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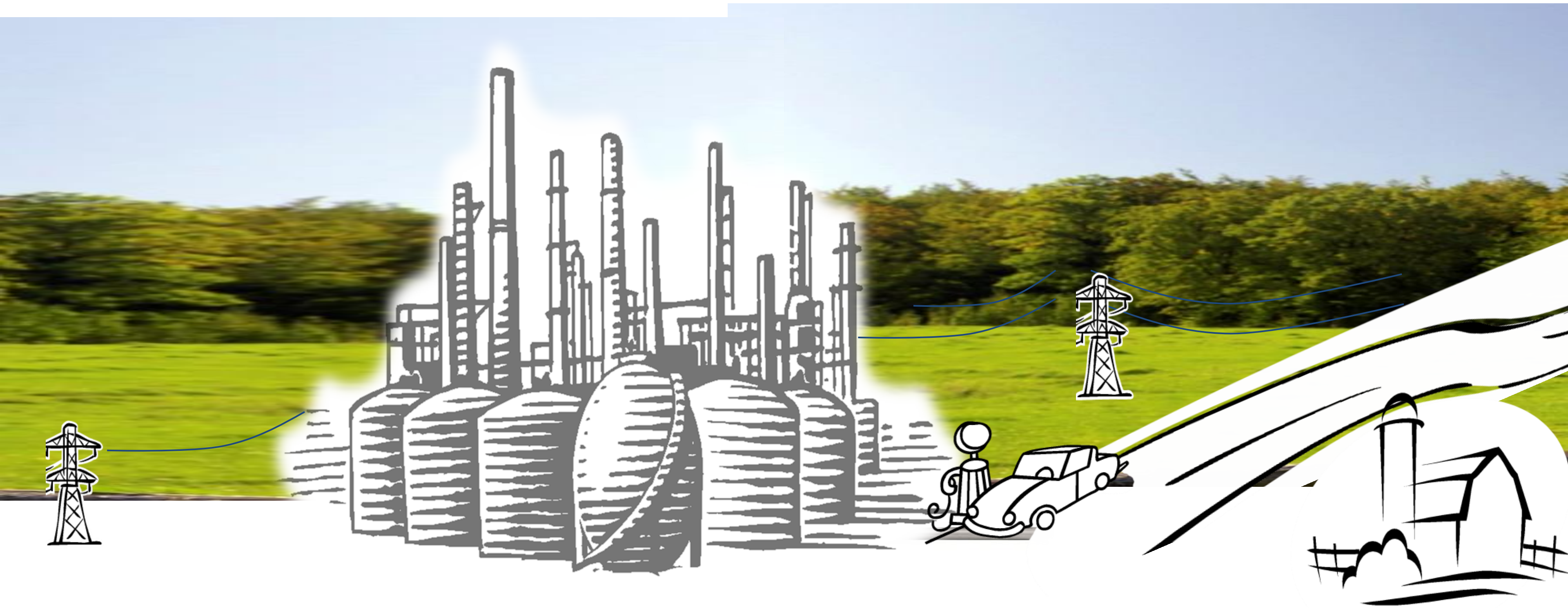

Biorefinery – New Area for Interdisciplinary Research and International Cooperation

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UWM
CBEO
modelowe kompleksy agroenergetyczne
BAŁTYCKI KLASTER EKOENERGETYCZNY

BSRUN, Olsztyn, May 31, 2013

Prerequisites:

I. sustainable development needs sustainable energy

↑ increasing share of energy from renewables, incl. biomass
↑ increasing energy efficiency
↓ reduction of greenhouse gas emission

II. sustainable energy needs sustainable biomass production

- Biorefinery } bio-industry, bio-economy, sustainability, …

III. sustainable biomass production requires transformational breakthroughs in bio-based research

Outline:

- General climate and energy context for bio-based industry
- Biomass – photosynthetic efficiency and high productivity research context
- Biorefinery – feedstock, processes
- Cascading biomass use – biochemicals
- Recapitulation

1. General Energy Context – Global Use of Primary Energy – Reserves of Fossils

	1990	=> 2008
World energy consumption:	368	=> 512 EJ (39%)

