Sustainable Forest Biorefineries – Vision for the Future

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Abstract

Forest industries has been a long standing globally competitive industry in the US and North America for much of the last century. The focus has been primarily on producing low cost cellulose fiber and fiber based products including building materials. This is a mature commodity industry with high capital costs and low profit margins. With increasing cost of raw materials and labor and operational efficiency and leveling the technology playing field for conventional fiber based products, the forest industry is increasingly looking to expand the revenue streams and profitability to become a full fledged biorefineries. With significant expertise in the understanding, logistics, handling and processing of lignocellulosic biomass and sustainable forestry practices, the forest industry has much to offer in contributing to the future development and engineering of sustainable biorefineries. In addition to high value cellulose fiber and fiber based products including nano-cellulose composites, the individual constituents of biomass namely hemi-cellulose, lignin, extractives etc. can be sustainably extracted and converted to value-added products. In addition to second and third generation biofuels, bioenergy and other bio-based products offer a tremendous renewable products opportunity for the US and much of the world. Thermochemical or biochemical approaches or a combination of the two hold promise for the future. There are still unsolved scientific and engineering challenges in achieving future sustainable biorefineries including recalcitrance of biomass, density of biomass feedstock, low cost biomass pretreatment approaches, separation and purification of sugar and non-sugar streams, bioengineering of fermentative organisms, removal of fermentation inhibitors, novel bioprocessing approaches suitable for mixture of biomass feedstocks, value added co-product development etc. The approaches and solutions need to include the local and regional natures of biomass species and sustainability considerations and they can be in combination with existing forest and other biomass based industries.

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Vision for the Future

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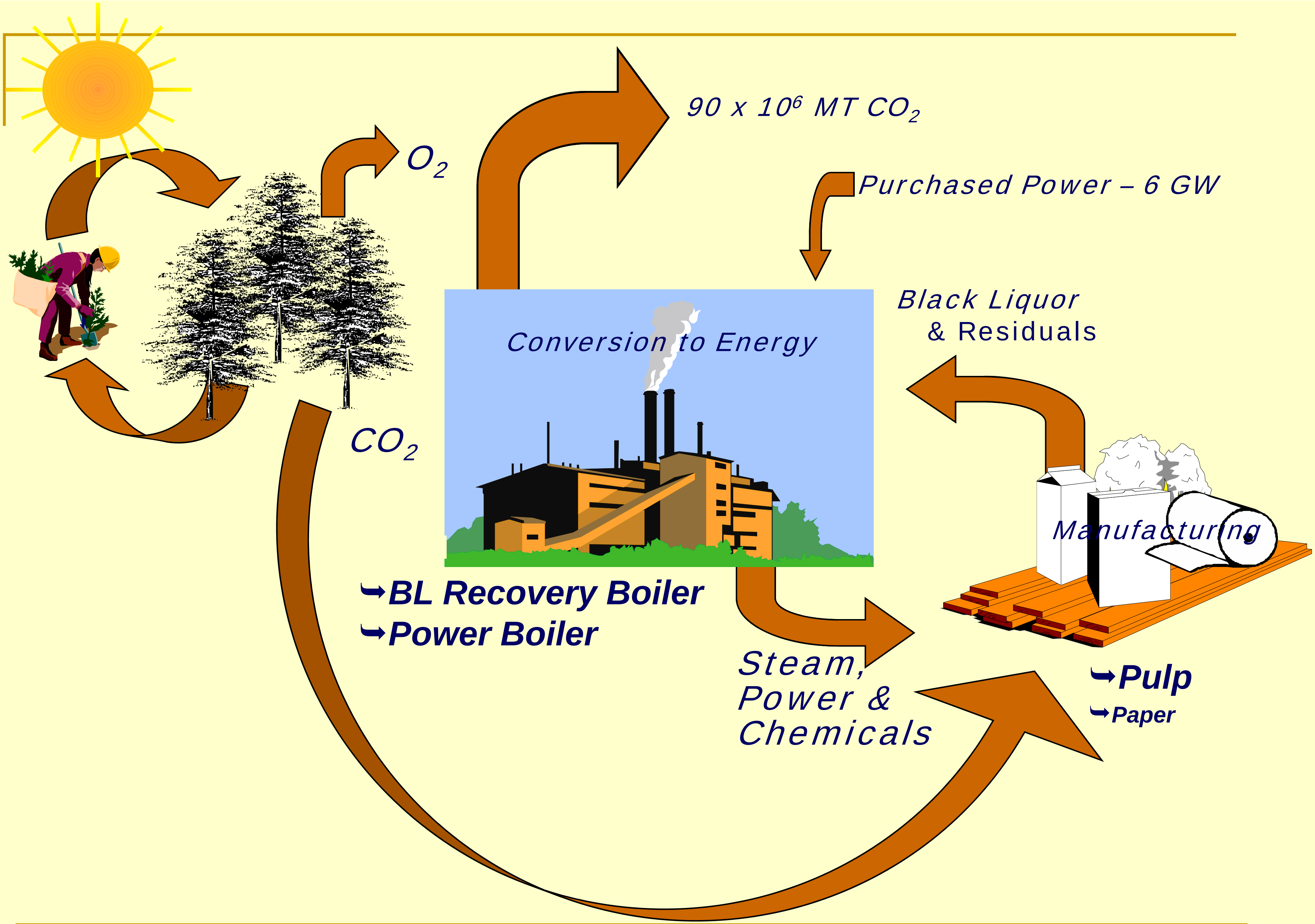
U.S. Forest Industry
&
Sustainability

Forest Industry – Forest Products and pulp and paper industry one of the leading manufacturing sectors in the US, Canada, Scandinavia and other parts of the world

In the U.S.

- **5% of GDP**
- **Top 10 manufacturing industry**
- **$175 billion in products**
- **900,000 employees**



Current Pulp and Paper Mill

Forest Industry Sustainability Elements

* Sustainable Use of Renewable Resources

(SFI, FSC certification)

* Recycling and reuse (~63.4% recycling rate)

* Reducing environmental footprint (SO_x, NO_x, CO_2)

* Energy and Materials

– generation and conservation

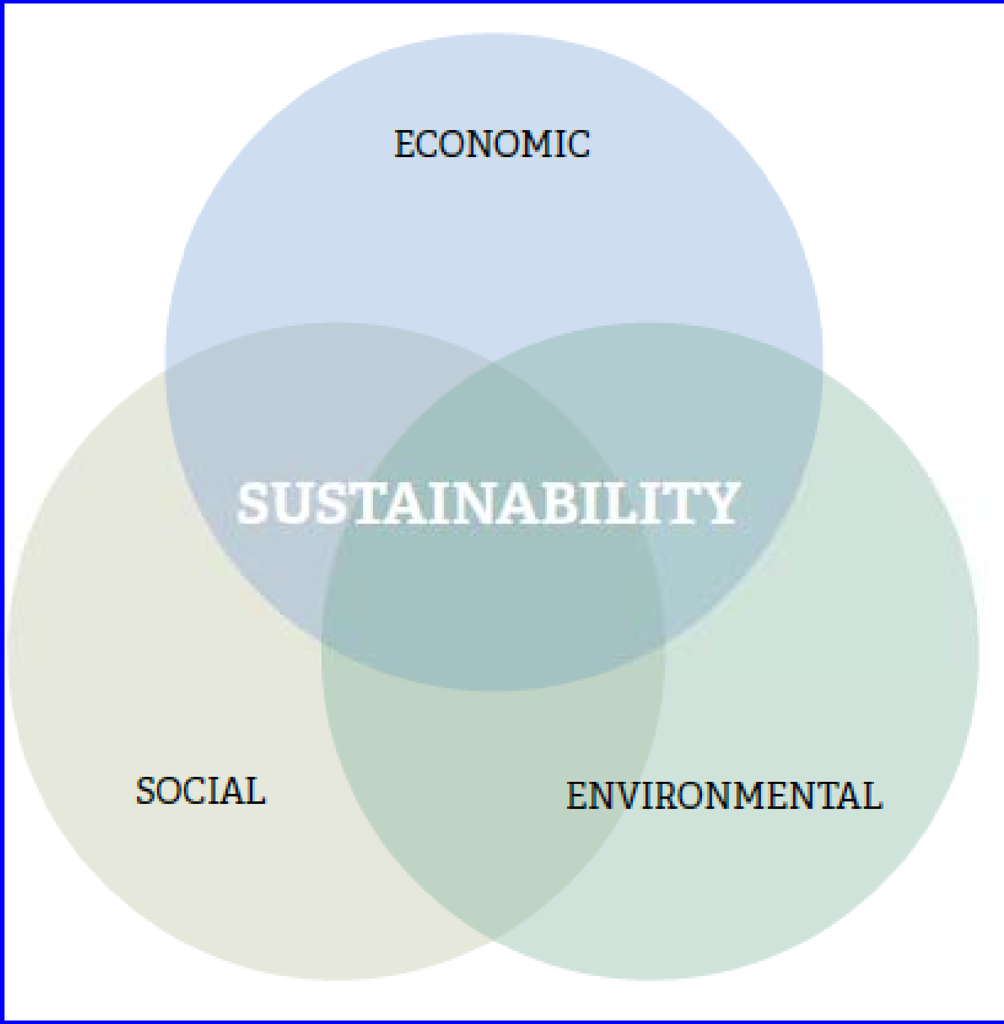
* Reducing Greenhouse Gas emissions

* Improved societal benefits

– communities, employees

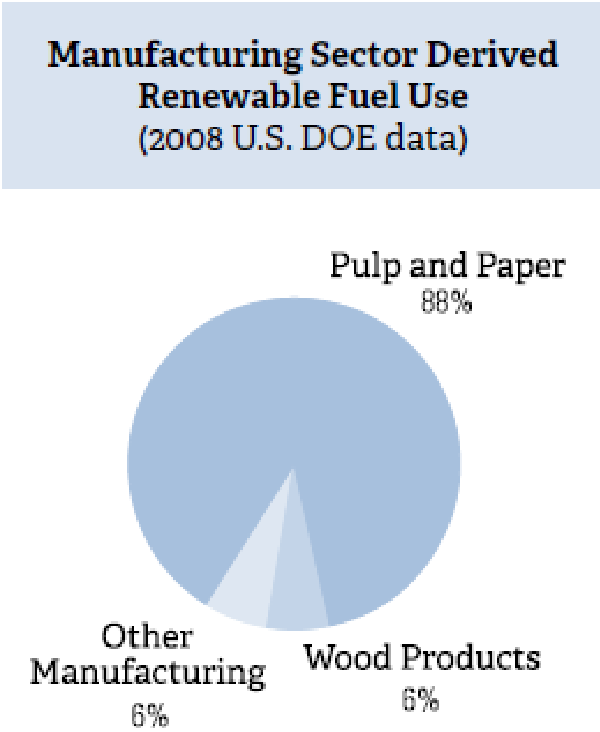
"Best Practices, Better Planet 2020" – Sustainability Goals

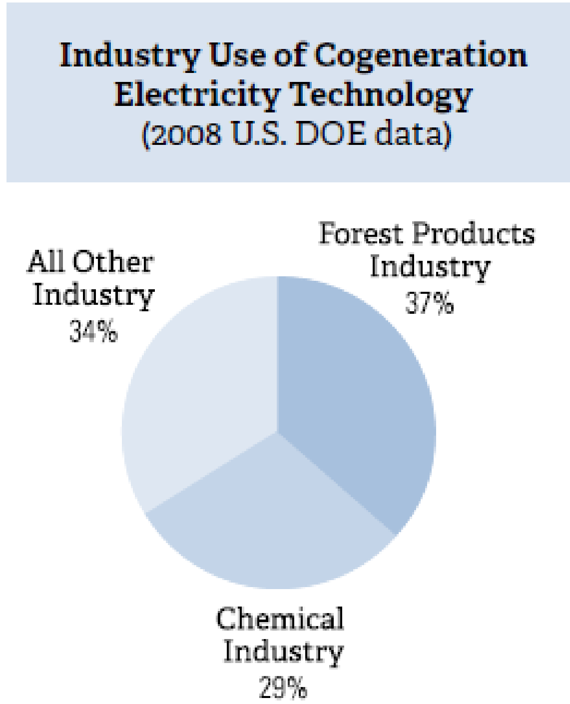
Three essential pillars of sustainability



