



“Biorefinery and Green Chemistry to Biofuel Production”

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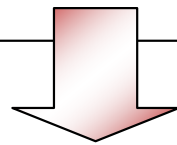
Issues

- Fossil fuel reserves depletion
- Global warming
- Costly and problematic waste recycling
- Inexorable population growth

Trends

Developing a new bioeconomy based on agro-resources

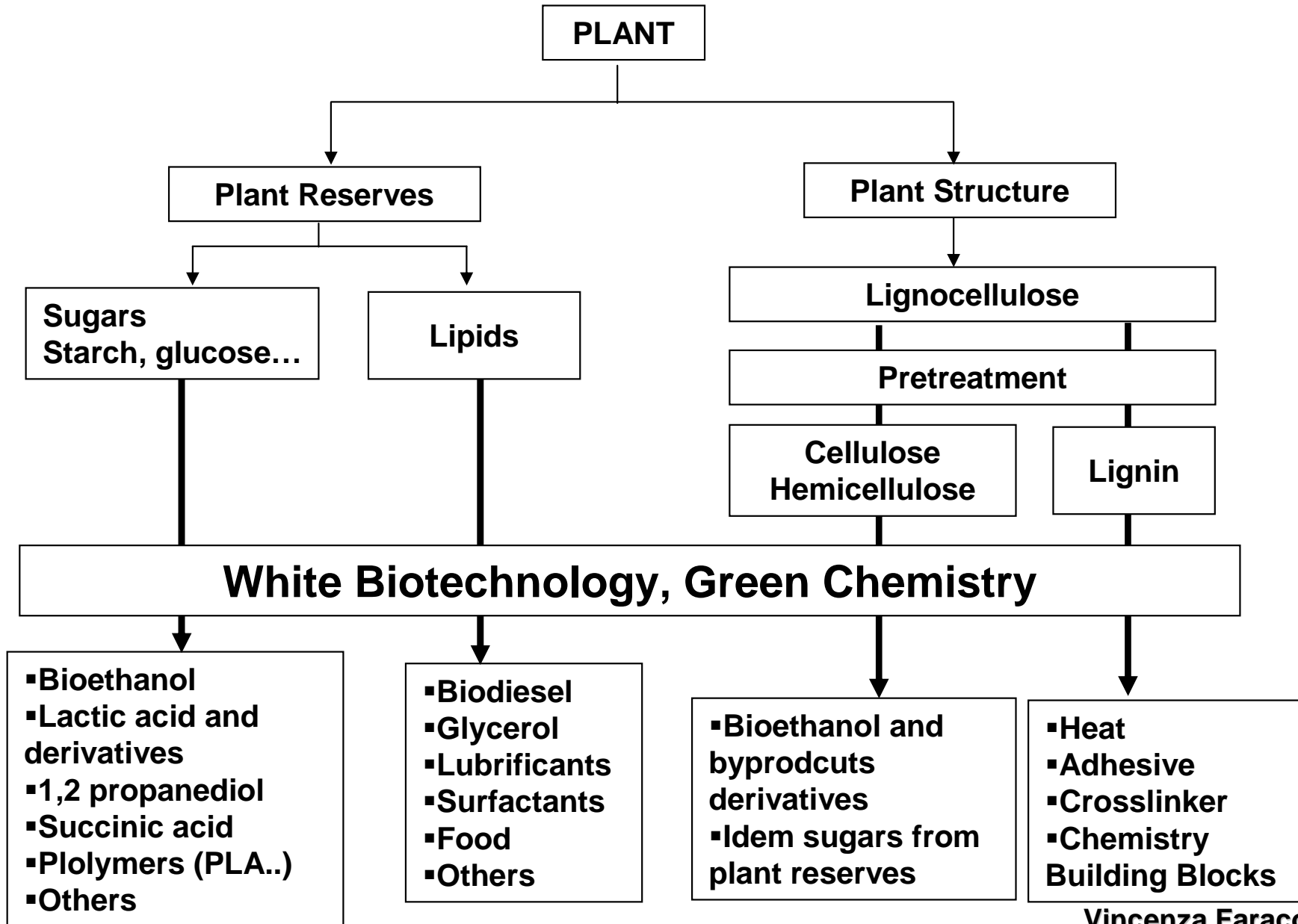
- Developing renewable sources of energy
- Reducing dependence on imported oil
- Reducing global warming (Greenhouse Gas emissions)



Biorefinery concept

Biorefinery concept

Valorization of the whole plant



Biorefinery concept

General definition

- « *the co-production of a spectrum of bio-based products (food, feed, materials, chemicals) and energy (fuels, power, heat) from biomass* » **by IEA [Bioenergy Task 42]**
- « *a facility that integrates biomass conversion processes and equipment to produce fuels, power, and value-added chemicals from biomass* » **by NREL**

Towards an “Industrial metabolism”

« *The reduction of the wastes or byproducts could be linked not only to one whole plant transformation but also to the use of several plants based different complementary processes belonging to different factories: wastes and by-products of the first factory can be the starting material or the energy source for the second or the third factory* » **by Octave and Thomas, 2009**