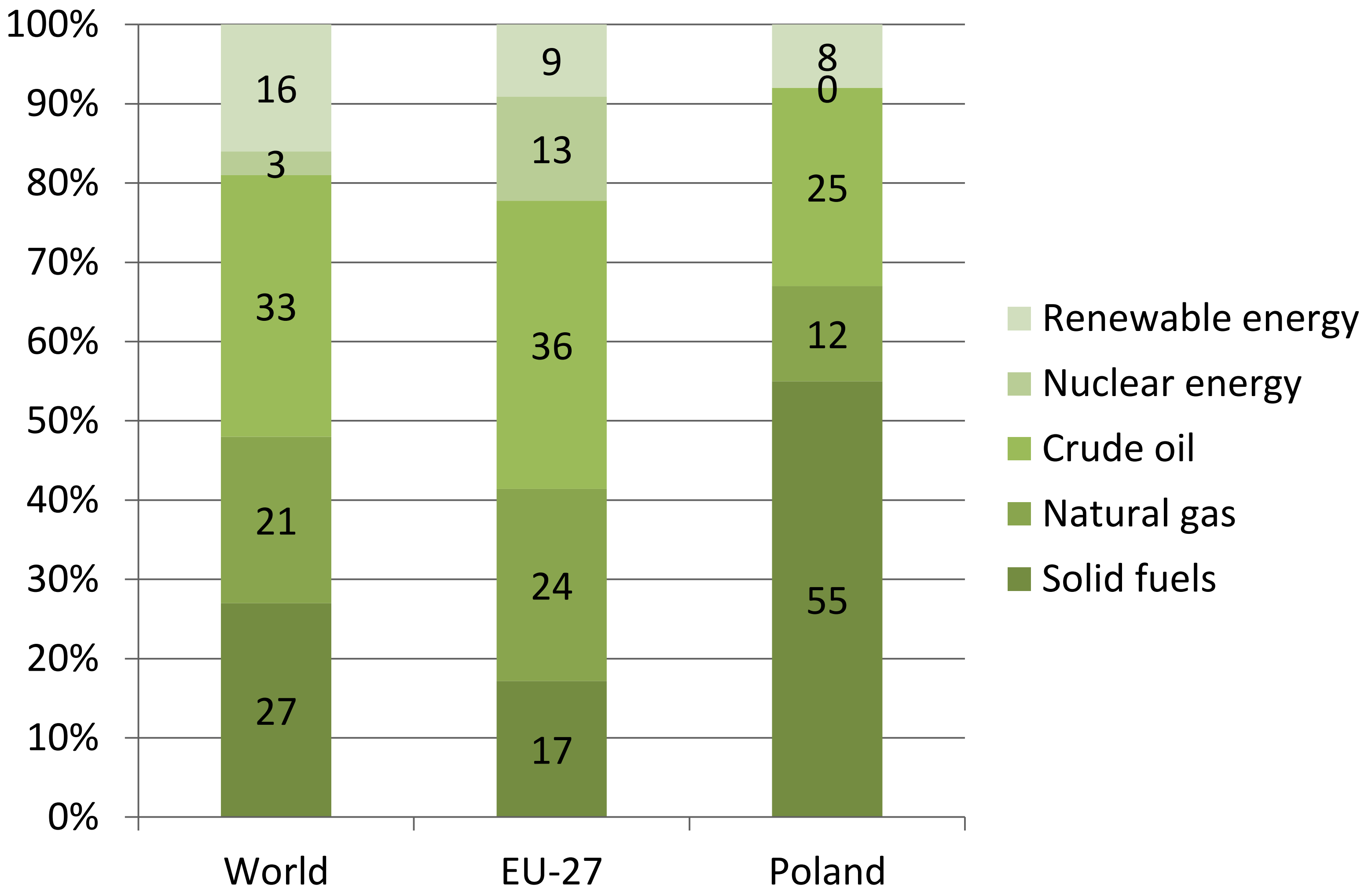
Reserves-to-Production (R/P) Ratio in Years

Fuel	World average	OECD	Other	EU	Former Soviet Union
Oil	**46**	14	88 (OPEC)	9	26
Gas	**59**	15	84 (non OECD)	14	77
Coal	**118**	134	92 (non OECD)	108	452
Uranium	**60**	main suppliers – Canada, Australia			

European Commission President, José Manuel Barroso – The Third Industrial Revolution: “Oil and other hydrocarbons are a limited resource, and our own internal reserves are dwindling. Today we import around 50% of our energy. By 2030 that will be nearer 70%, if we continue with current policies. (...)”