Interdependent factors supporting long term viability, economic growth and environmental improvement

Renewable Energy and Cogeneration





* 94% of the total renewable fuels use in manufacturing
* Leader in the use of cogeneration
* Energy self sufficient – 65-75% from renewables

Putting it into Perspective – Carbon emissions and forest sequestration

44,033,998 tons CO_2 sequestered 100 yrs

÷

5.73 tons CO_2 emitted annually[1]

=

Offset CO_2 emissions from **76,915** cars or **2.2%** of the total CO_2 emissions annually

616,711 acres

3,478,218 cars in MN[2]

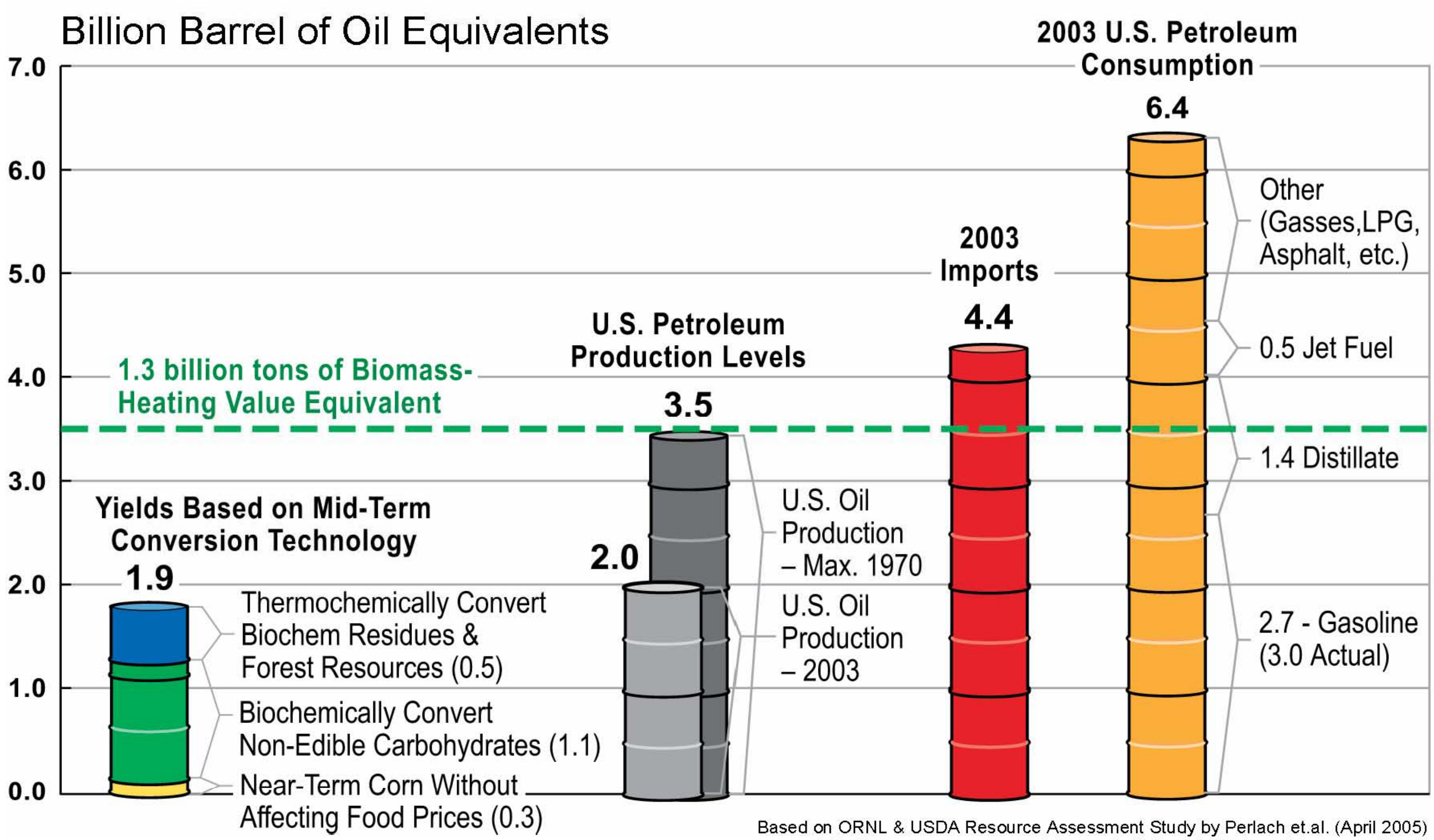
On a global scale, trees absorb about 25% of total Carbon emissions – almost all from cars and trucks[3]

[1]US EPA 2000
[2]MN Dept. Public Safety 2009
[3] NY Times, 10-1-11

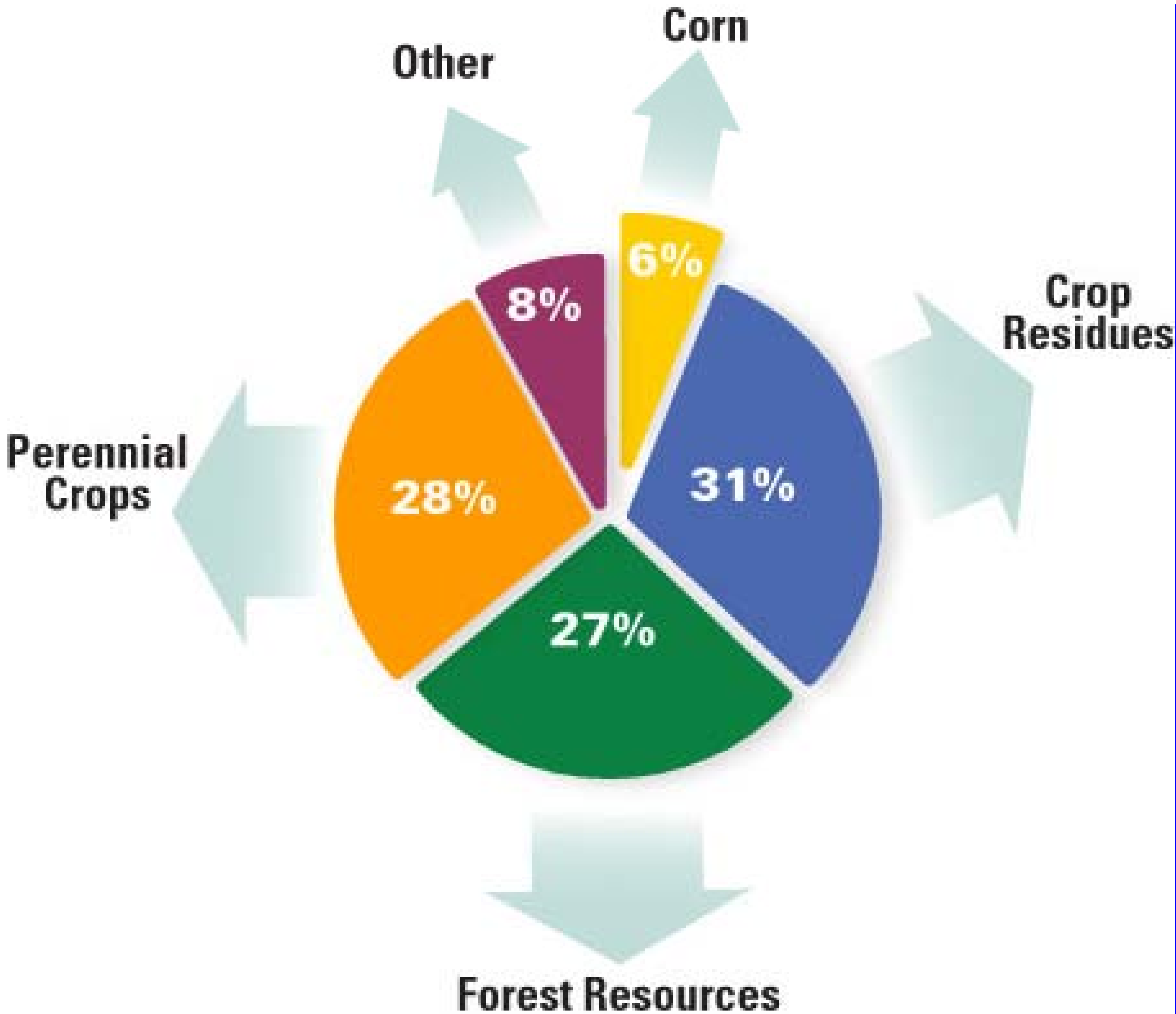
U.S. Forest Resources for Conventional & Emerging Bio-based (forest) industry

NREL National Renewable Energy Laboratory

The 1.3 Billion Ton Biomass Scenario



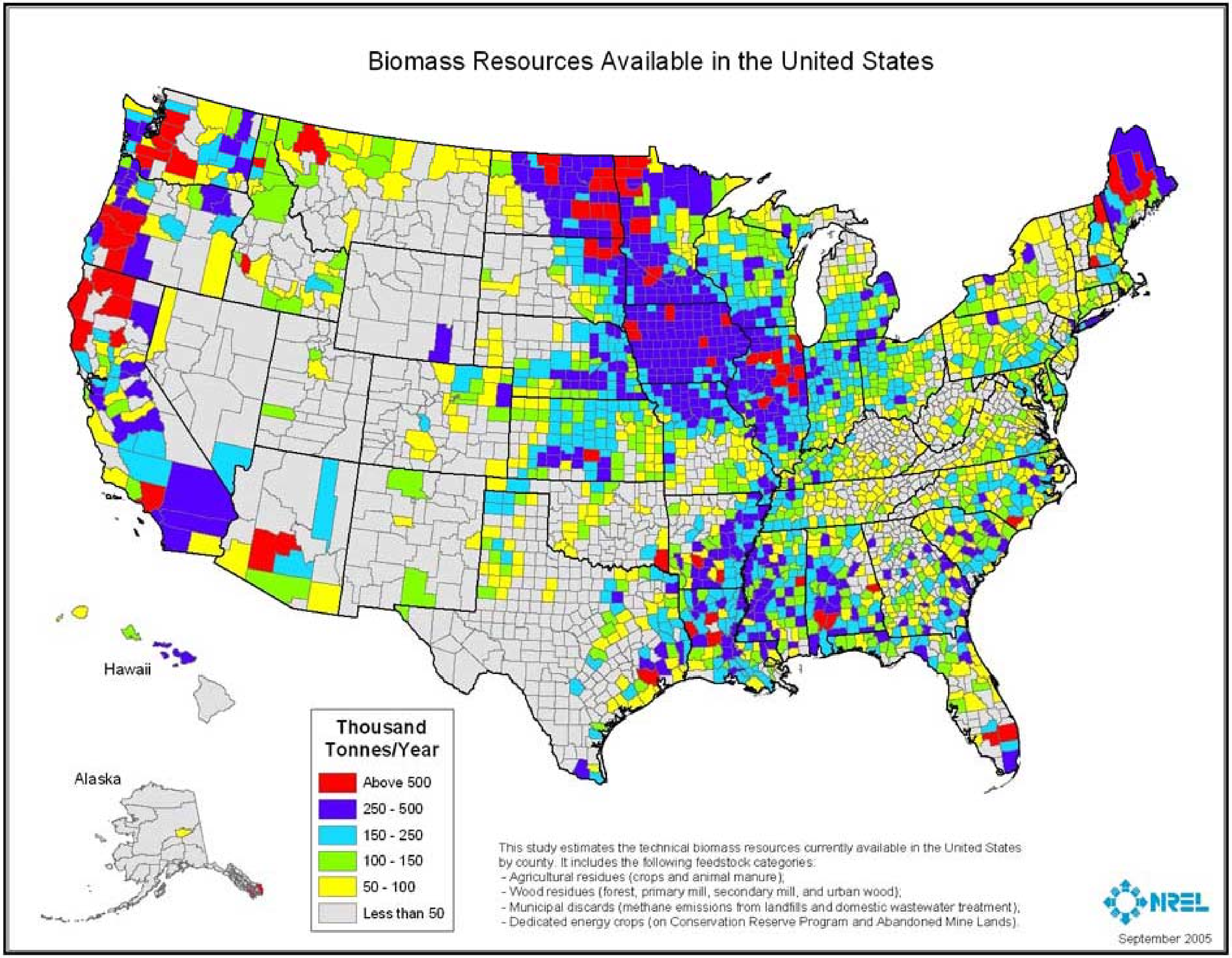
Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf