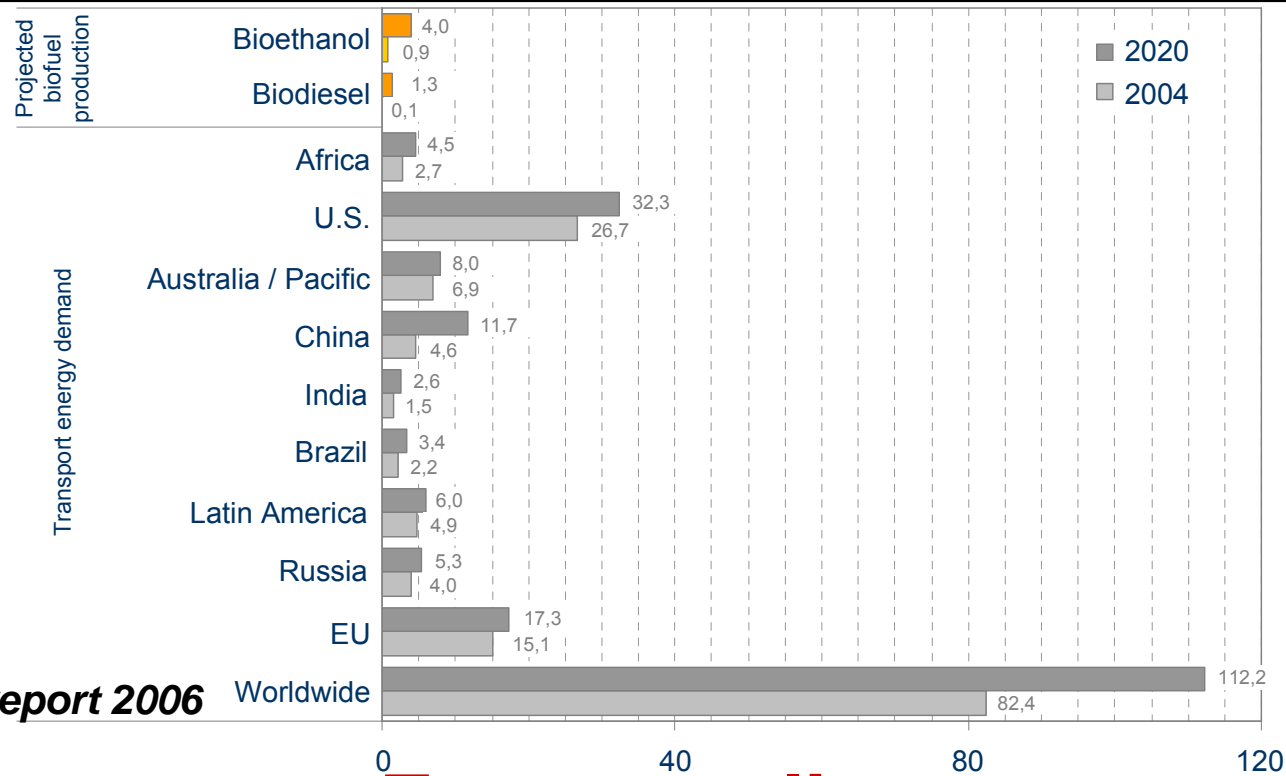
Biorefinery products

✓ **Molecules:** solvent surfactants or chemical intermediates in substitution of oil derivatives

✓ **Materials:** fibers can be valorized in materials like composites

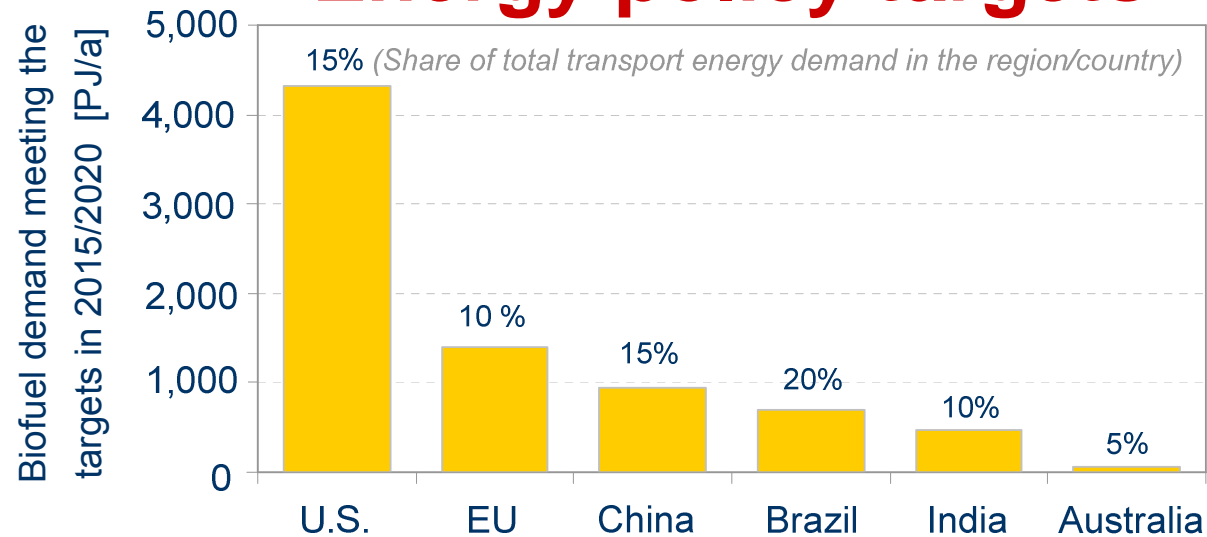
✓ **Energy:** sugars and oils are used to produce biofuels

Transportation fuel demands

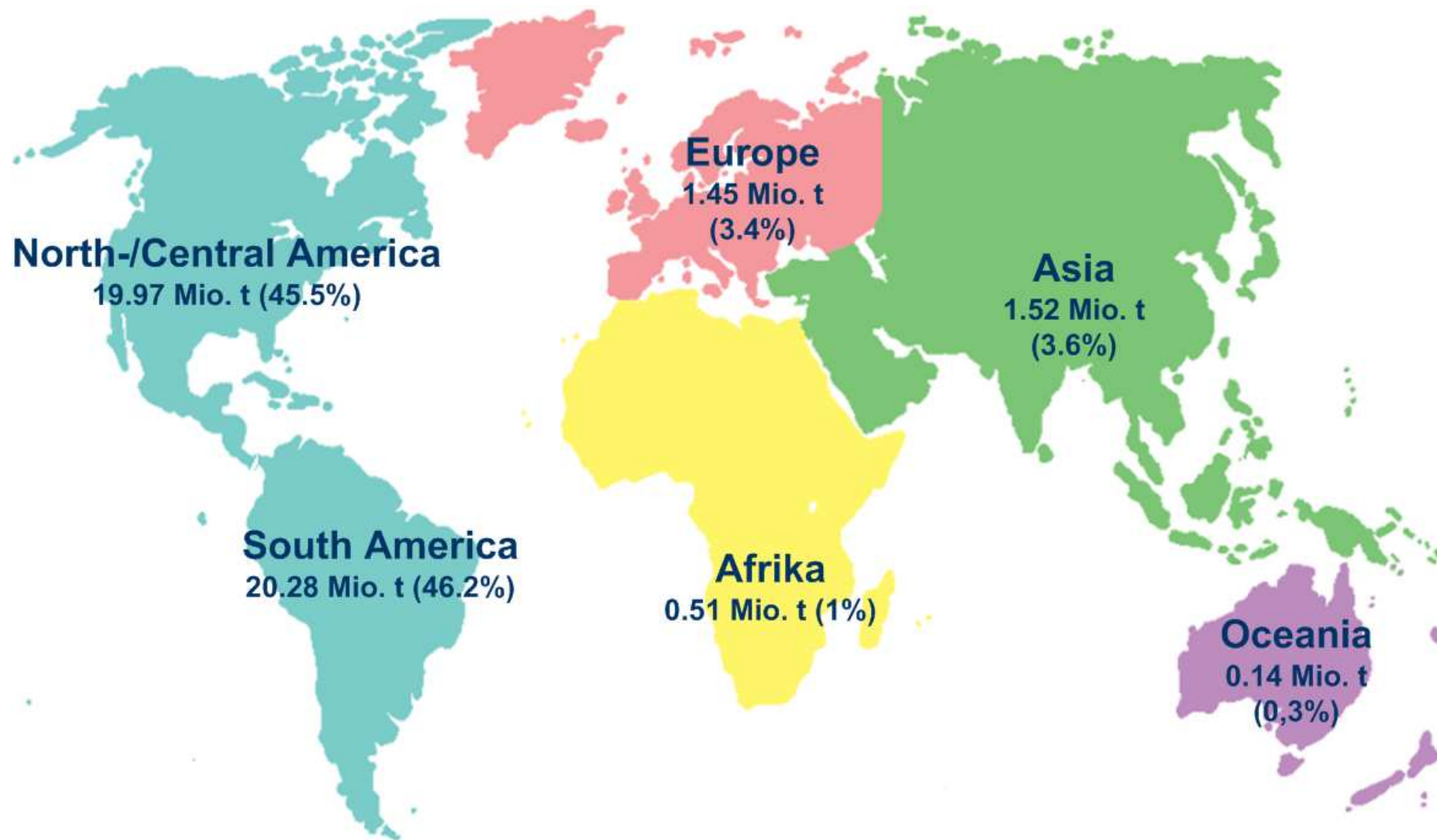


Data source: IEA report 2006

Energy policy targets



Bioethanol production worldwide



1st Generation Bioethanol

Bioethanol from sugar cane, palm, grains, jatropha, beet, maize...

