and solar PV (traditional use excluded)
  - Only renewable energy source for liquid biofuels: hard-to-electrify sectors

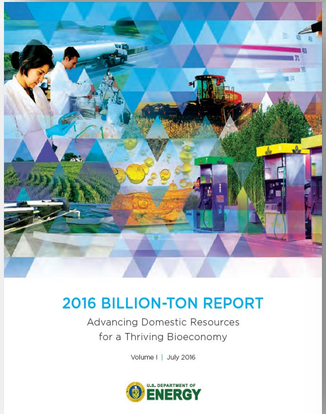


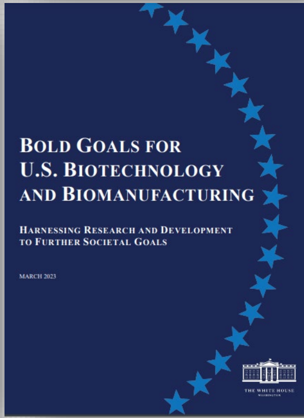
Source: IEA

The "billion-ton" potential and national goals

- Billion-Ton Study (2005), Update (2011), and Report (2016)
  - 1.3 billion dry tons of nonfood biomass
  - Feedstock: types, availability, and supply
- Bold Goals for U.S. Biotechnology and Biomanufacturing (March 2023)
  - 4 Themes: transportation fuels, chemicals and materials, climate-focused agricultural systems, and CO_2 removal

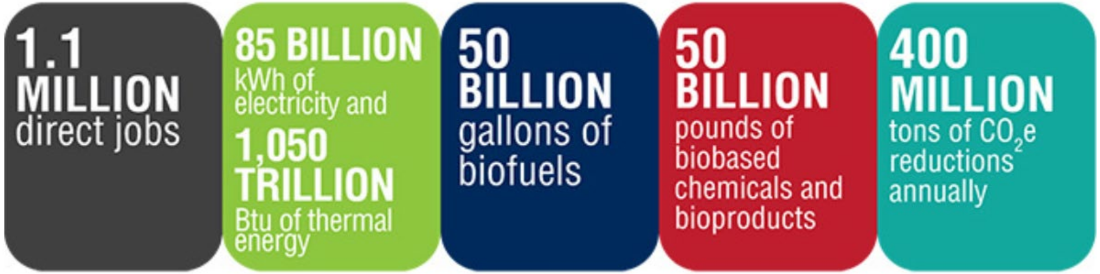


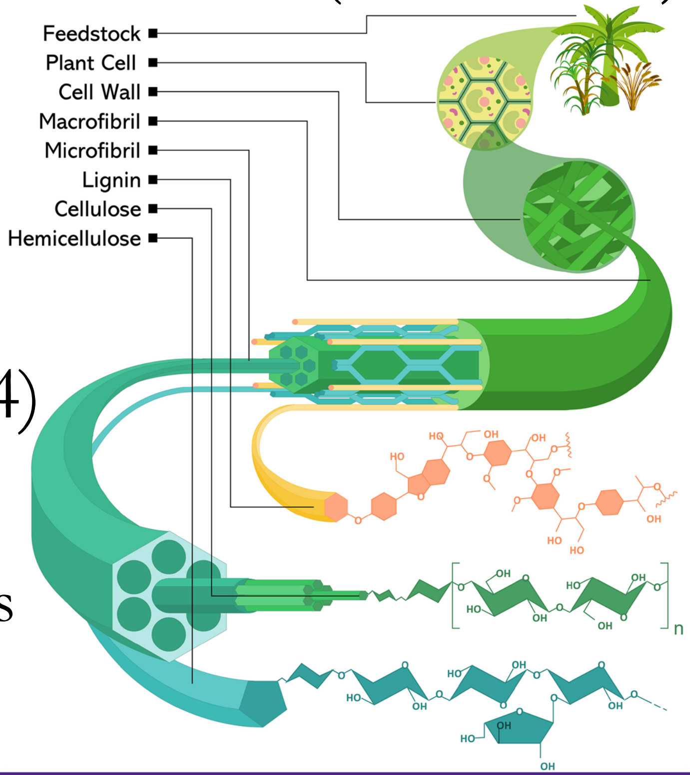




More than energies

- 1 billion dry tons of <u>sustainable nonfood</u> biomass (DOE 2016)