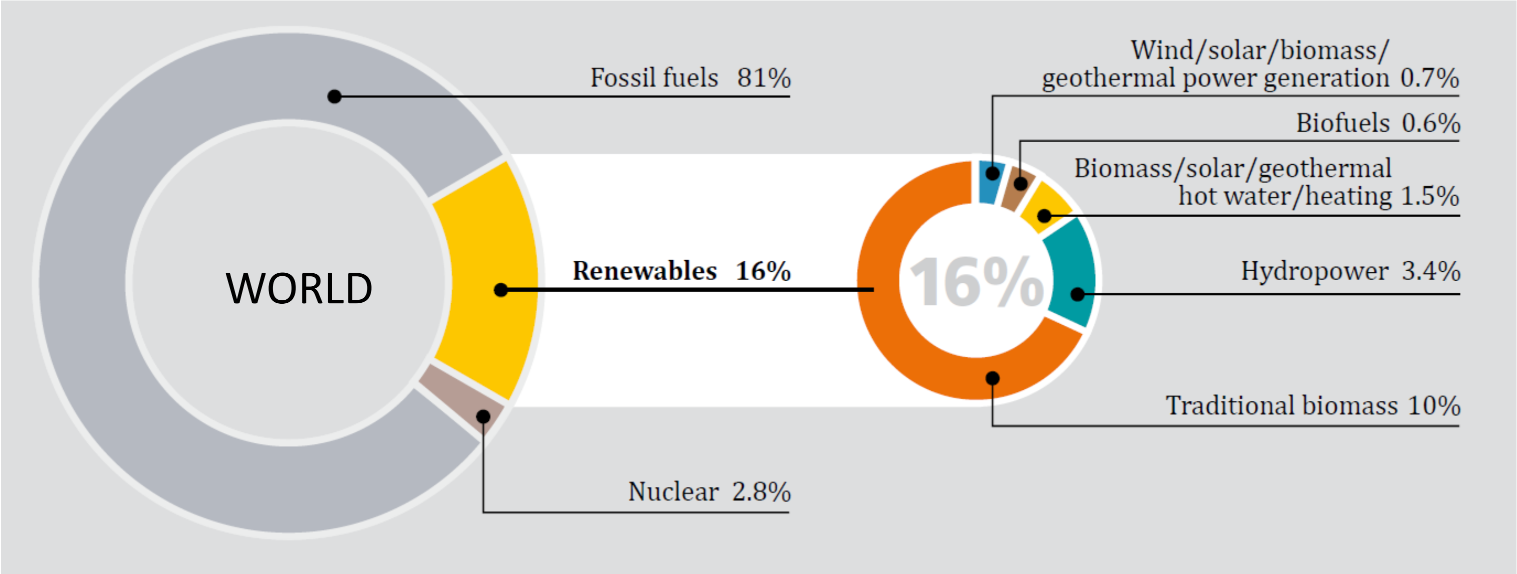
BP Statistical Review of World Energy (2011) on the source of reserves data: Survey of Energy Resources, World Energy Council 2010.