Problems, challenges

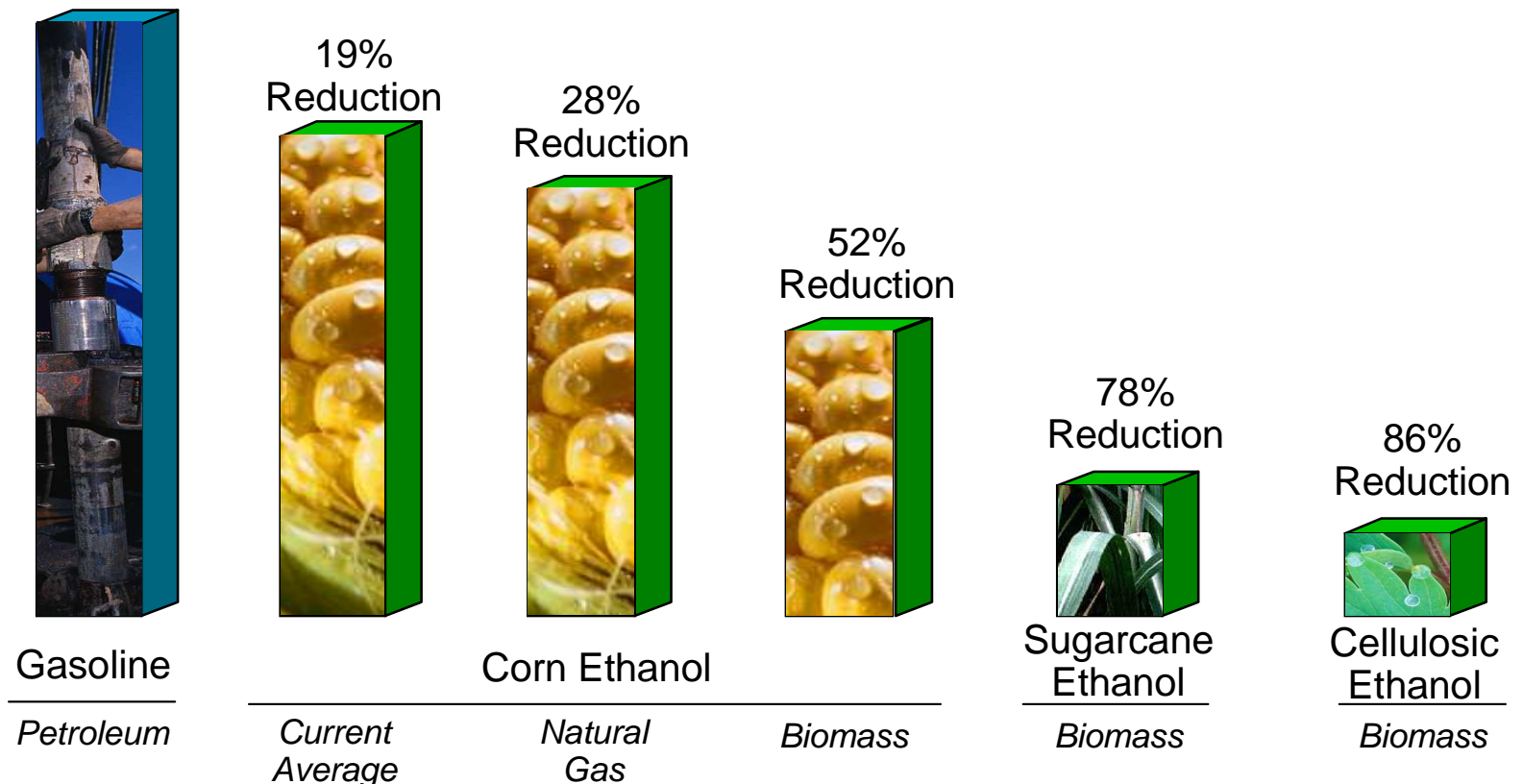
- Food-versus-fuel debate, preference for nonedible biomass (ex: jatropha)
- There is a lot of waste material, find ways to convert lignocelluloses present in waste
- Try to use algae as feedstock
- Savings in greenhouse gases sometimes are not as low as required
- Decreasing production costs by means of genetic engineering
- Focus on lowering energy consumption

Supply of starch and sugars is expected to be not sufficient to meet the increasing ethanol demand!

2nd Generation Bioethanol

Bioethanol from lignocellulosic raw materials

- Lignocellulose represents the most abundant biomass
- Lignocellulosic raw materials are geographically more evenly distributed
- Lignocellulosic raw materials minimize the potential food-versus-fuel conflict
- Raw material is less expensive than conventional agricultural feedstock
- Biofuels from lignocellulose generate low net greenhouse gas emissions

