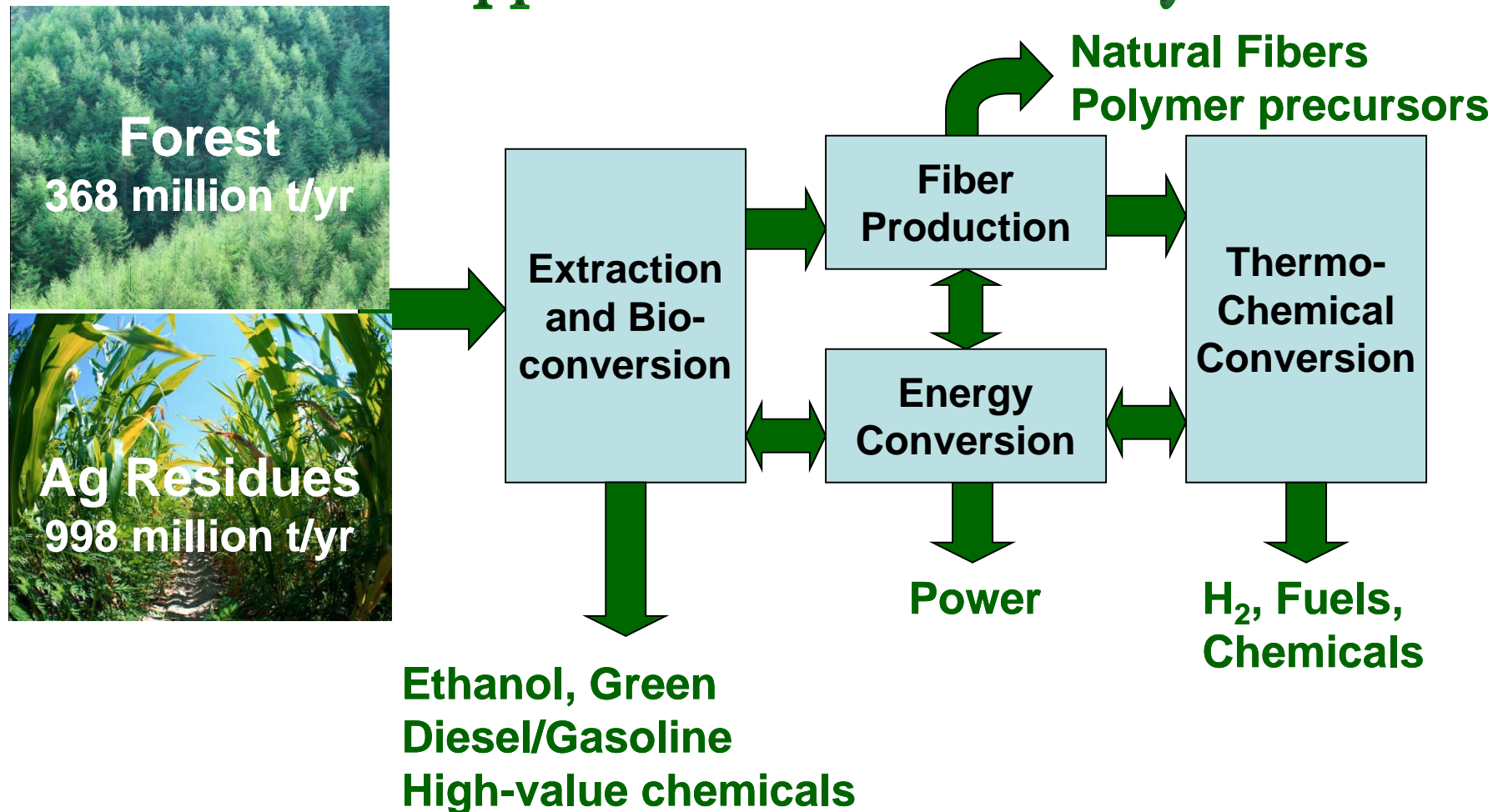


# Biorefineries

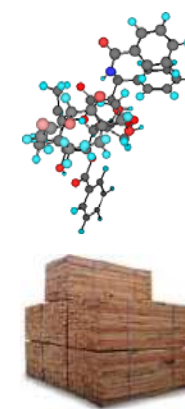
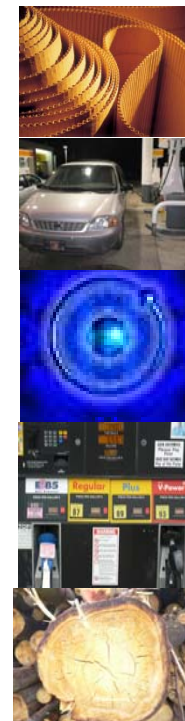
## Opportunities for Industry