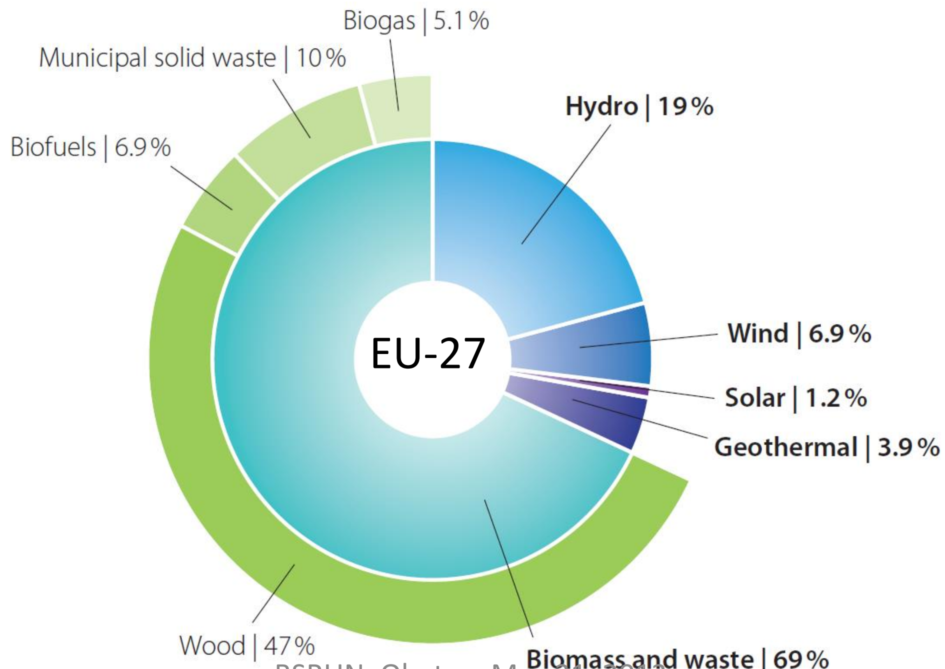
2. General Energy Context – Final Energy Consumption Mix



Source:
1) Renewables 2011. Global Status Report.
2) European Commission. Renewables make the difference. Luxembourg: Publications Office of the European Union 2011

3. General Energy Context – Renewables – Energy Consumption, Breakdown by Sources





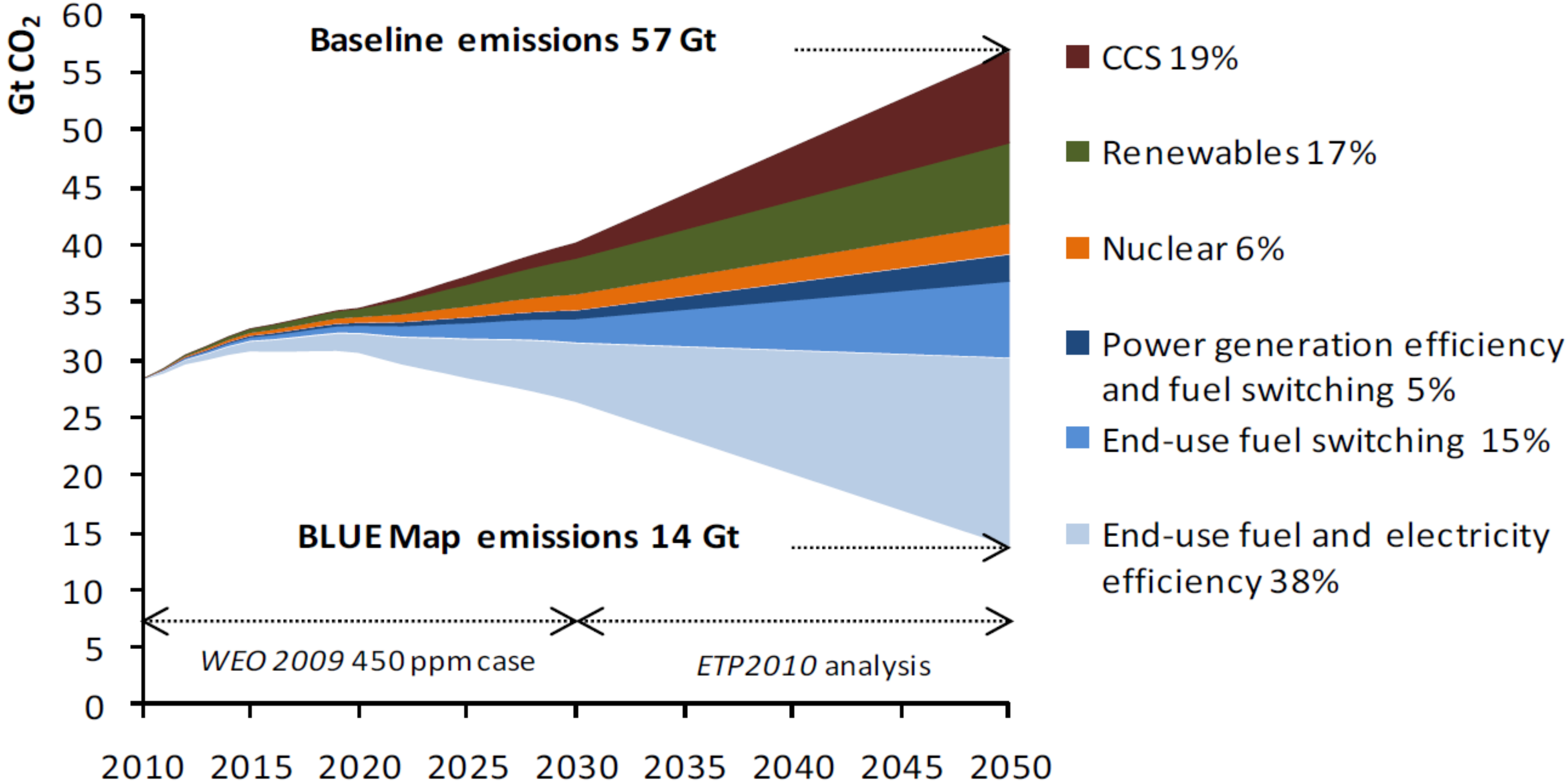
Source:

1) Renewables 2011. Global Status Report.

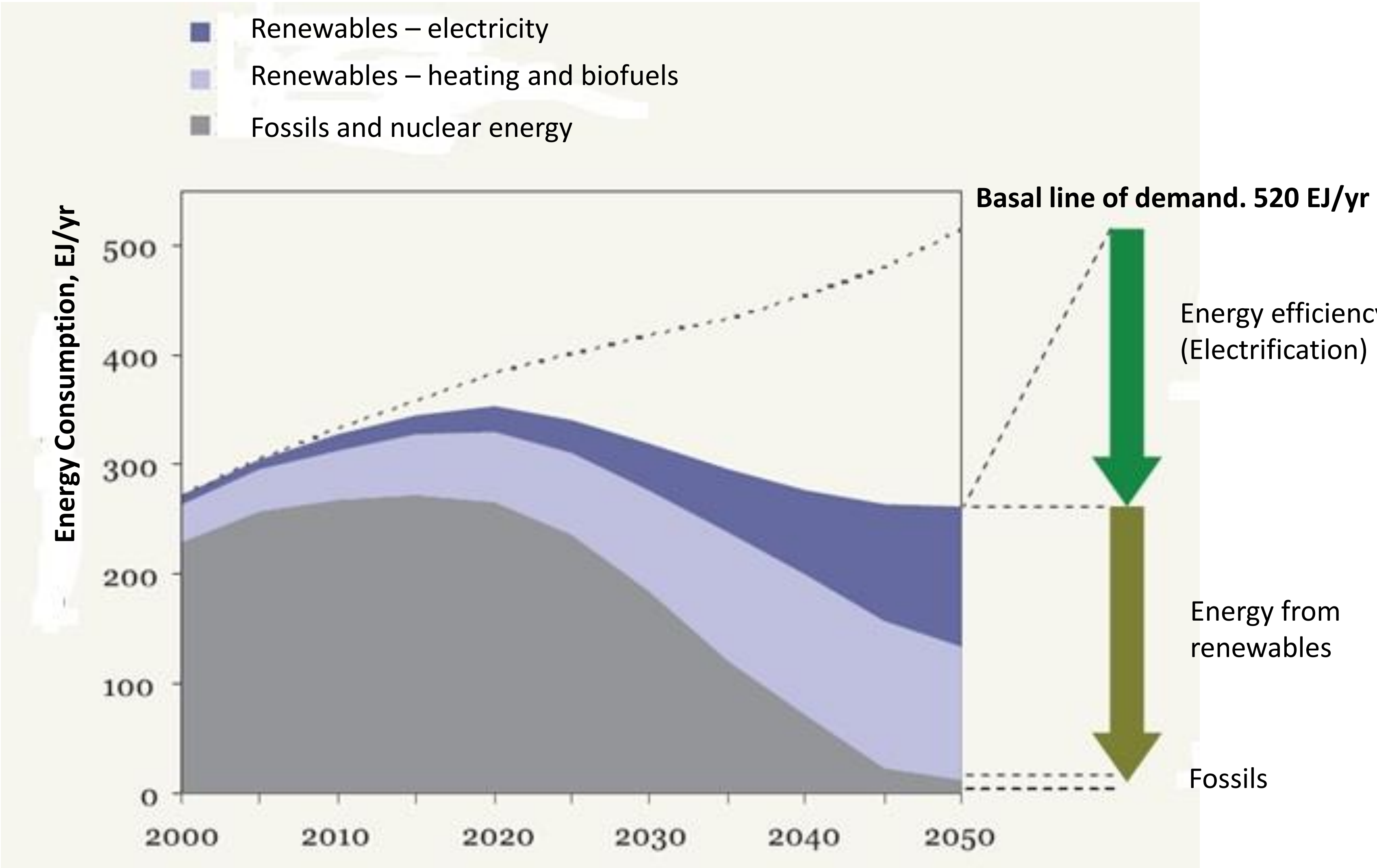
2) European Commission. Renewables make the difference. Luxembourg: Publications Office of the European Union 2011