Projected U.S. Biofuel Sources

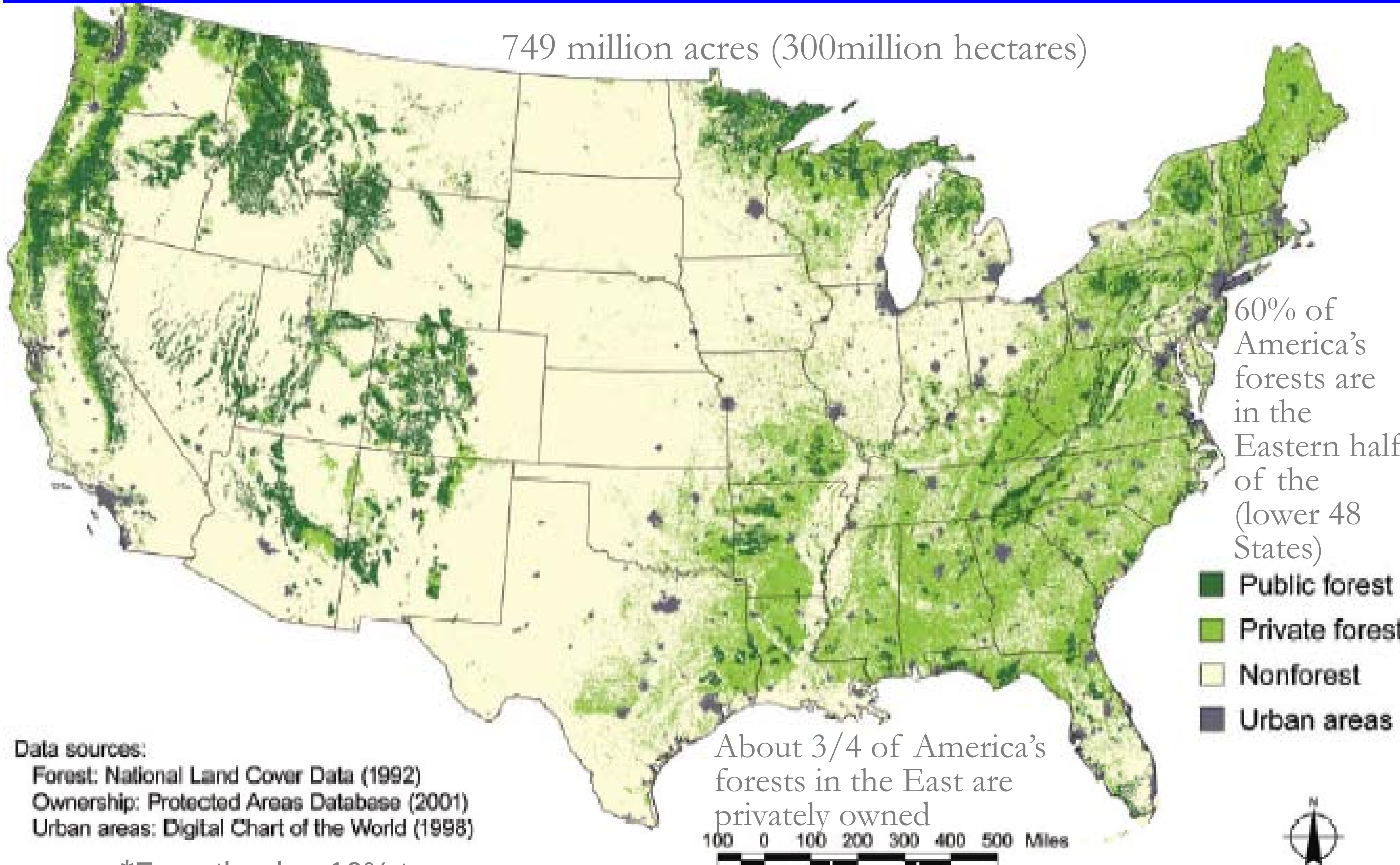
Source: Biomass as Feedstock for a Bioenergy and Bioproducts Industry: Technical Feasibility of a Billion Ton Annual Supply. 2005. DOE and USDA.

U.S. Biomass Availability



America's Forest Resource*

749 million acres (300million hectares)



60% of America's forests are in the Eastern half of the (lower 48 States)

About 3/4 of America's forests in the East are privately owned

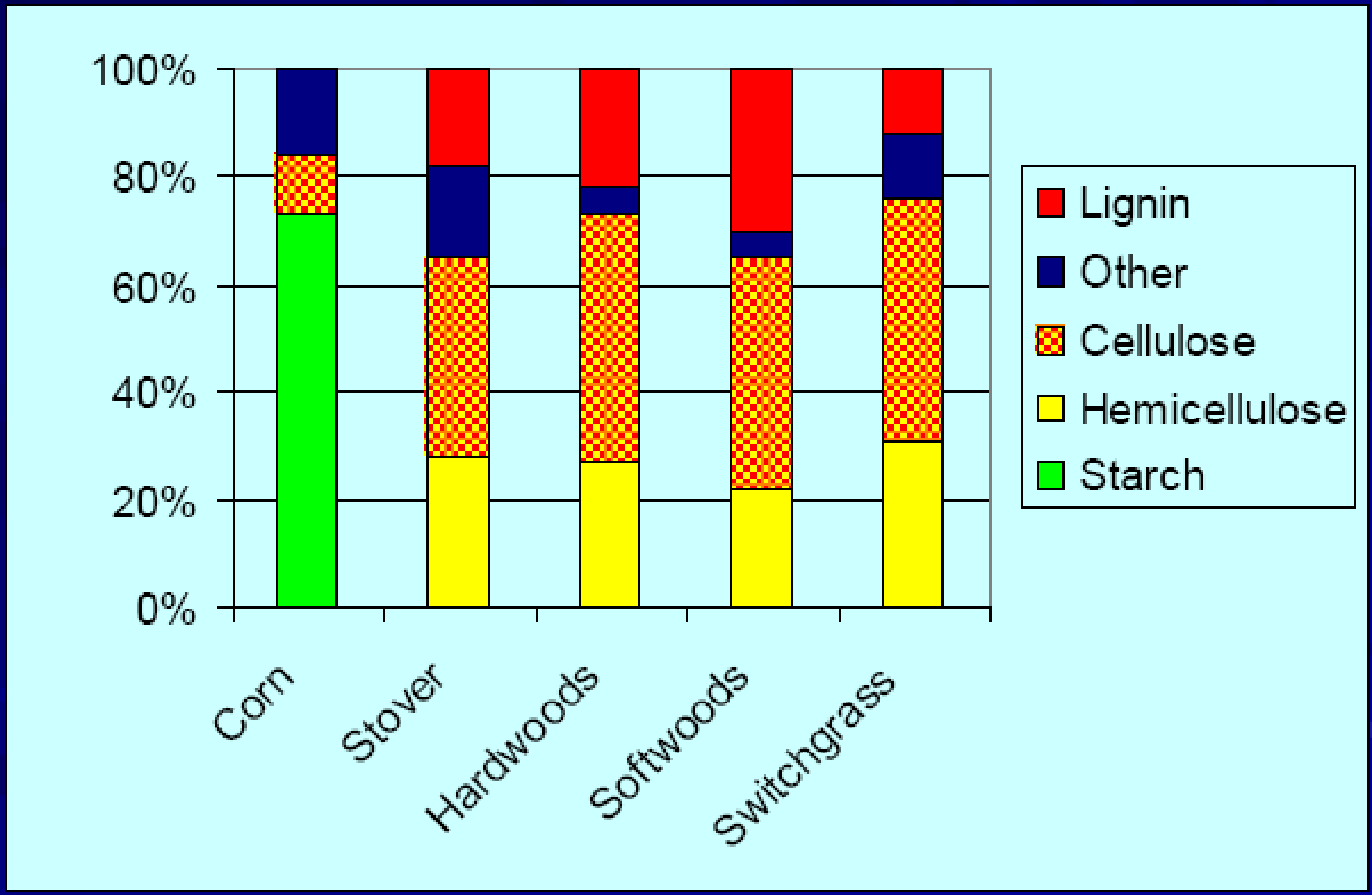
*Forestland > 10% tree cover

Forms of Forest Biomass

Forest Biomass for Biofuels Production

- Longer storage life and lower storage costs
- Higher bulk density (lower transportation costs)
- Less intensive use of water and fertilizers
- Established collection system
- Can be left to grow for longer periods of time
- Can be used for a variety of value-added products
- Compared to many agricultural materials
  - Higher lignin content
  - Lower ash content