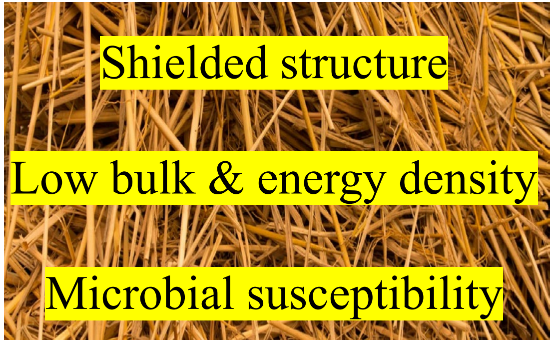


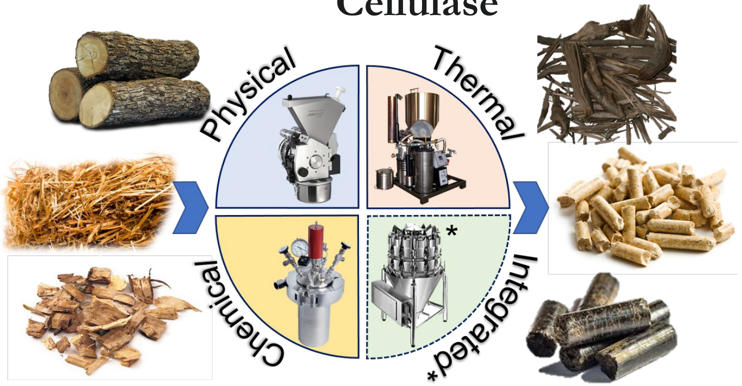


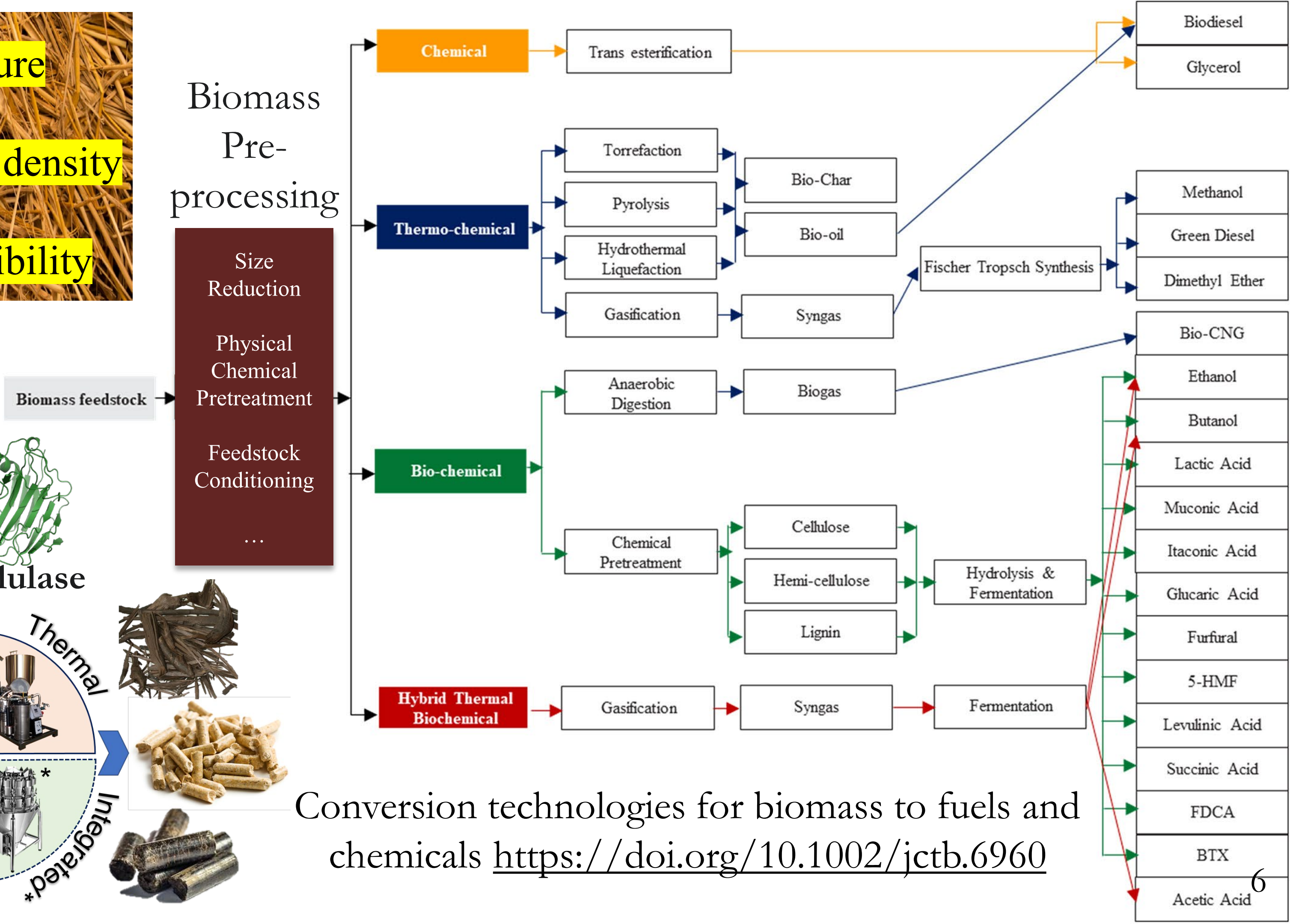
- 12 <u>building block</u> chemicals (DOE 2004)
  - Chemical
  - Thermo-chemical
  - Biochemical
  - Hybrid thermo-biochemical