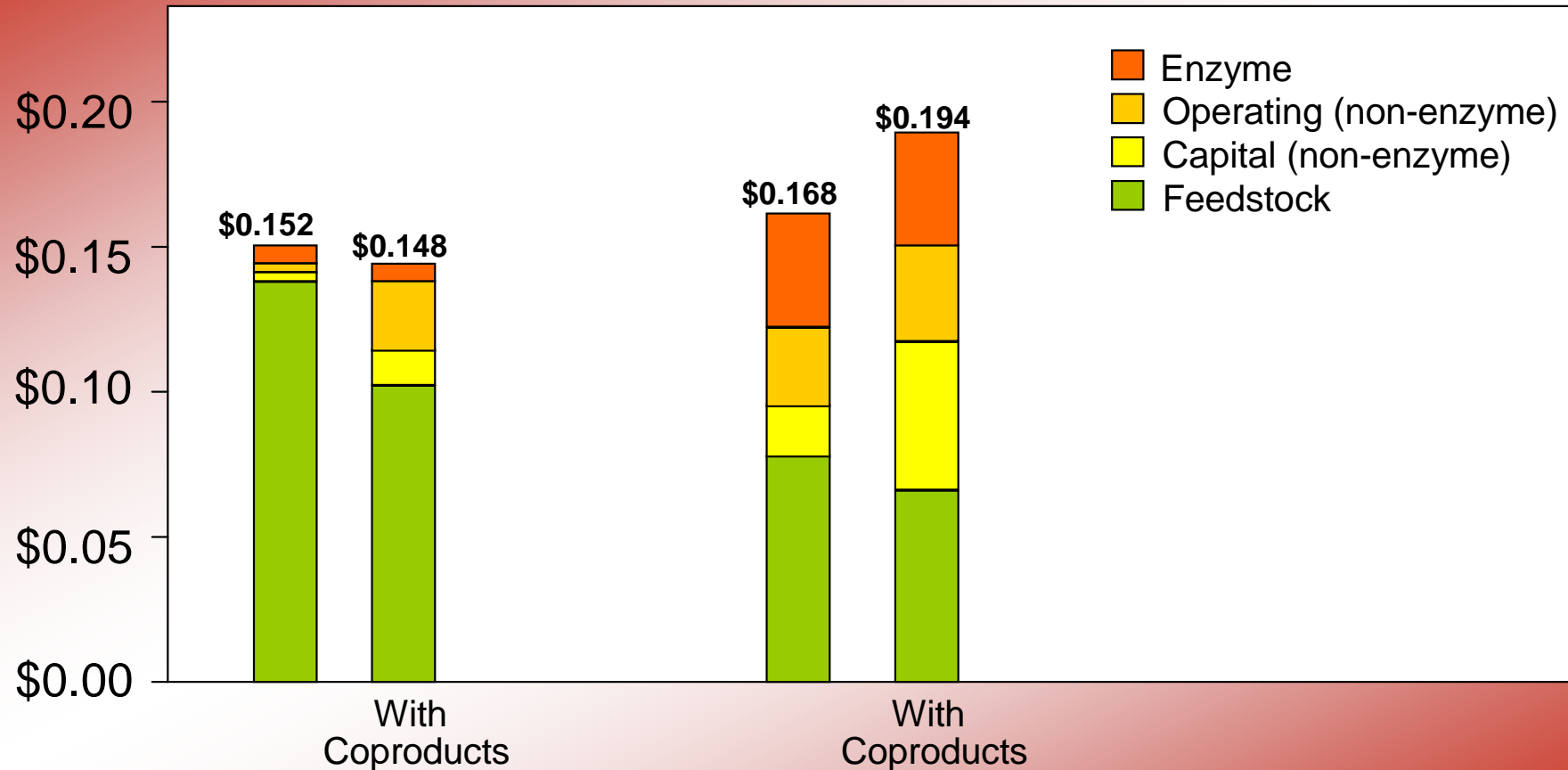


Challenges for 2nd Generation Bioethanol production

- ✓ **Effective, economical pre-treatment** to increase accessibility/digestibility of cellulose and hemicellulose through an efficient lignin degradation
- ✓ **Rapid and efficient conversion** of all of the sugars present in both its cellulose and hemicellulose fractions, **increasing the yield of the hydrolysis process**

Cost for processing corn and cellulosic biomass

Fermentable Carbohydrate Cost (\$/kg)



Corn (dry mill)

Cellulosic Biomass

Lynd et al, 2008

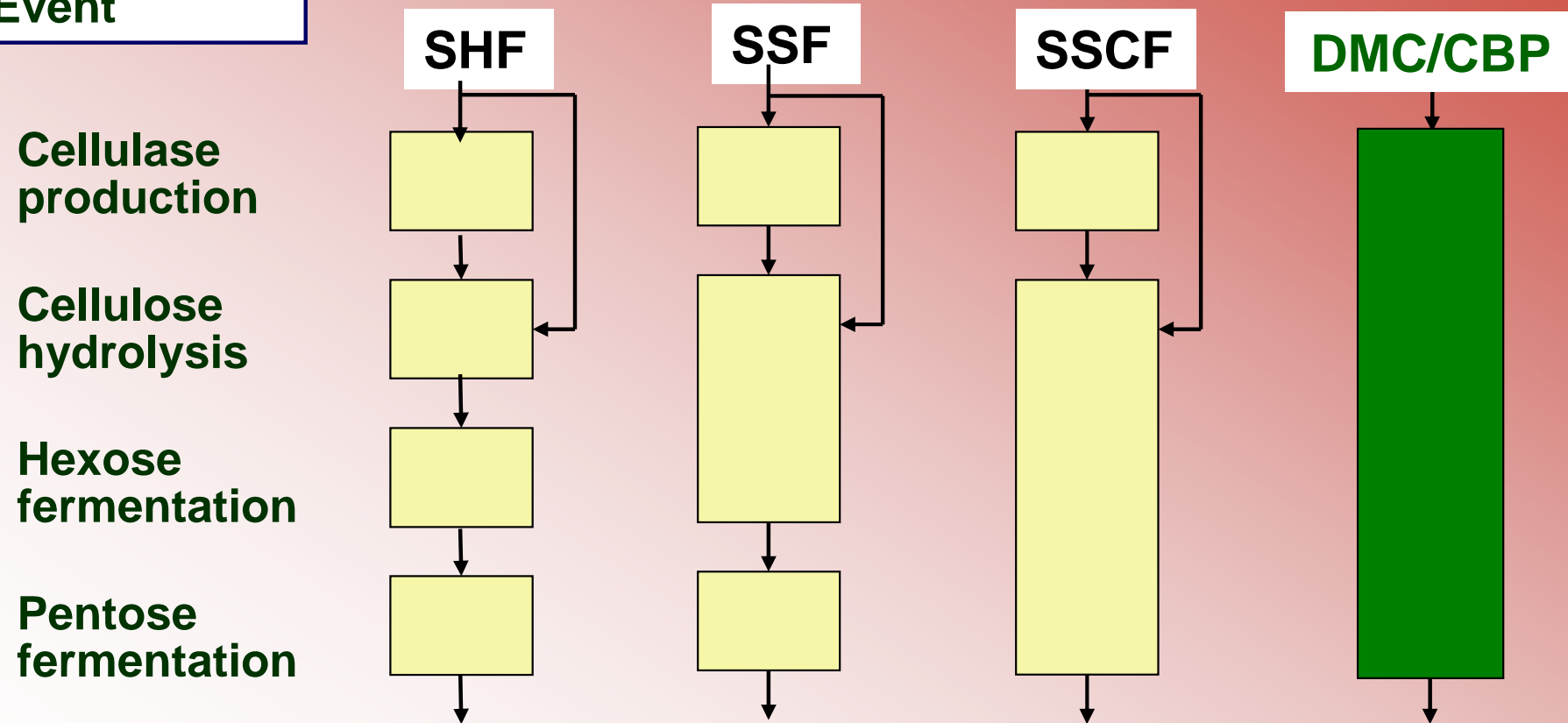
For current technology, the advantage of the lower purchase price of cellulosic biomass is entirely cancelled by the cost of hydrolysis

How Biotechnologies Can Help Biofuel production

Evolution of Biomass Processing Featuring Enzymatic Hydrolysis

Biologically-Mediated Event

Processing Strategy (each box represents a bioreactor)