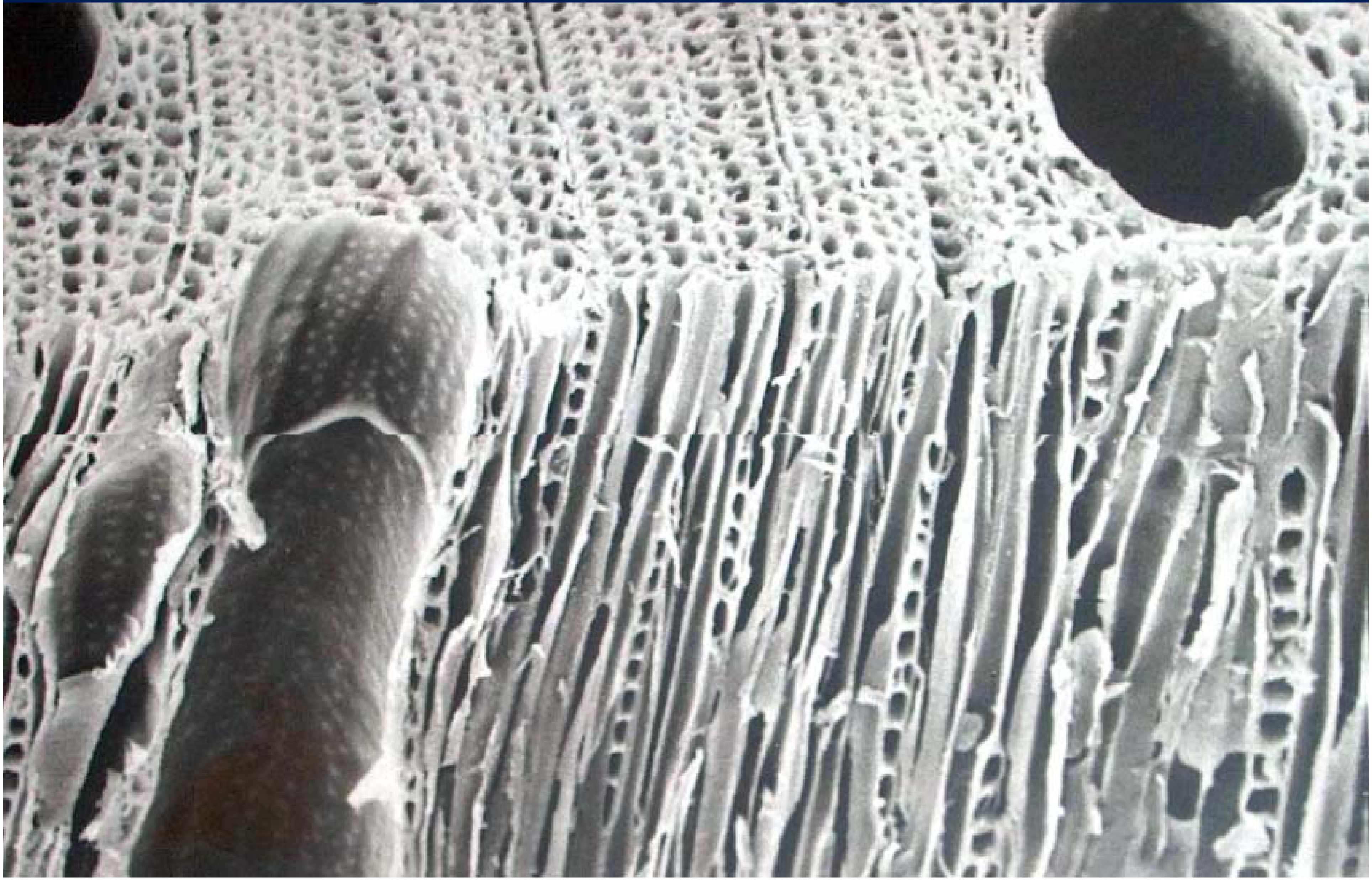
Composition of Various Forms of Biomass



Starch & Cellulose Yield Six Carbon Sugars
Hemicellulose Yields Five & Six Carbon Sugars

Lignin is a cross-linked aromatic compound
Other includes ash content

Wood Structure



Lignocellulosic Constituents

Lignin: 15-25%

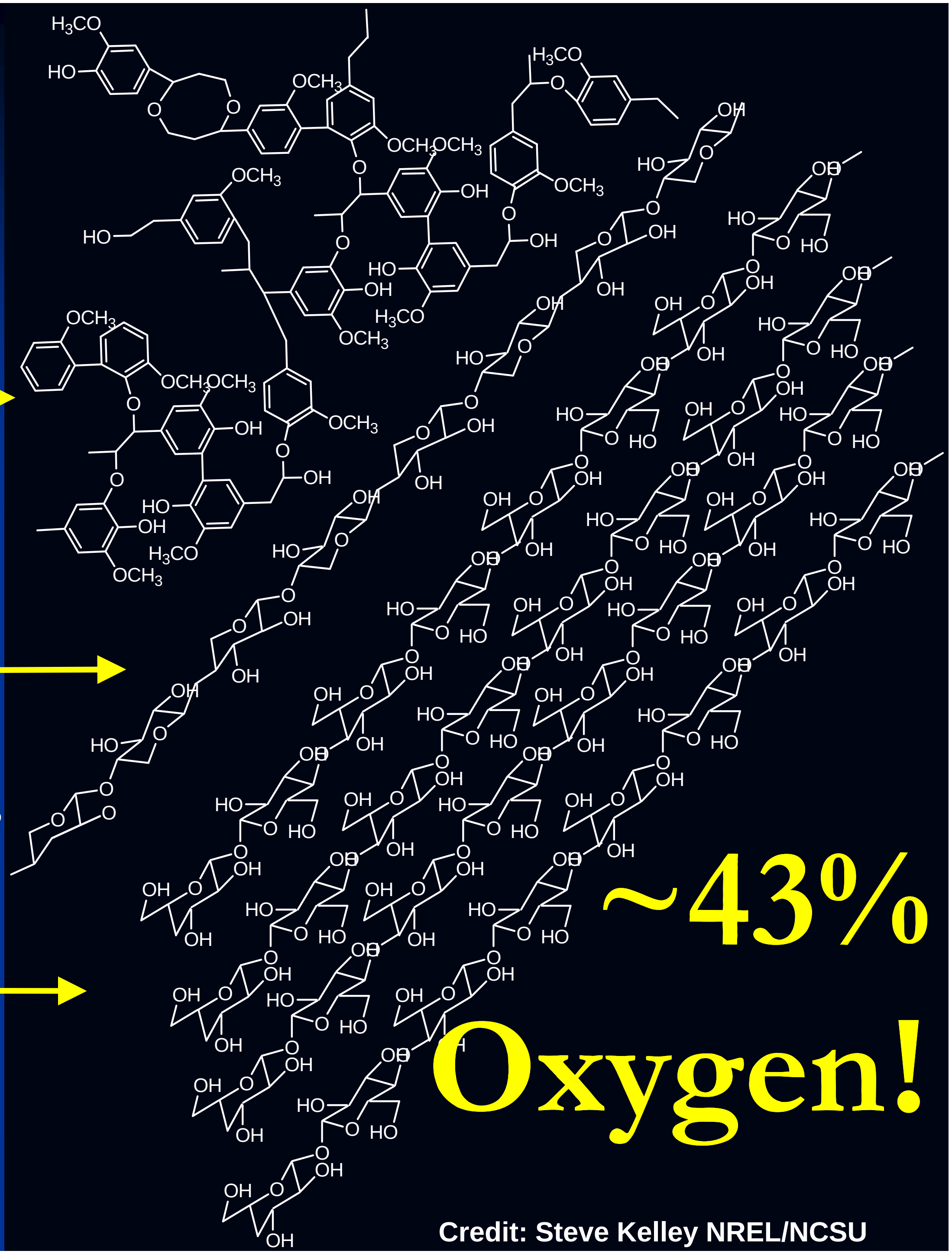
- Complex aromatic structure
- Very high energy content
- Resists biochemical conversion

Hemicellulose: 23-32%

- Xylose is the 2nd most abundant sugar in biosphere
- Polymer of 5- and 6-carbon sugars, marginal biochemical feed

Cellulose: 38-50%

- Most abundant form of carbon in biosphere
- Polymer of glucose, good biochemical feedstock

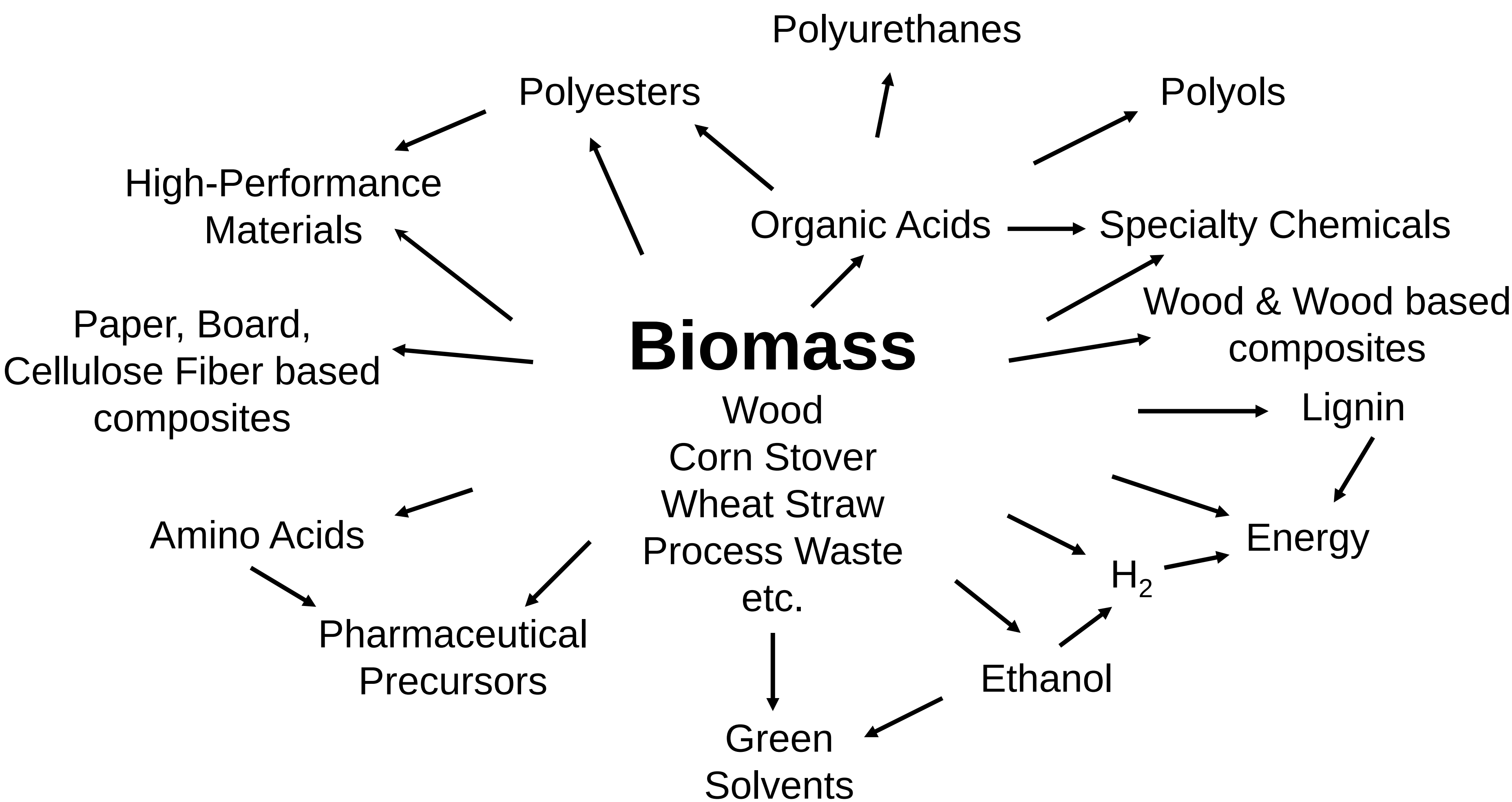


~43% Oxygen!