} Conversions

https://doi.org/10.1002/bbb.2048



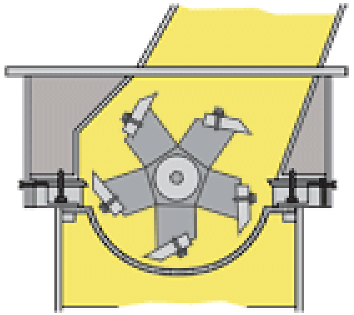




Conversion technologies for biomass to fuels and chemicals https://doi.org/10.1002/jctb.6960

Effort 1: Structural understanding (Biochemical)

- The role of biomass particle size, smaller the better?



Size reduction in a cutting mill

Particle size

Accessible surface area

Crystallinity

Hemicellulose content

Lignin content

Assessed how millimeter and submillimeter biomass particles performed during pretreatment and hydrolysis.

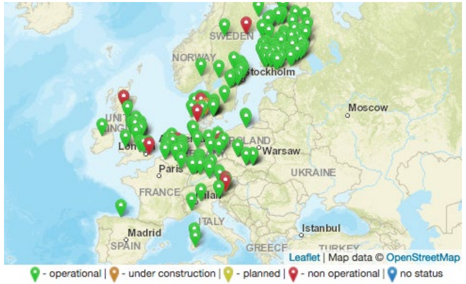
1. Size reduction (comminution) by itself was insufficient to attain economically feasible sugar yields.
2. Submillimeter particles' advantage in enzymatic hydrolysis efficiency was outweighed by their low solid and sugar recoveries in pretreatment.
3. Enzyme-accessible surface area was a strong indicator.
4. Crystallinity was a weak indicator.
5. Hemicellulose/lignin removal increased enzymatic hydrolysis efficiency.