# *Biorefinery Studies*

- Biorefinery Products
- Enabling Technologies
- Biomass Characterization
- Biomass Separation





# *Biorefinery Products*

## Fiber

### Products from wood prior to pulping

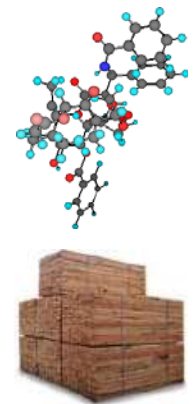
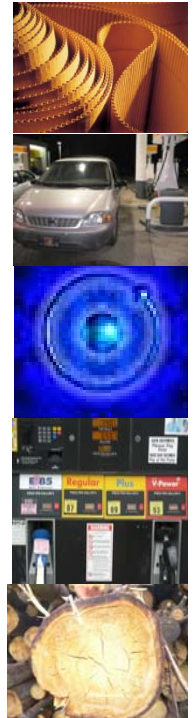
- Ethanol from hemicellulose
- Higher value materials from hemicellulose
- Pharmaceuticals and nutraceuticals from wood

### Syngas-derived products

- Power
- Hydrogen
- Alcohols
- Ethanol - Butanol from bioconversion
- Methanol & DME
- F-T Liquids

### Building block chemicals from wood

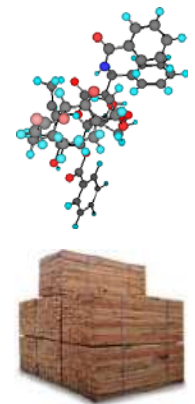
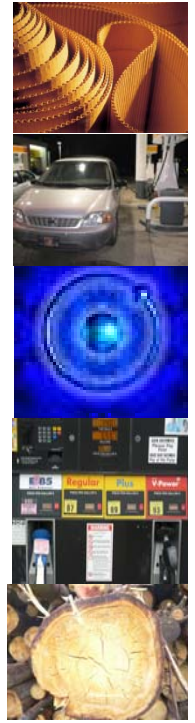
- From cellulose
- From hemicellulose
- From lignin





# *Enabling Technologies for Biorefineries*

- ***Extraction:*** Pharmaceuticals, flavorings and food additives, etc.
- ***Bioconversion:*** ethanol, organic chemicals, precursors for plastics, etc.
- ***Chemical conversion:*** fibers, nanomaterials, adhesives, etc.
- ***Thermochemical conversion:*** fuels, chemicals via methanol route





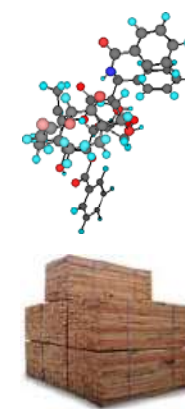
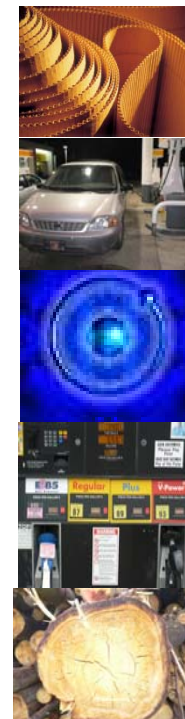
# *Enabling Technologies*

## Extraction of Hemicellulose

- More selective extraction
- Higher concentration in extract
- Recovery of acetate