Credit: Steve Kelley NREL/NCSU

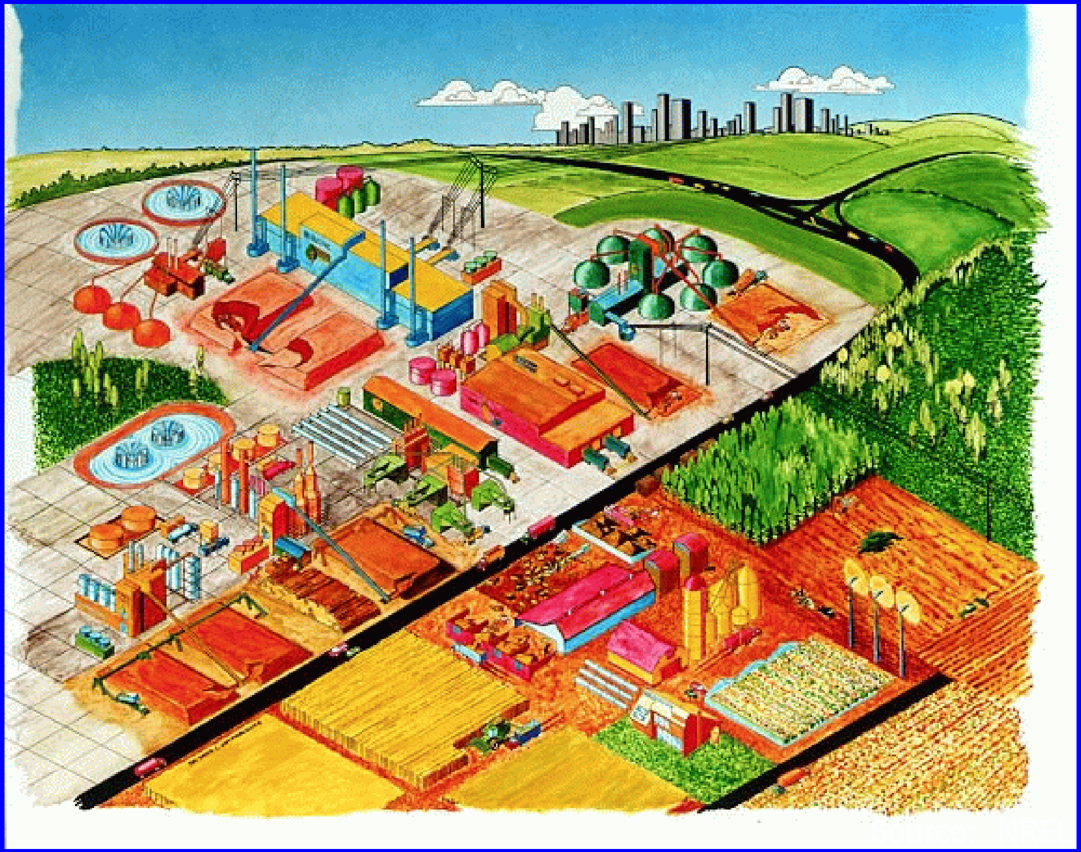
Sustainable Forest Biorefineries

Biorefining Vision



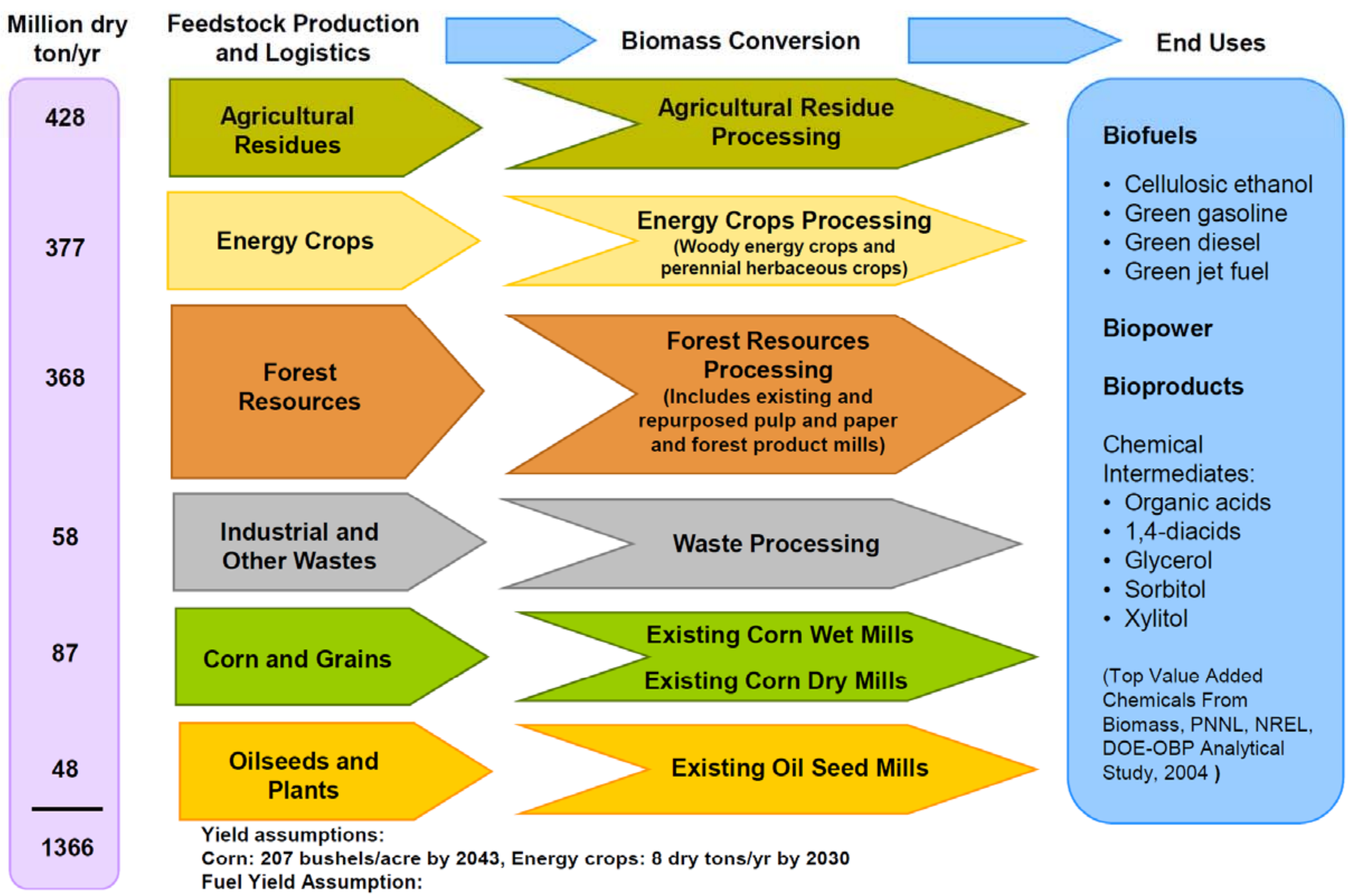
Biomass can substitute for Petroleum in many applications

BioEconomy Vision



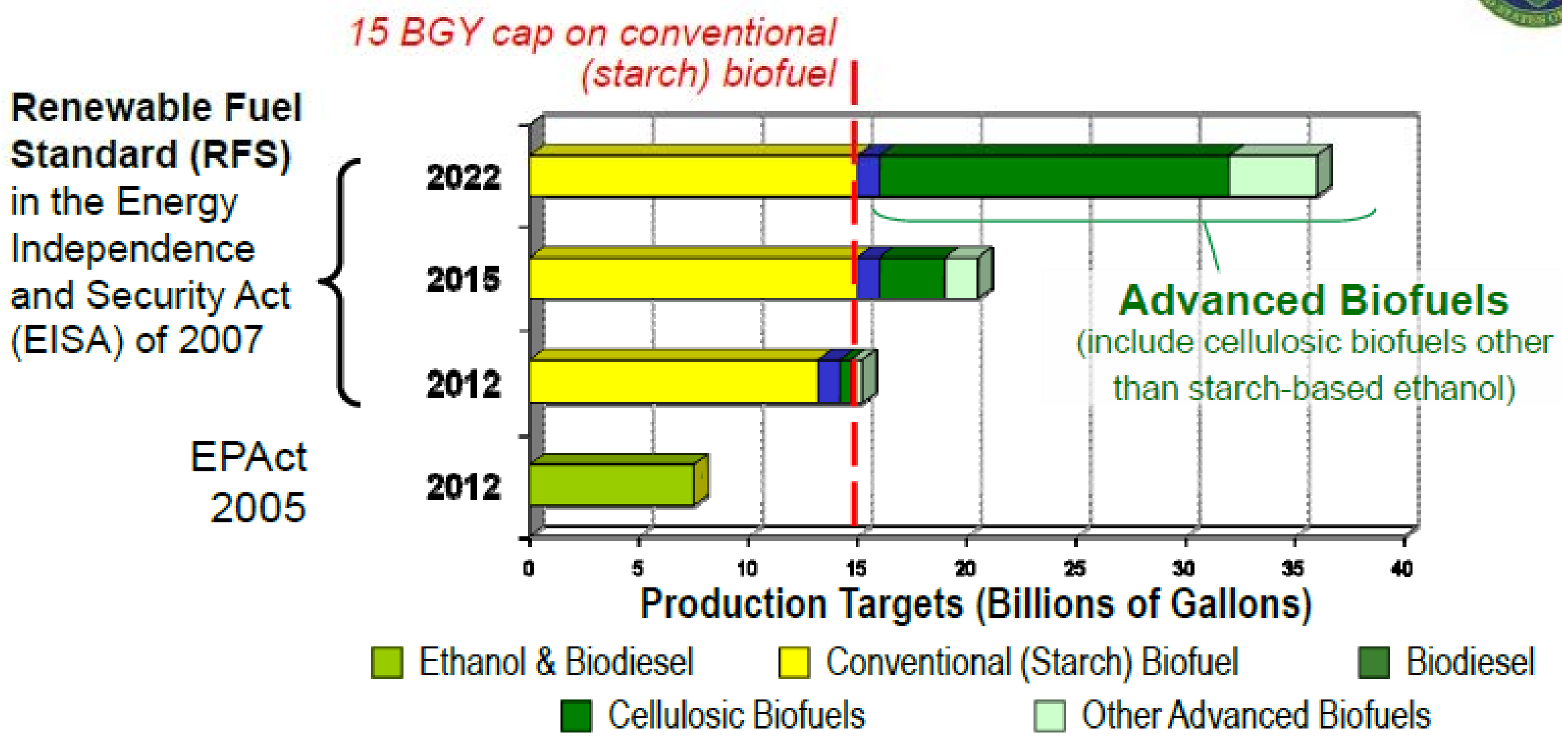
Biorefinery:
Cluster of biobased industries producing chemicals, fuels, power, products, and materials.

Major Biomass Pathways



Yield assumptions:
Corn: 207 bushels/acre by 2043, Energy crops: 8 dry tons/yr by 2030
Fuel Yield Assumption:
1.366 billion dry tons biomass at 100 gallons/ton = 136.6 billions gallons/year