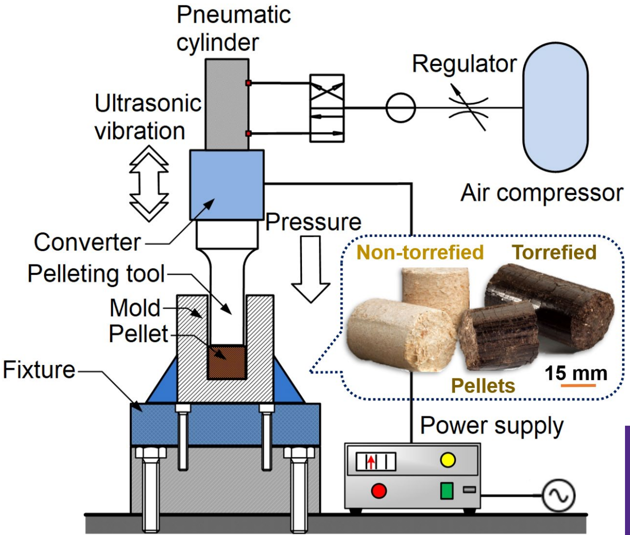
Yang et al., 2022, https://doi.org/10.1007/s13399-021-02169-3

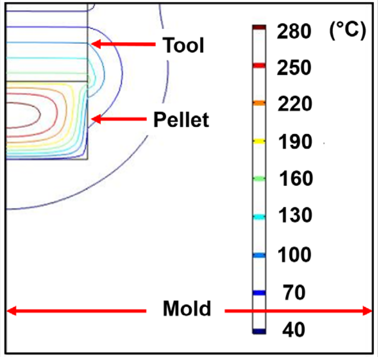
Effort 2: Process innovation (Thermo-chemical)

- Can torrefied pellets be made in a single step?

Co-firing in EU







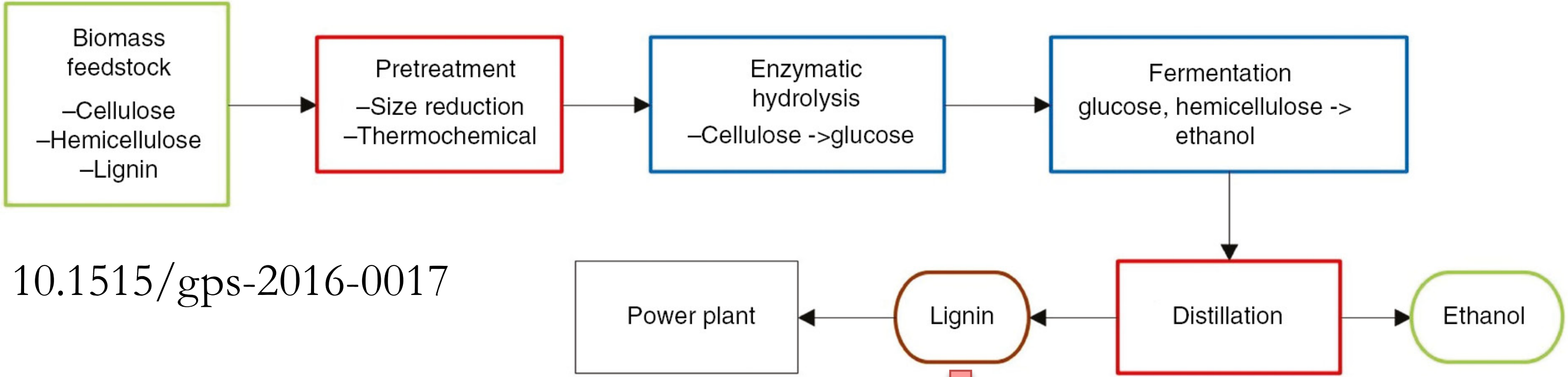
Viscoelastic heating

1. Two fuel upgrading actions (torrefaction and pelleting) happened simultaneously with the assistance of ultrasonic vibration.
2. Enhanced density, durability, and hydrophobicity of torrefied pellets.
3. Mass balance, TEA, and LCA are needed.