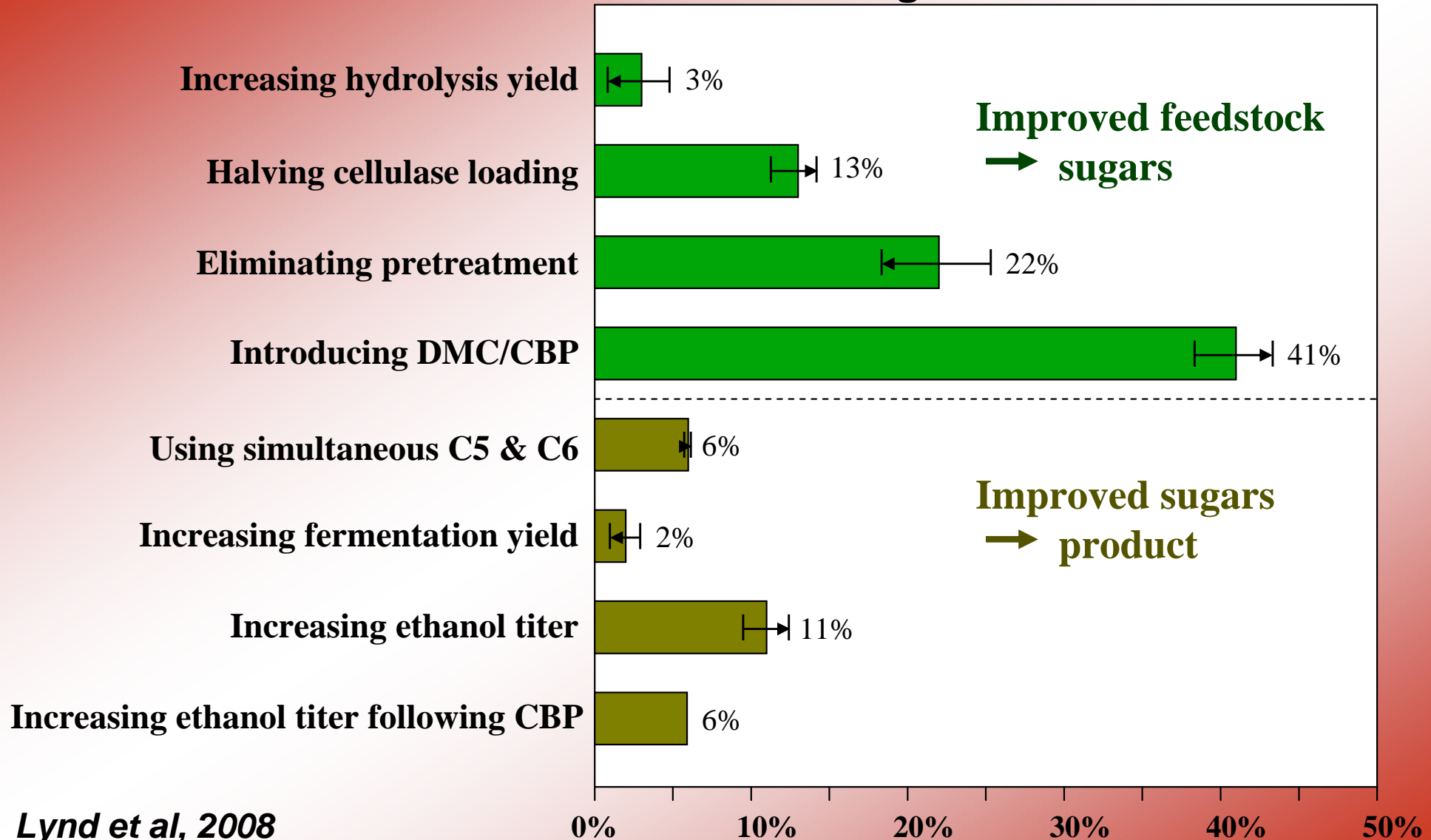


SHF: Separate hydrolysis & fermentation, SSF: Simultaneous saccharification & fermentation, SSCF: Simultaneous saccharification & co-fermentation,
DMC: Direct Microbial Conversion, CBP: Consolidated bioprocessing

Lynd, 2006

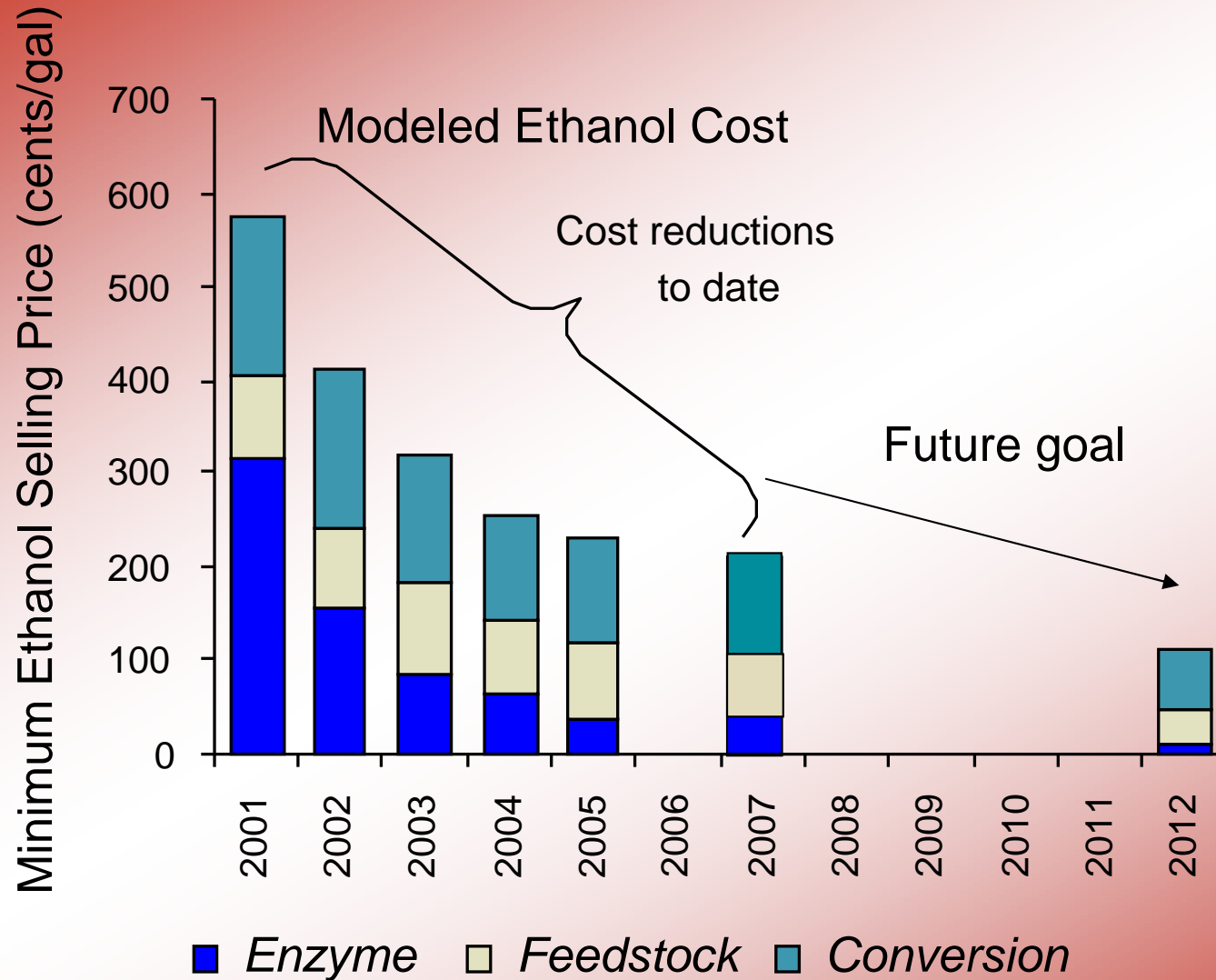
Cost savings of various potential process improvements