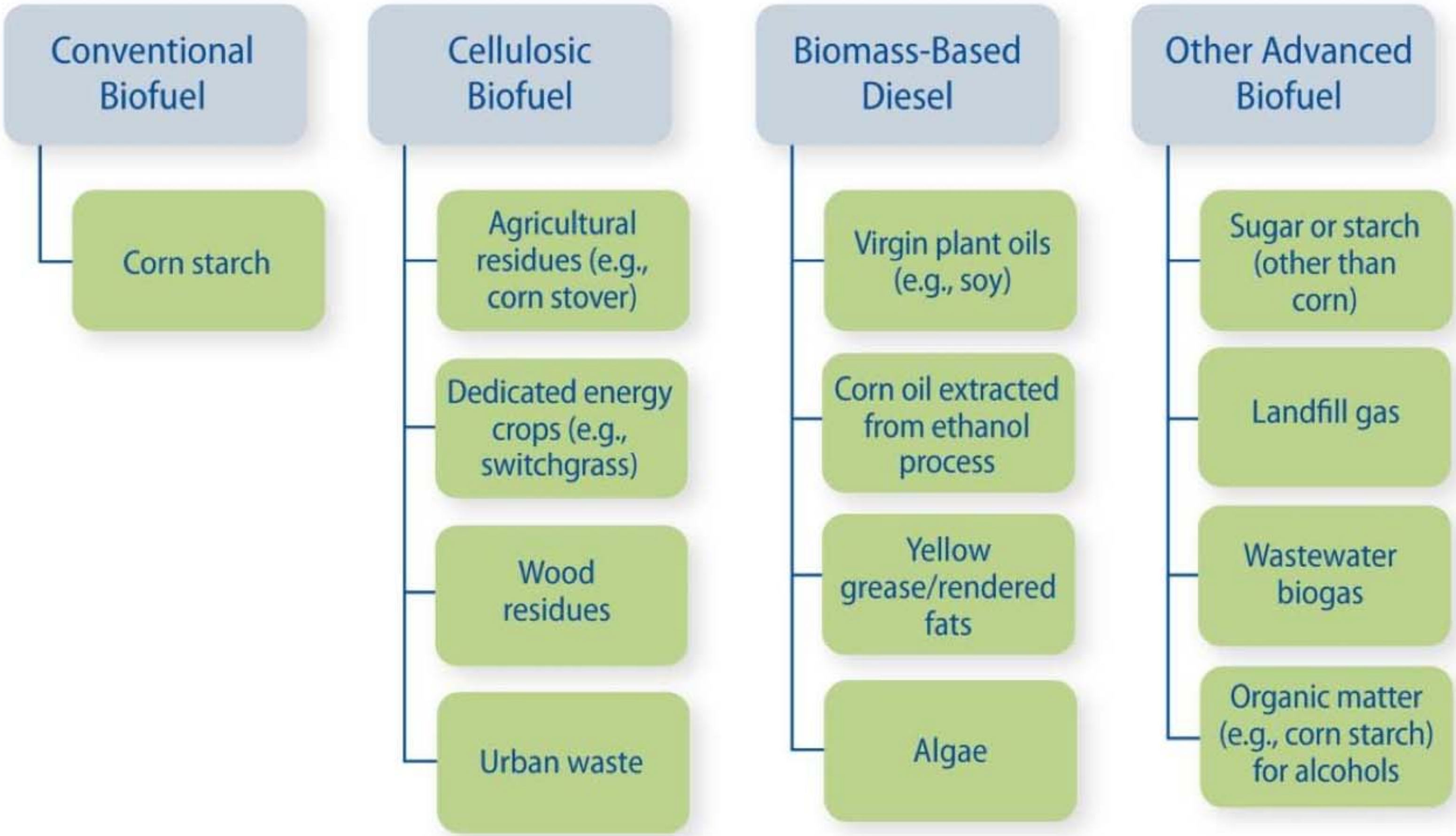
EISA Mandated Production Targets



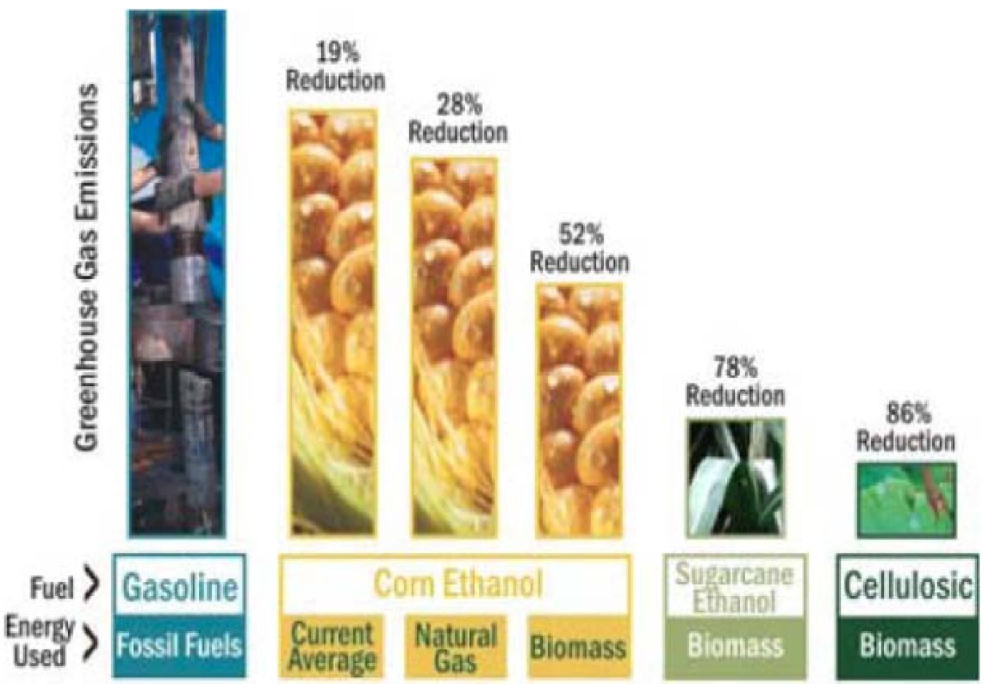
EISA defines ***Cellulosic Biofuel*** as "renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions…that are *at least 60 percent less* than baseline lifecycle greenhouse gas emissions."

EISA defines ***Advanced Biofuel*** as "renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions…that are *at least 50 percent less* than baseline lifecycle greenhouse gas emissions."

EISA RFS2 biofuels



Green House Gas Considerations
Carbon Footprint



Source: Wang et al, *Environmental Research Letters*, Vol. 2, 024001, May 22, 2007

In comparison to gasoline, ethanol made from cellulose and produced with power generated from biomass byproducts can result in an 86 percent reduction in greenhouse gas emissions.

Forest Biomass to Energy

Forest Biomass Feedstock

- Pulpwood
- Slash
- Short rotation woody crops
- Thinnings

Conversion Processes

- Co-firing/ Combustion
- Gasification/Pyrolysis
  - F-T Liquids
  - Gas/liquid fermentation
- Bioconversion
  - Hydrolysis/fermentation
- Catalytic Conversion

USES

Fuels

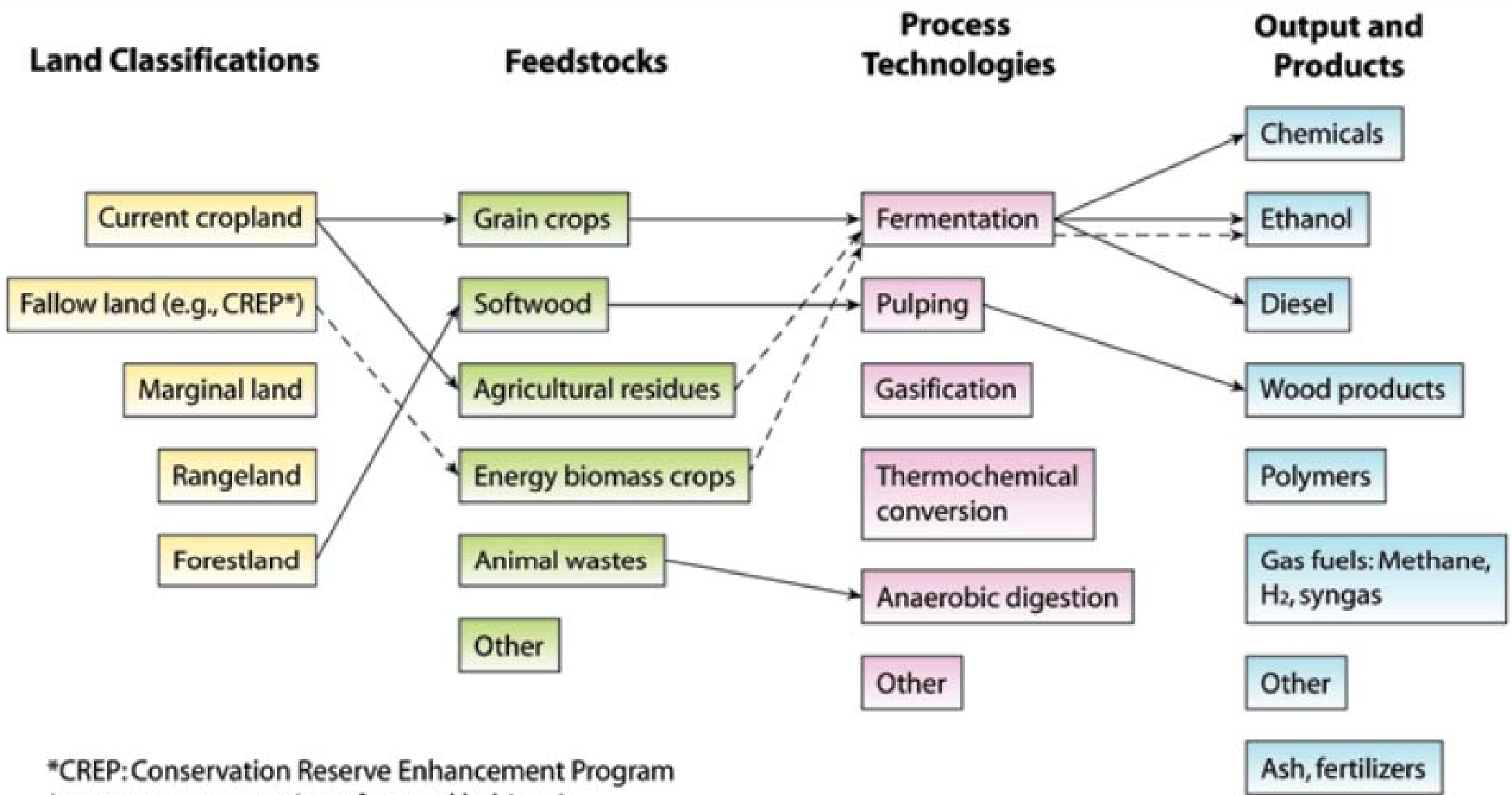
- Ethanol
- Advanced biofuels
- Renewable diesel

Electricity and Heat

Biobased Products

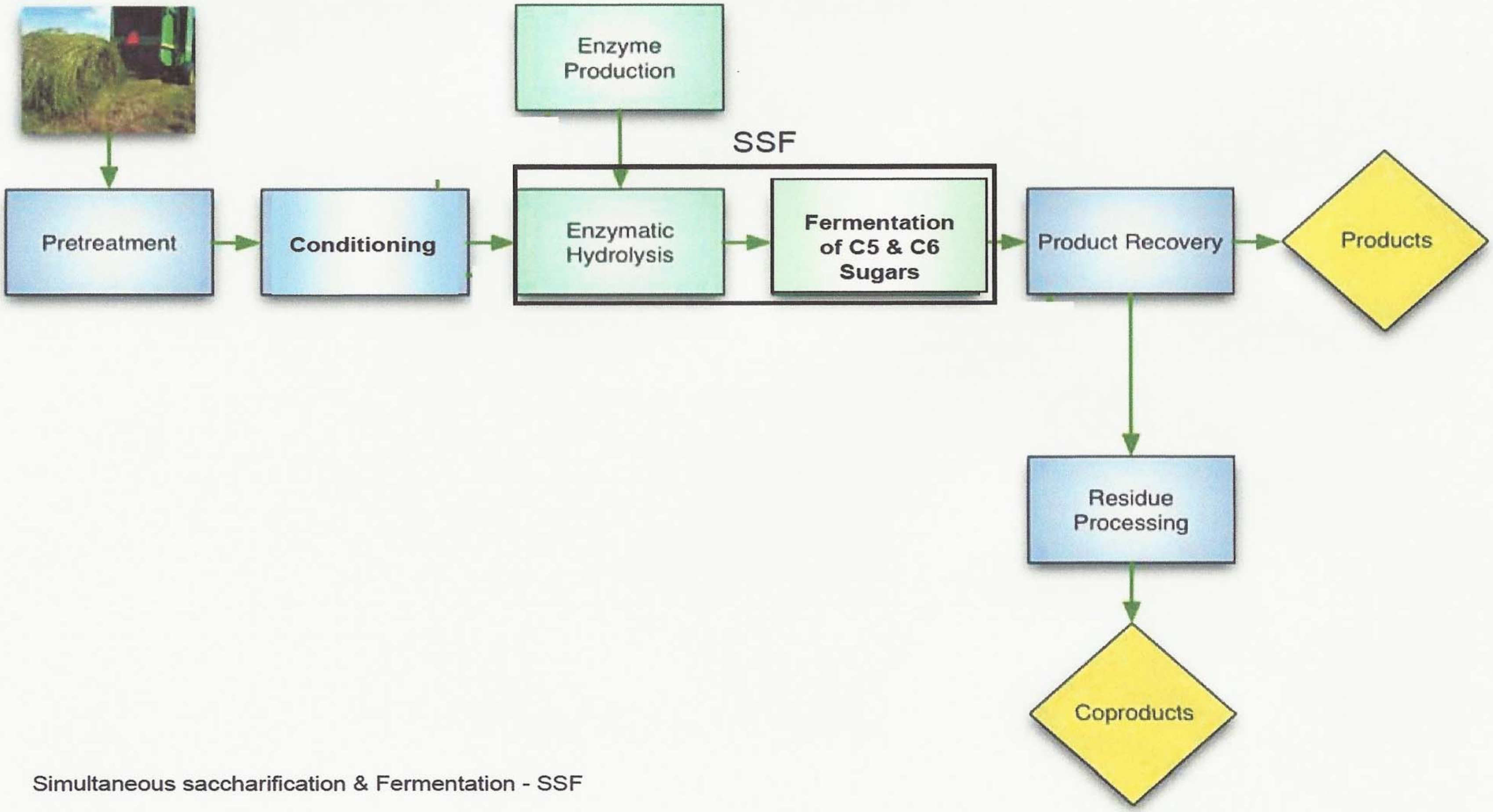
- Composites
- Specialty products
- New products
- Chemicals
- Traditional products