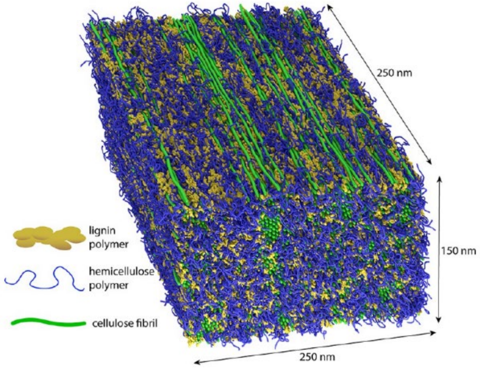
Yang et al., 2019, https://doi.org/10.1016/j.renene.2019.04.112

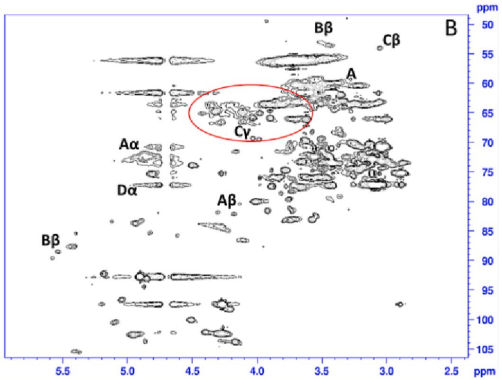
Effort 3: Platform integration (Bio-Thermo-Chemical)

- Utilizing hydrolysis residue as an additive for fuel pellets



DOI 10.1515/gps-2016-0017





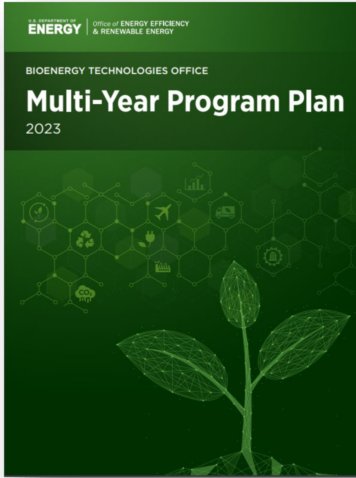
NMR of hydrolysis residue showed signal gains representing **G-type** and **H-type** lignin and an increase in lignin **resinol** unit content.

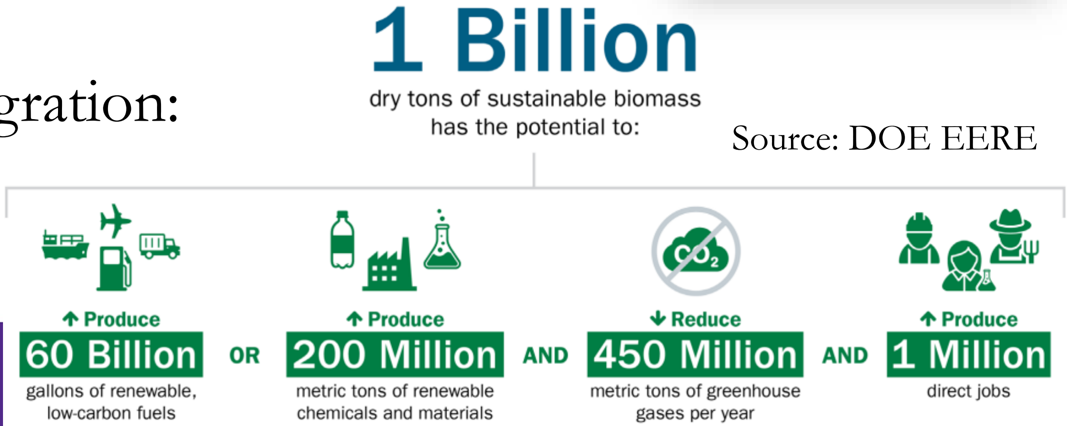
1. Benefits pellet combustion performance
2. Produce dense and durable pellets
3. Create a hydrophobic pellet surface

Yang et al., 2023, https://doi.org/10.1016/j.fuel.2023.128582

Outlook

- Feedstock-conversion interface:
    - Key feedstock and operation factors
    - Biomass flow behavior and abrasion mechanisms
    - Intelligent control systems and performance criteria
- Biomass deconstruction and fractionation:
    - Pretreatment strategies that can save water and preserve lignin
    - Lignin deconstruction and valorization
- Systems development and integration:
    - Critical unit operation validation
    - Feedstock variability
    - Data, modeling, and analysis