Processing Cost Reduction



Lynd et al, 2008

Cellulosic Ethanol Costs



NREL Modeled Cost

The main challenges for biomass biorefineries

- ✓ **Complete use of all biomass components:** carbohydrates, lignin, protein, lipids, minerals, pigments, pectin, organic acids
- ✓ **Production of both biofuels and high-value biobased products:** the latter would enhance the economy of biomass biorefinery

Chemicals from renewable resources

Number of Carbon Atoms	DoE Report^a: Top 12 building-block chemicals that can be produced from sugars	BREW Report^b: 21 White Biotechnology chemicals from renewable sources
0		Hydrogen
2		Ethanol, acetic acid
3	Glycerol, 3-hydroxypropionic acid	Lactic acid, 3-hydroxypropionic acid, 1,3-propanediol, acrylic acid, acrylamide
4	1,4-succinic, fumaric and malic acids, aspartic acid, 3-hydroxybutyrolactone	Succinic acid, fumaric acid, aspartic acid, 1-butanol, 1,4-butanediol
5	Glutamic acid, itaconic acid, levulinic acid, xylitol/arabinotol	
6	2,5 furan dicarboxylic acid, glucaric acid, sorbitol	Sorbitol, 5-hydroxymethylfurfural, adipic acid, citric acid, caprolactam, lysine
complex		Natural fats and oils derivatives
complex		Polyhydroxyalkonates

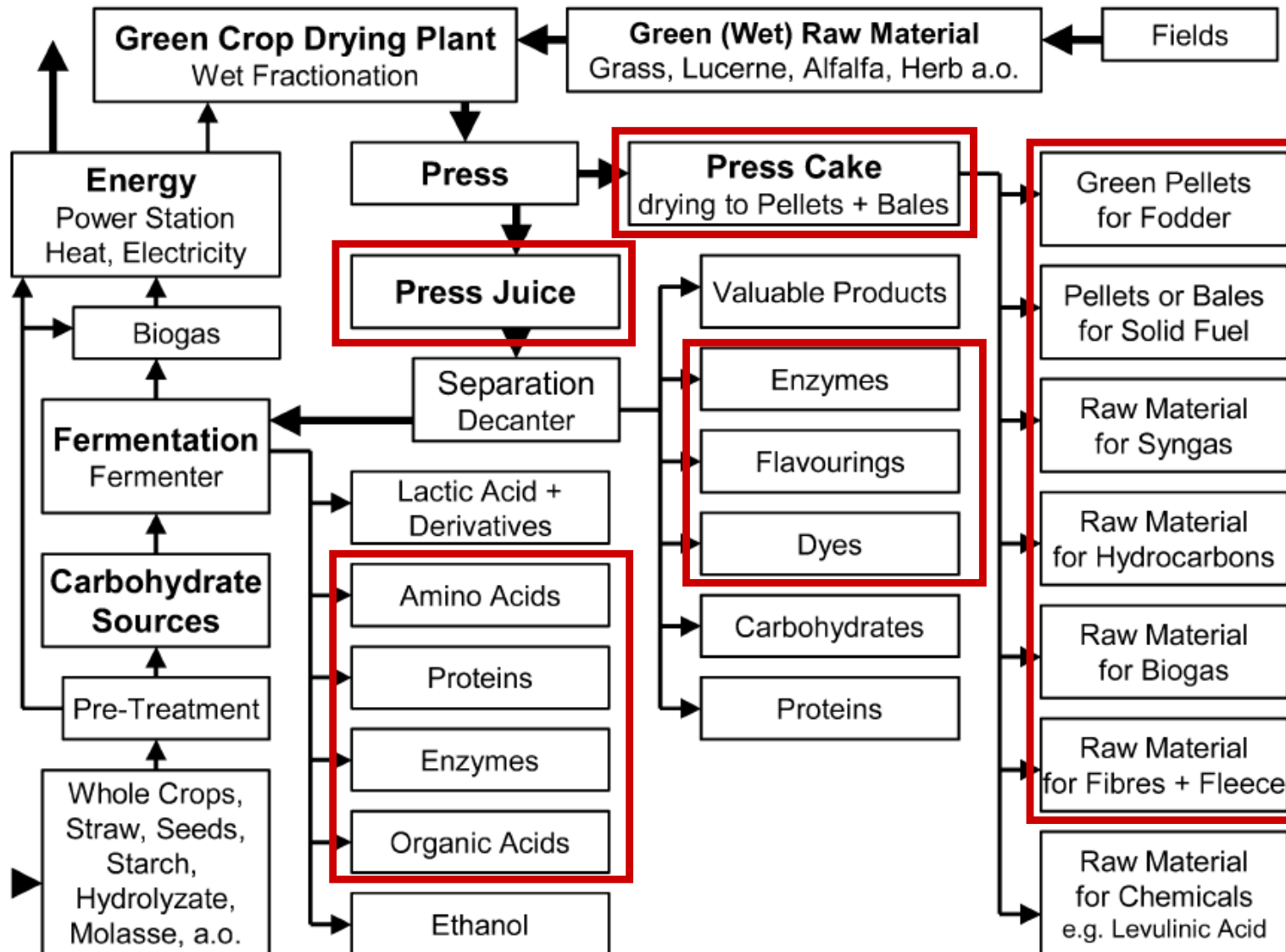
Jenkins, 2008

^a <http://www1.eere.energy.gov/biomass/pdfs/35523.pdf> [January 25, 2008].