Biomass Conversion Pathways to Bioproducts



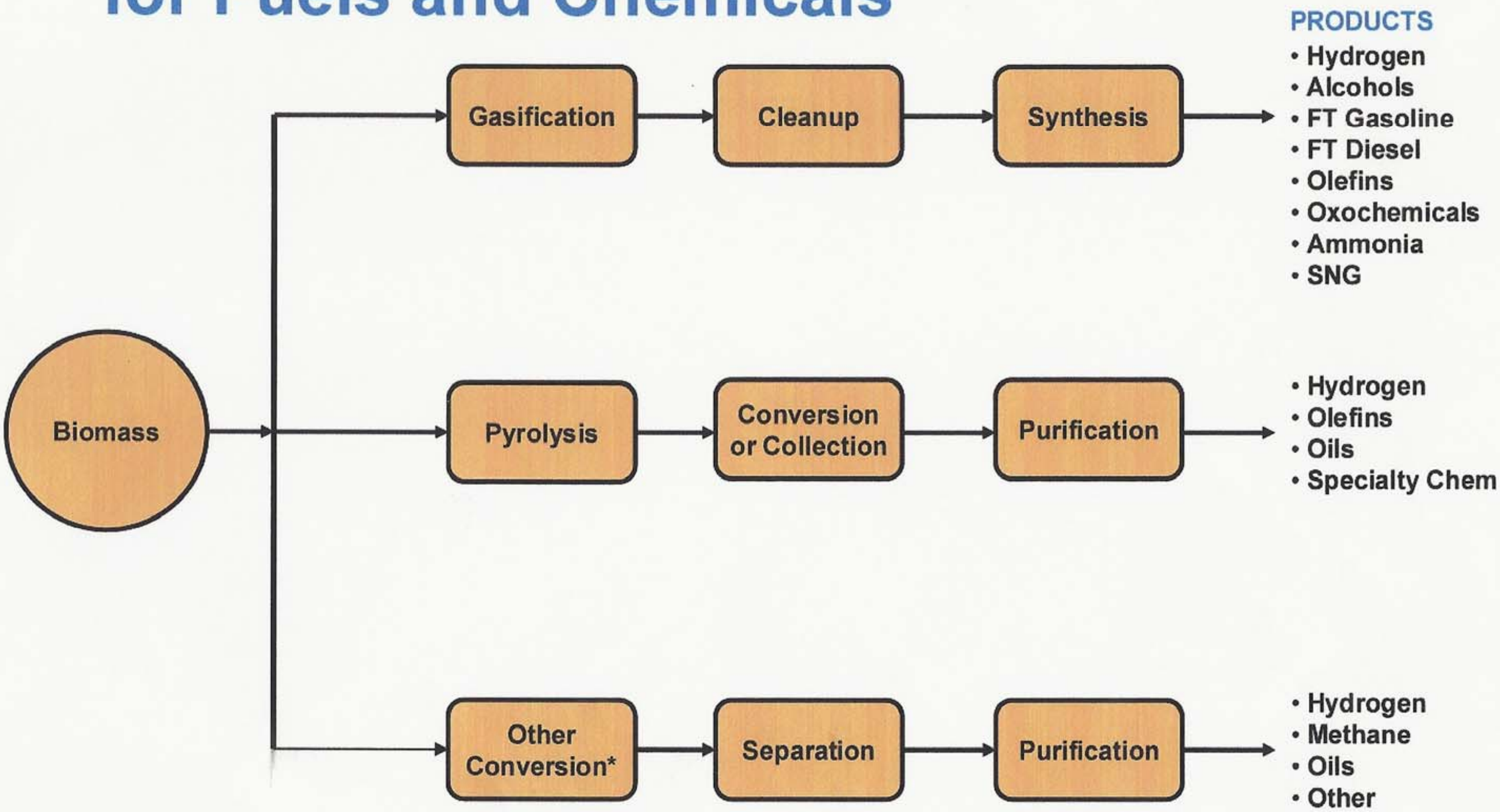
*CREP: Conservation Reserve Enhancement Program (encourages restoration of natural habitats)

Biochemical Conversion for Ethanol via PT/Hyd/Ferm

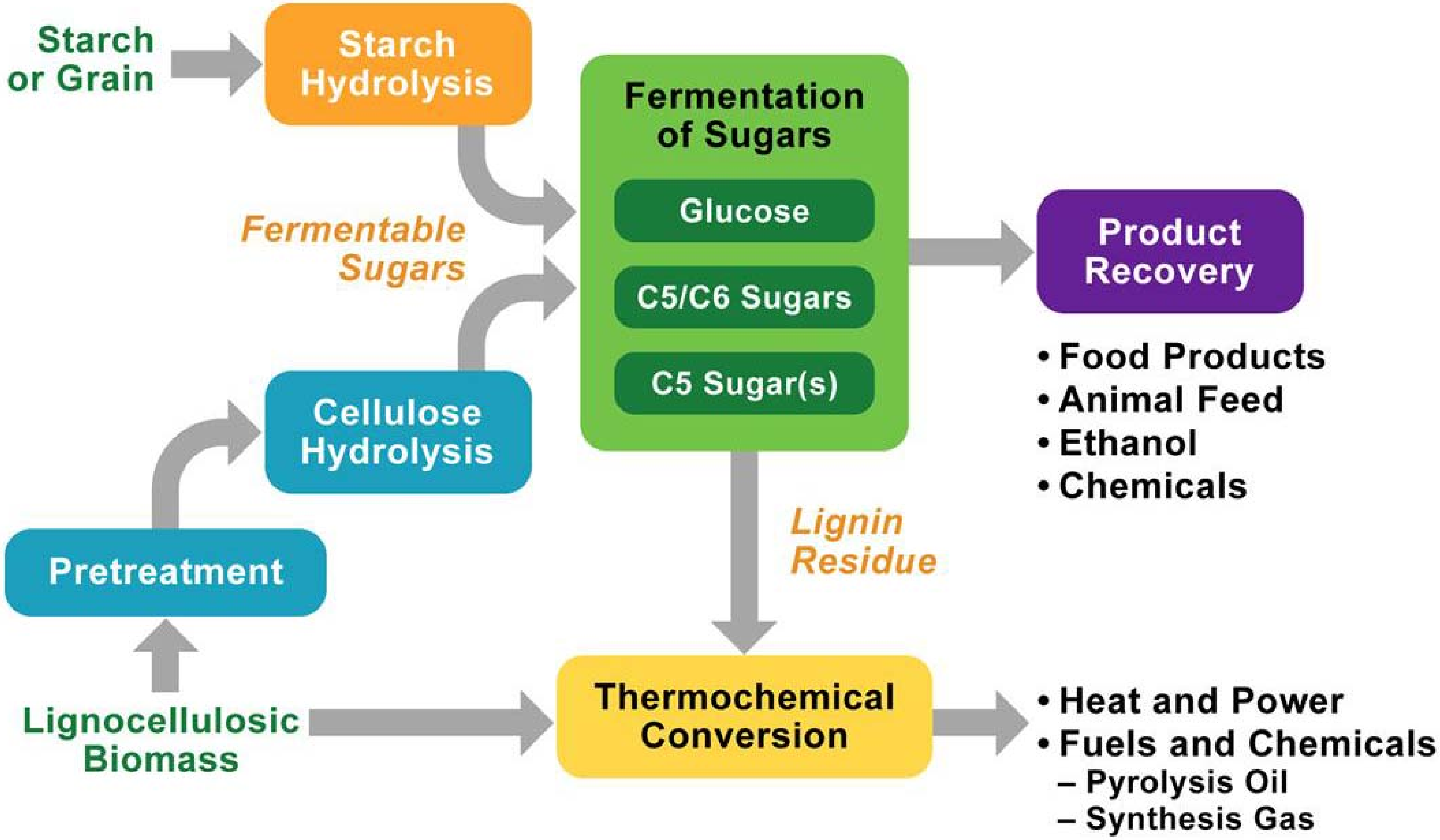


Simultaneous saccharification & Fermentation - SSF

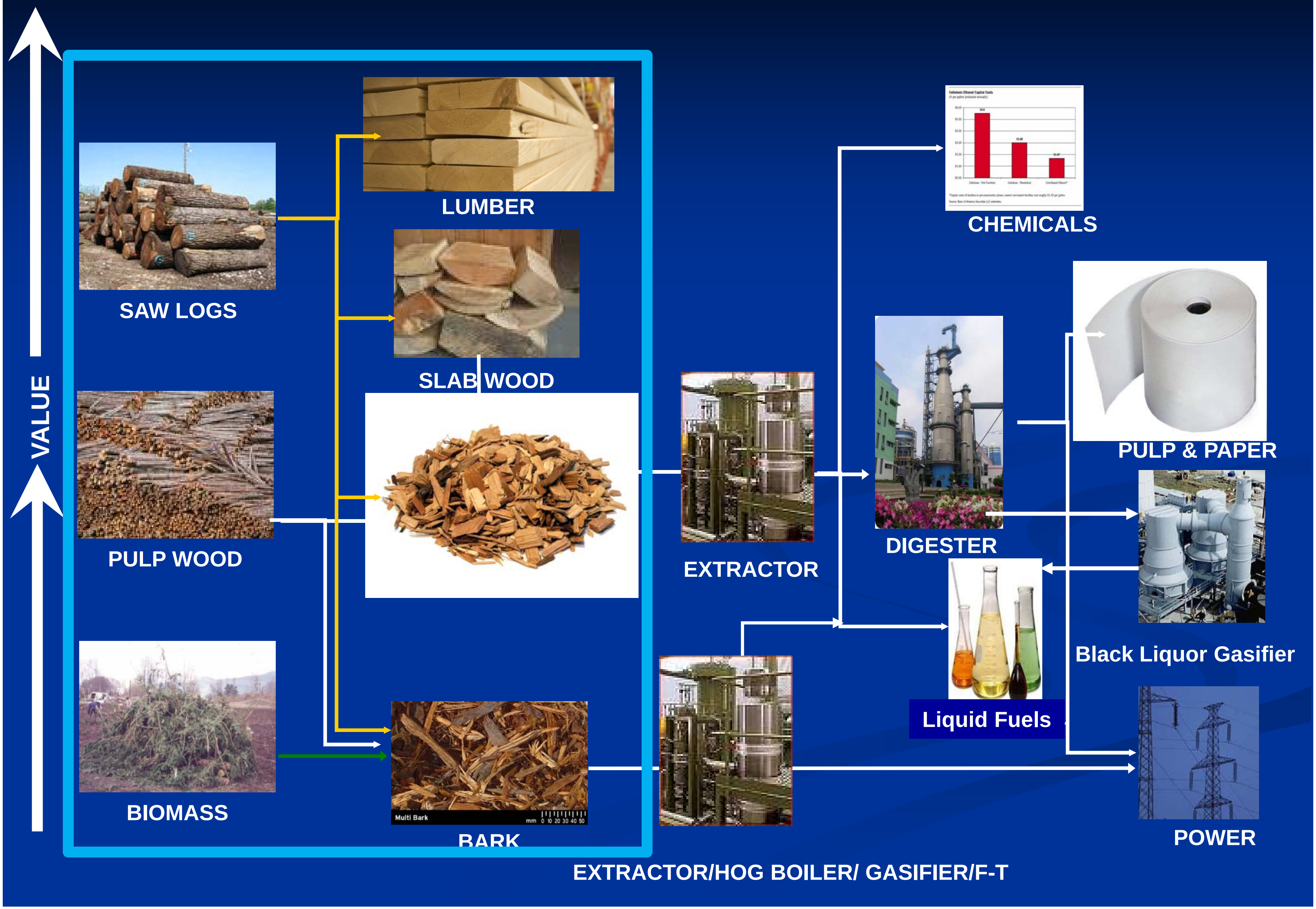
Biomass Thermochemical Conversion for Fuels and Chemicals