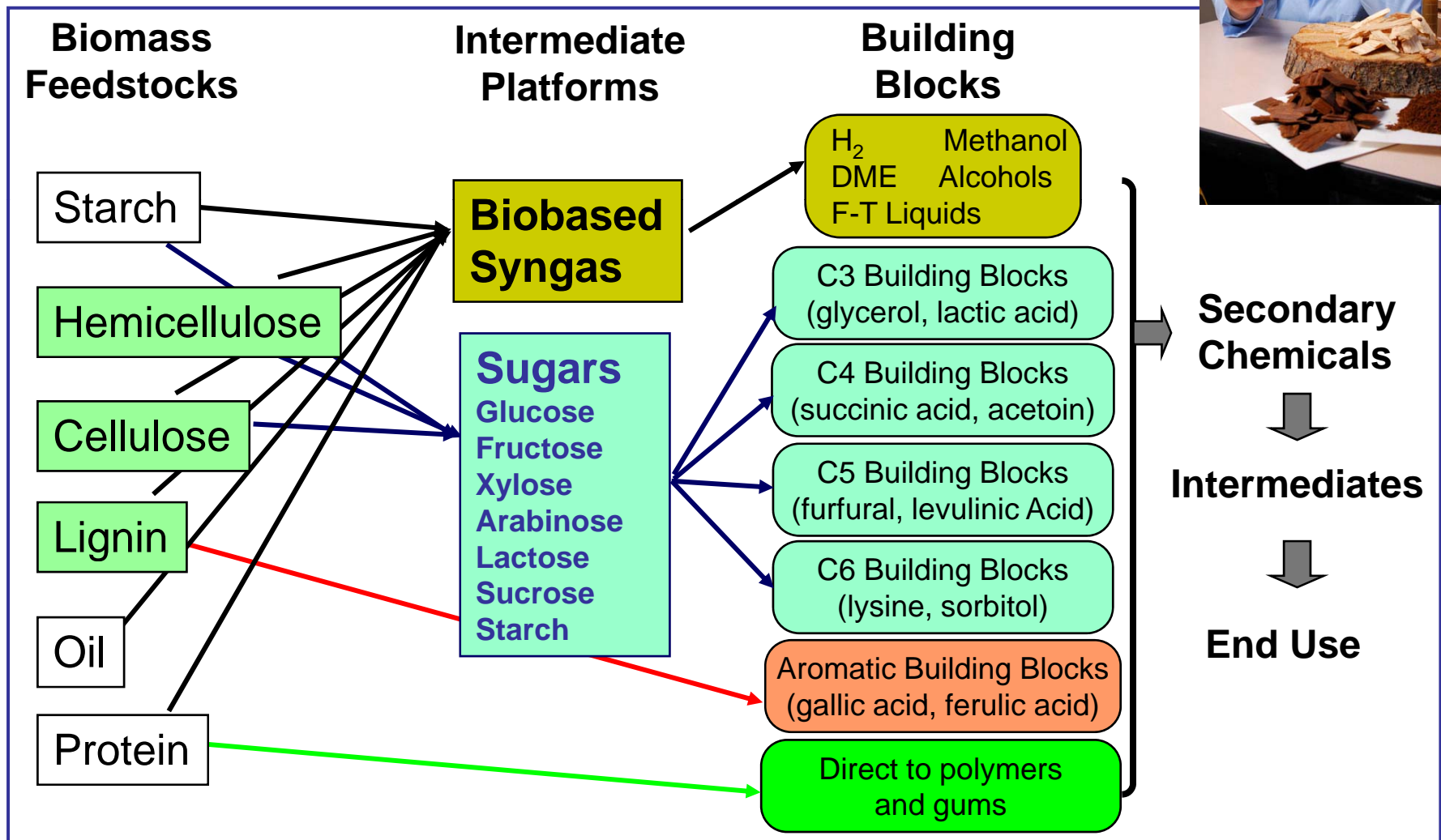
## Conversion Technology: Hemicellulose to Higher Value Materials

- Nanomaterials
- Hydrogels
- Films, Foams



# Enabling Technologies

## Biochemical Conversion for *Building Block Chemicals* from Wood

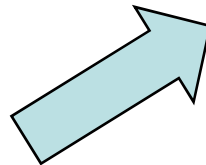


# Select Biorefinery Chemicals

## Building block chemicals

These are molecules with *multiple functional groups* that can be transformed into high-value bio-based chemicals or materials.

Building block chemicals that can be produced from sugars via biological or chemical conversions



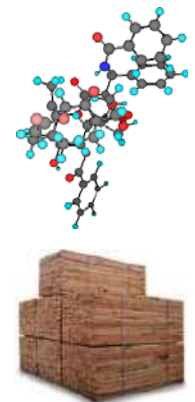
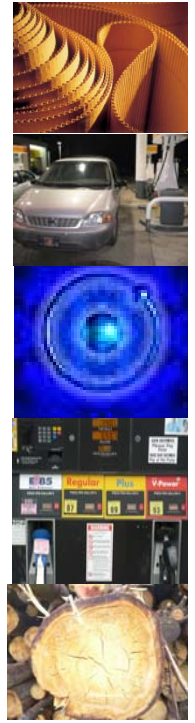
- 1,4 succinic, fumaric and malic acids
- 2,5 furan dicarboxylic acid
- 3 hydroxy propionic acid
- aspartic acid
- glucaric acid
- glutamic acid
- itaconic acid
- levulinic acid
- 3-hydroxybutyrolactone
- glycerol
- sorbitol
- xylitol/arabinitol



# *Wood Available to Biorefineries*

- U.S. forestlands can produce **368 million dry tons** annually. This includes
  - 145 million: residues from wood, pulp, paper mills
  - 52 million: fuel wood harvested from forests
  - 47 million: urban wood residues
  - 64 million: residues from logging and site clearing operations
  - 60 million of biomass from forests to reduce fire hazards.
- All of these forest resources are sustainably available on an annual basis.

Source: Perlack et al., 2005.







# *Product Options*

- *Pharmaceuticals:* taxol
- *Food additives:*  $\beta$ -sitosterol, a cholesterol suppressant
- Plastics
- Nanocellulose
- Carbon fibers
- Adhesives
- Chemicals