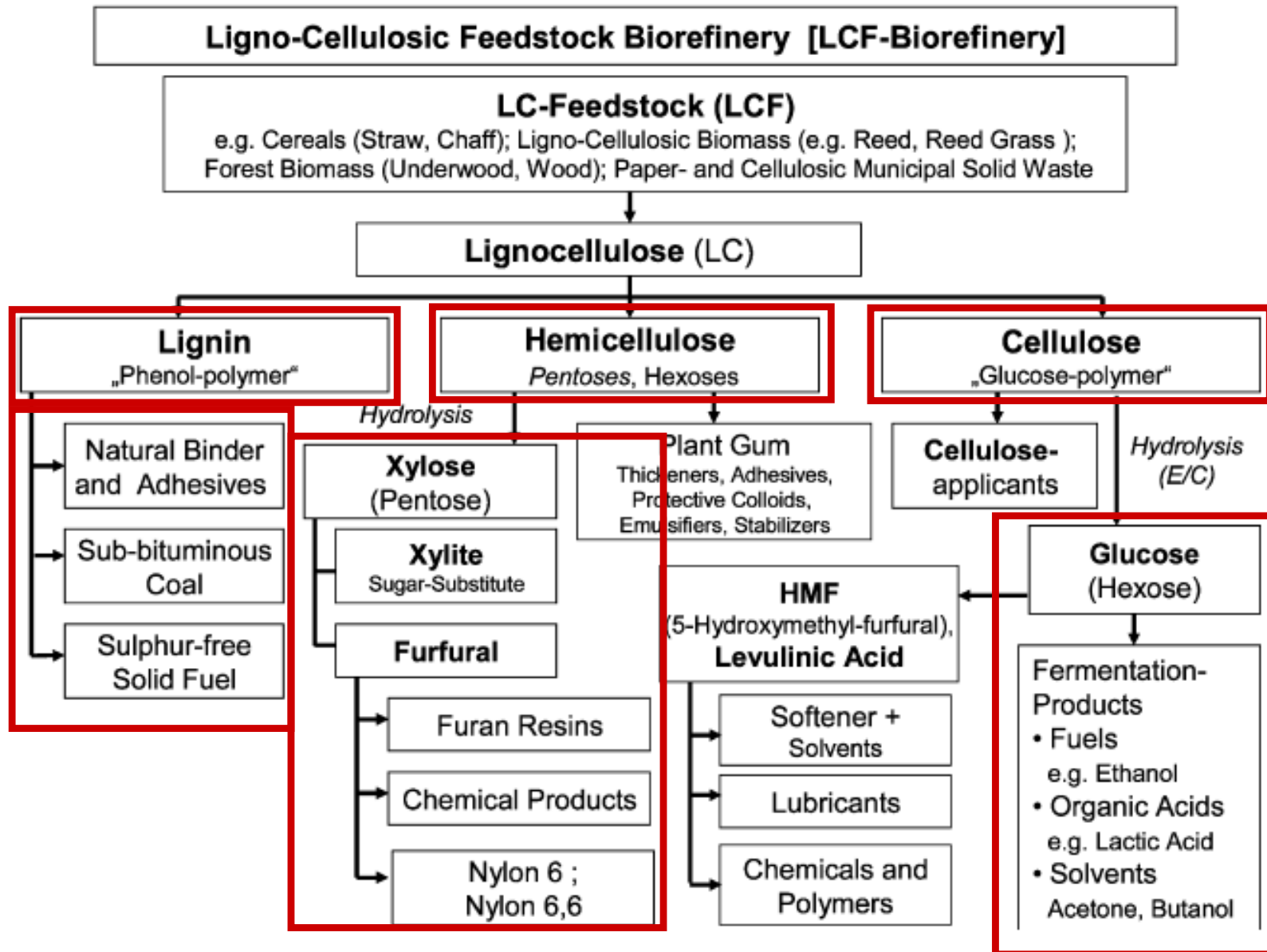
^b <http://www.biomatnet.org/publications/2026final.pdf> [January 25, 2008].

Vincenza Faraco (DCOB)

Green Biorefinery

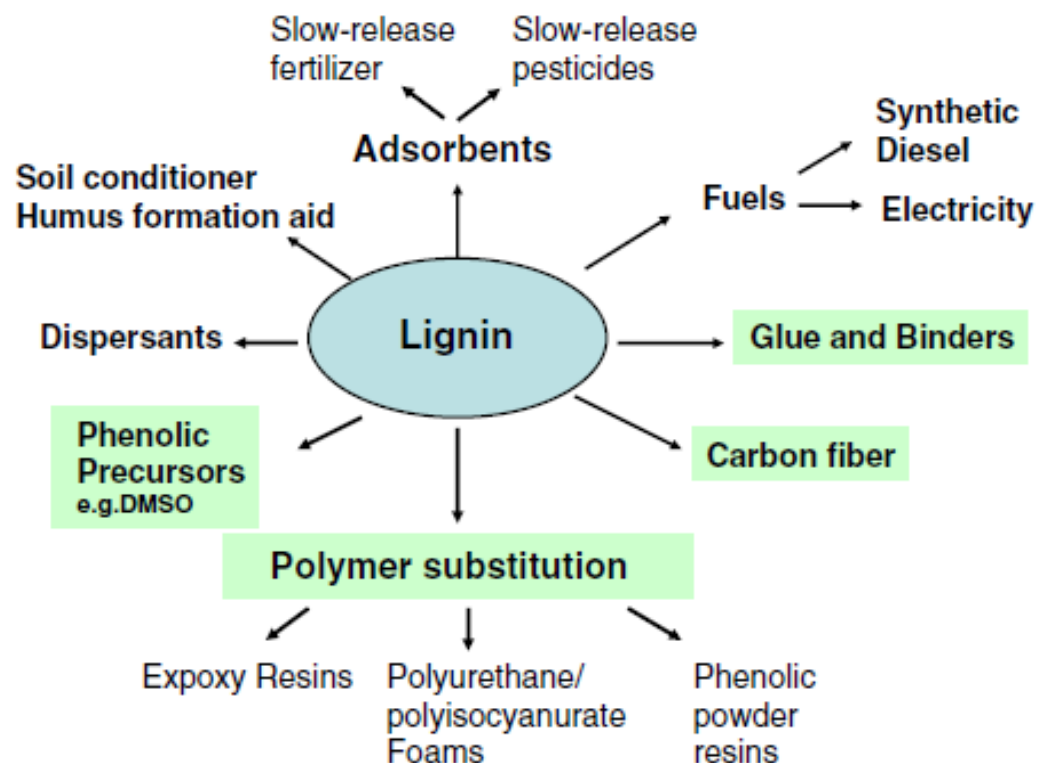


Lignocellulose-Feedstock based Biorefinery



Future of lignin

Lignin The most promising building block for aromatic chemistry



Biorefinery Development Approaches

Two different approaches to the biorefinery concept

✓ **“Bottom-up Approach”**

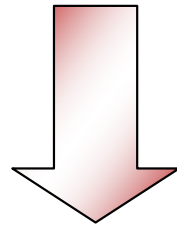
Existing plants for biochemical or thermochemical conversion of biomass for the production of one or few main products are upgraded with regard to the processable biomass and/or the production and refinement of products.

✓ **“Top-down Approach”**

Development of new, highly integrated plants, for the waste-free production of a huge variety of different products mainly from low grade (cheap) biomass fractions.