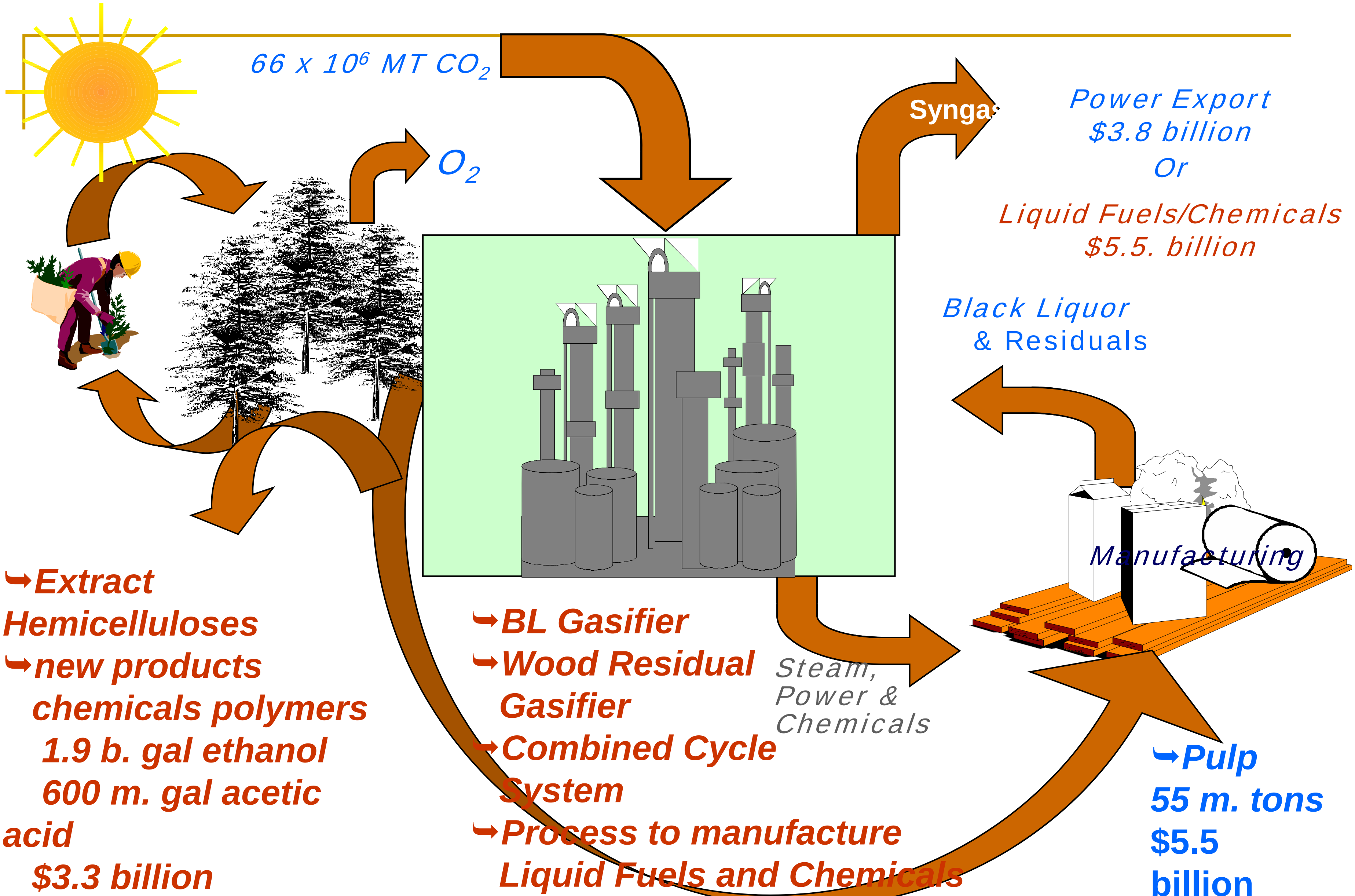


Integrated Biorefinery



Forest Products Industry Biorefinery Value Map





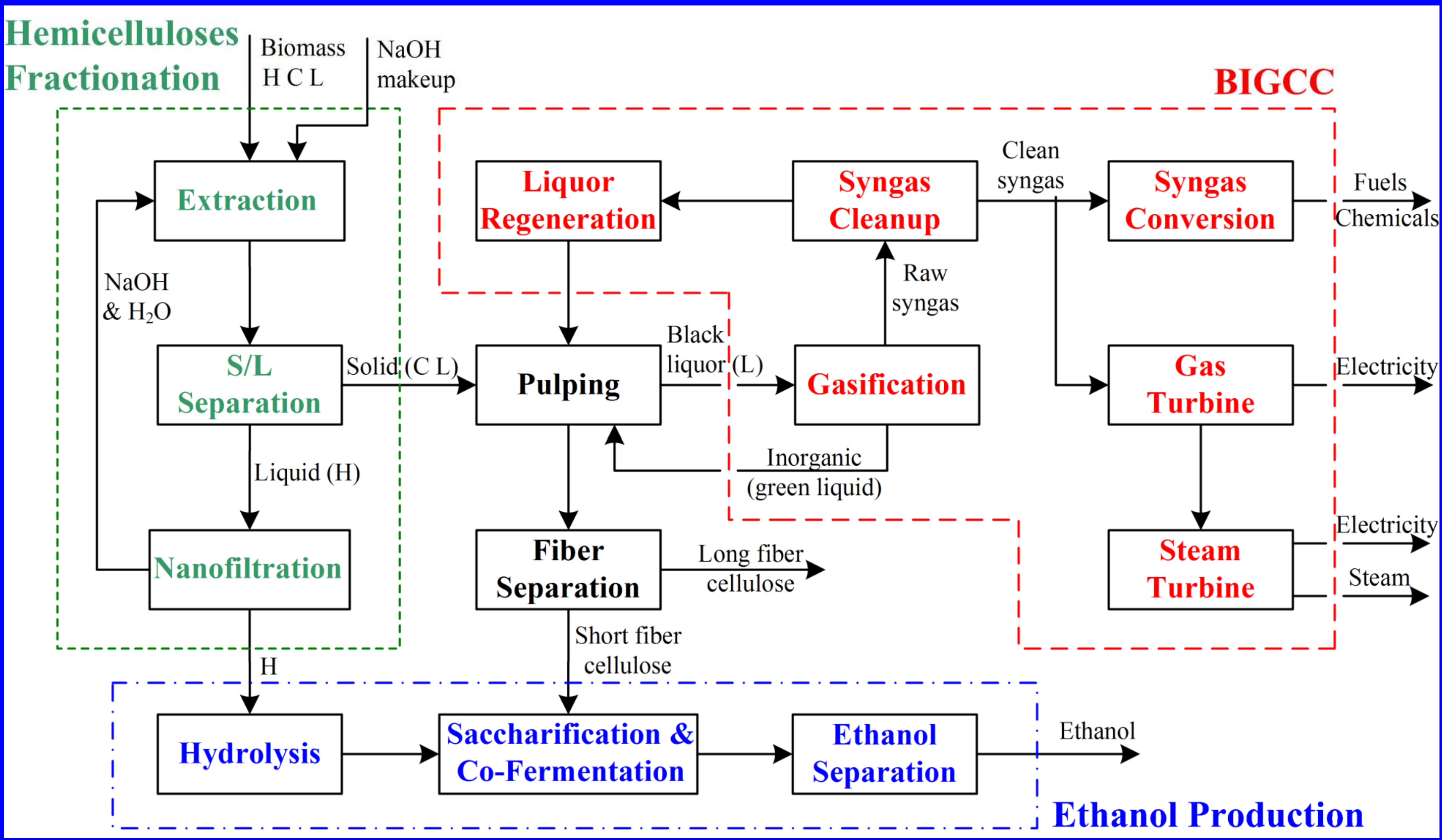
Forest Biorefinery

Net Revenue Assumptions:

Acetic Acid - $1.73/gallon
Ethanol - $1.15/gallon
Pulp - $100/ton net profit

Purchased Electricity - $43.16/MWH
Exported Electricity - $40.44/MWH
Renewable Fisher Tropsch Fuel - $57/bbl

Integrated Forest Bio Refinery (IFBR) – Fiber, Energy, Fuels and Chemicals



Sustainable Forest Biorefineries Challenges and Opportunities

Forest Resources & Biomass Characteristics

- **EISA restrictions on forest biomass sources make plantation and short rotation woody crops important**
- **Impacts on existing wood use markets**
- **Need for a wider variety of wood sources including pulp quality wood, slash, thinnings and short rotation woody crops, energy crops**
- **Sustainable production systems; Minimize environmental impacts/maximize ecosystem services**
- **Better understand carbon metabolism, density tolerance, growth habit and disease and stress resistance to produce more biomass**
- **Better understand cell-wall makeup and structure to produce better feedstocks; Breeding and engineering to enhance sugars, minimize lignin and toxic inhibitors**

Biorefinery – Process & Products

* Recalcitrance of complex biomass components
* Effective, low cost pre-treatment technologies to provide sugar streams from biomass at higher concentrations
* Enzyme-lignocellulose interactions; better degradative enzymes
* Ability to use complex sugars; mixed sugar C5, C6 conversion
* More robust microorganism – higher conversion and yield; able to handle inhibitors – metabolic engineering
* Efficiency of Bioseparation - C5, C6, & inhibitors

Biorefinery – Process & Products

* Cost, efficiency and integration of bioconversion processing steps – CBP, SSCF
* Cost and energy efficient product separation
* Syngas catalysts development – improved yield, selectivity
* Gas cleanup and conditioning
* Stabilization and upgrading of pyrolysis biooil
* Significant potential for higher value-added co-products along with bioenergy
* Sustainability analyses (LCA) integrated with process design and analysis

Forest Industry well positioned to be the leaders in sustainable biorefineries

* Significant expertise in sustainable use of biomass and manufacturing bio-based products

* Integration with current operation - higher efficiencies, added revenue & lower costs, i.e. hemicellulose extraction & conversion, waste (short) fiber conversion, biomass power, BL gasification

* Strong commitment for research and appropriate policies

Absolutely Critical to achieve BioVision!

Acknowledgements

- Ben Thorp, Bioenergy Deployment Consortium
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Thank You!

Questions ?