Source: DOE EERE

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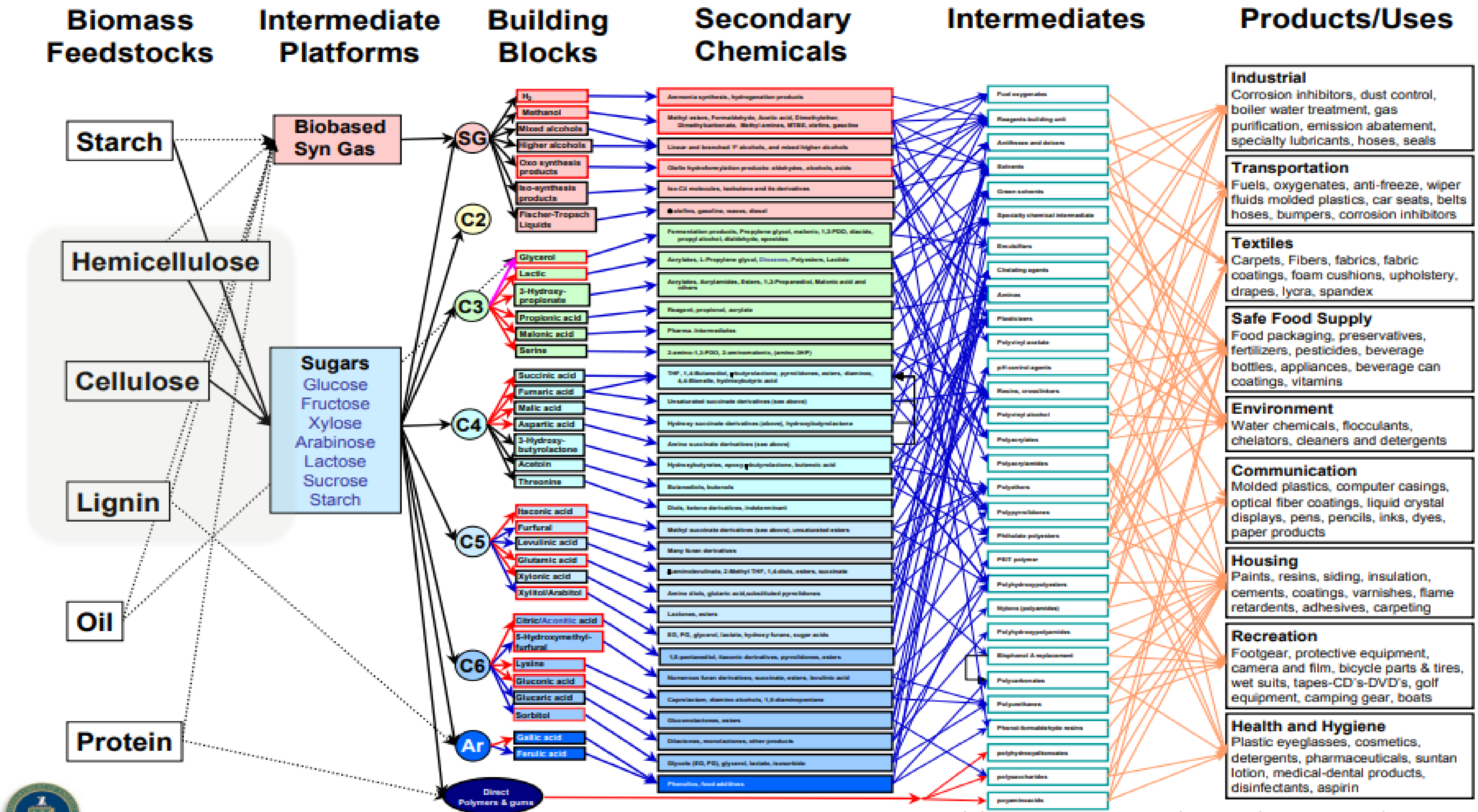

https://www.nrel.gov/docs/fy04osti/35523.pdf

Figure 3 – Analogous Model of a Biobased Product Flow-chart for Biomass Feedstocks