Biorefinery Logistics

- Feedstock cost and availability are the key factors affecting biorefinery locations
- Logistical and feedstock diversity are the main bottlenecks



Pioneer supply systems

Individually designed for biorefineries using specific feedstock types and varieties based on local geographic conditions

As the industry develops, the supply systems will incorporate advanced technologies that will eliminate downstream diversity and provide an uniform, tailored feedstock supply system for multiple biorefineries located in different regions

Worldwide progress in biorefinery development

Company	Location	Products	Raw materials
Iogen Corporation http://www.iogen.ca	Canada	Bioethanol	Wheat, oat and barley straw
Abengoa Bioenergy http://www.abengoabioenergy.com	Europe (Spain) USA	Bioethanol	Grain, DDG Wheat/barley straw
Broin jointly with US DoE, DuPont and Novozymes http://www.poetenergy.com/news/showRelease.asp?id=13	USA Iowa	Cellulosic ethanol	Corn fiber and stover
NatureWorks LLC http://www.natureworkslc.com	USA Nebraska	NatureWorks® Indigo™ fibers	Starch byproducts
Novamont http://www.novamont.com	Italy	Bioplastics Mater-Bi™	Corn starch vegetable oil
Solvay http://www.solvay.com	France	Epichlorohydrin	Glycerine
Verbio Vereinigte BioEnergie AG http://www.verbio.de/en/desktopdefault.aspx	Germany	Bioethanol Bio-diesel	Grain Rapeseed oil
British Sugar http://www.britishsugar.co.uk	United Kingdom	Pharmaceutical nutraceutical products	Sugar beet
Agrana http://www.agrana.com	Austria Hungaria	Bio-ethanol Protein-rich animal feed	Cereals
Tereos http://www.tereos.com/en	France, Czech Republic, Brazil.	Bio-ethanol	Sugar beet, wheat and sugar cane
Inbicon http://www.inbicon.com/pages/index.aspx	Denmark	Bio-ethanol	Wheat straw
Sekab http://www.sekab.com	Sweden	Bio-ethanol	Forestry products

Examples of public/private international projects developed in the biorenewables sector (1)

Country	Project	Participants	Location	Objective	Timeline&funding
USA	Cellulosic ethanol biorefineries	US DoE, Abengoa Bioenergy, ALICO Inc, BlueFire Ethanol, Broin Companies, Iogen, Range Fuels.	Six cellulosic ethanol biorefineries in Kansas; LaBelle, Florida; Southern California; Emmetsburg, Iowa; Shelley, Idaho; Soperton, Georgia.	Pilot-scale demonstration of cellulosic ethanol production helping to bring cellulosic ethanol to market.	Up to £385m funding to begin in 2007 and run through financial year 2010.
	Cellulosic bioethanol research centre	US DoE	Bioenergy Research Centres in Oak Ridge, Tennessee; Madison, Wisconsin; Berkeley, California.	To increase research and development effort to realise President Bush's <i>Twenty in Ten</i> initiative	Up to \$375m for the first five years of operation (2008-2013).
	Energy Biosciences Institute	BP, University of California Berkeley, University of Illinois, Urbana-Champaign, the Lawrence Berkeley National Laboratory.	EBI research laboratories in campuses of UC Berkeley and the University of Illinois.	Application of bioscience to the production of new and cleaner energy, principally fuels for road transport.	\$500m over ten years.
Canada	Canadian Agriculture Bioproducts Innovation Network	Universities, colleges, companies, other private and public sector research organizations, federal government departments.	Across Canada	To promote research, development, technology transfer and commercialisation activities in biofuels, bioenergy, biochemicals, and biopharmaceuticals	\$145m from 2006 to 2011
China	863 National High-tech programme	Central and regional government and associated enterprises, universities and research institutes.	Across China.	To boost innovation capacity in the high-tech sectors through R&D investment. To increase strength in high-tech industries	1986-current day. 863 funding from central government. Total investment in 2001–2005 of £1b. Estimated government budget for 2006–2010 of 24 £1.6 b.

Examples of public/private international projects developed in the biorenewables sector (2)

Country	Project	Participants	Location	Objective	Timeline&funding
Europe	BIOHUB	Roquette; Arkema; DSM; Cognis; Sidel; Tergal Fibres; Eurovia/Vinci; Metabolic Explorer; INSA Lyon; INSA Rouen; IMMCL (CNRS).	Across France and Europe.	To develop new production outlets for chemicals based on renewable agricultural raw materials through the creation of new integrated bio-refineries.	An R&D budget of €98m over seven years. €730m Industry investment starting after 2010.
	CLIB 2021	Bayer; Cognis Deutschland; Evonik Degussa; Henkel; LANXESS; Artes Biotechnology; bitop; Bioreact; Cilian; c-Lecta; DASGIP; Direvo Biotech; Dohms Ingredients; EVOcatal; Insilico Biotechnology; m2p-labs; MöllerTech; PharmedArtis; Phytowelt GreenTechnologies; Prot@gen Rhein Biotech; Taros Chemicals & Co; Forschungszentrum Jülich GmbH; Fraunhofer IME; Fraunhofer UMSICHT; Fraunhofer WKI; Heinrich Heine Universität; Düsseldorf; ISAS-Institute for Analytical Sciences; Universität Bielefeld; Universität Dortmund; Universität Münster.	Across Germany and Europe.	To successfully establish German and European industrial biotechnology in industry (SMEs) and academia by taking a cross-regional approach to make innovative business plans become reality.	2007/8 €40m budget to promote cooperation projects between industry, SMEs and academia.
	Ghent Bioenergy Valley	Ghent University; The city of Ghent; The port of Ghent; POM Oost- Vlaanderen; Alco-Bio Fuel; BIORO; Electrabel; SPE; Organic Waste Systems; Oiltanking; Oleon Biodiesel; Sea-Invest; Desmet Ballestra; Genencor International; Lalemant; Cargill; Fabricom; AXTOLL; BnS Engineering.	The region of Ghent, Belgium .	To promote the development of the bio-based economy.	2006–

Biorefinery advantages

- creation of new workplaces in the local economy,
depending on the geographic supply chain structure
- development of rural areas and regional development
 - Biorefineries are propelling agriculture**
 - “Industrial nations are facing a revolution in the fields that will propel agriculture from its current peripheral existence to the forefront of innovation.....biomass and agricultural products are thus becoming key pillars of technology for the 21st century”, by Dr. Arend Oetker, President of the Stifterverband, the business community’s innovation agency for the German science system www.stifterverband.de*
- increase of environment protection and overall sustainability
 - renewable materials both as feedstock and processing agents
 - ready to use products that have lower carbon footprint than their fossil counterparts
 - improving the efficiency of water use
 - handling residues
 - reuse of co-products >> feedstock or energy carrier
 - increasing energy efficiency

The 12 Principles of Green Chemistry

- 1. Prevention**
- 2. Atom Economy**
- 3. Less Hazardous Chemical Synthesis**
- 4. Designing Safer Chemicals**
- 5. Safer Solvents and Auxiliaries**
- 6. Design for Energy Efficiency**
- 7. Use of Renewable Feedstocks**
- 8. Reducing Derivatives**
- 9. Catalysis**
- 10. Design for Degradation**
- 11. Real-time Analysis for Pollution Prevention**
- 12. Inherently Safer Chemistry for Accident Prevention**

Towards a new bio-economy and new industrial processes supporting the concept of sustainable development

A lot of work remains to be done

- **to improve cost, distribution and availability of biomass resources in specific geographic regions**
- **to overcome technological bottlenecks of feedstock processing**
- **to enhance social acceptance and public perception**
- **to contrast competition from the petroleum-based sector**

Thank you!

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