4. General Climate Context
– Decarbonisation – Sources, Perspectives

IEA 2010



5. General Energy and Climate Context
– Anticipated Key Changes in the Structure of Energy Consumption by 2050



World Wide Fund for Nature. The Energy Report. 100% Renewable Energy by 2050. 2011.

Orientation of research on biomass use

Biorefinery

Definition of biorefinery:

… the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)

Acc. to IEA Bioenergy Task 42

… co-products can also be food and/or feed

Acc. to „Biorefineries Roadmapas part of the German Federal Government action plans for the material and energetic utilisation of renewable raw materials"

Orientation of biobased research on biorefinery

- ✓ development of biorefinery concept for bio-based production is a great challenge for the present and future research activity
- ✓ today the main driver for the development of biorefinery processes is the transportation sector (biofuels are of the superior interest) - it is built on agriculture, food and forestry industries

- ✓ agro-biotechnology and agro-bio-chemical sciences will play a crucial role in the progress of research on bio-based products and finally chemical and process engineering for their implementation
- ✓ building the bio-based research portfolio today means to develop bio-industry (incl. bio-energy industry) tomorrow

- ✓ new field of research and new entity on the market
- ✓ new market requires a special economic approach that will consider all and any elements of sustainable development, including environmental and social aspects **– bio-economy**

Biomass – photosynthetic efficiency and high productivity research context

Biomass – the biorefinery feedstock

Types of biomass

- primary – agriculture & forestry & aquaculture primary production (dedicated)
- secondary – <u>crop and forest residues</u> that are generated as a result of harvesting and processing of primary biomass; <u>processing residues and byproduct streams</u> from food, feed, fiber and other industry production
- tertiary – <u>post consumer residue streams</u> from urban activities (fats, greases, oils, construction and demolition debris/wood), animal manure and other byproducts from industrial livestock production

Biomass resources

Forest ecosystems

↑ stabilize the global carbon circulation

↓ deforestation raises the emission of CO_2 and is a more serious contributor to the greenhouse gas effect than changes in other ecosystems

Agricultural sector

↑ main contributor to future energy portfolio

↓ responsible for 14% of global GHG emission, with methane and nitrous oxide creating a more serious impact on the greenhouse effect than carbon dioxide

Biologically derived waste

↓ presently much of the energy from „waste” biomass is simply lost in the natural decay processes

Aquatic ecosystems – new area for research exploration

Research Challenges – to enhance plant productivity by improvement of photosynthetic efficiency and better use of plant growth factors

Photosynthetic Conversion Efficiency

Crop	Type of photosynthesis	Photosynthesis – approx. solar energy conversion efficiency in %
Most of annual crops	C3	0.3
Switchgrass	C4	0.6
Corn	C4	0.8
Willow and poplar	C3	0.4
Tropical sugarcane	C4	2.6
Tropical Napier grass	C4	2.8

Contribution of sciences: biology, plant physiology, biochemistry, chemistry, agriculture

- water use efficiency (WUE)

  WUE=100-800 kg H_2O depending on crop (type of photosynthesis), agricultural practices, and others
- dry matter accumulation by improvement of nutrient use efficiency (NUE)

  NUE=40% N, 10% P, 40% K
- engineering of chemical composition of biomass, e. g. lignocellulosic crops

Klass D. Biomass for renewable energy and fuels. Encyclopedia of Energy. Oxford: Elsevier Inc.; 2004.

Research challenges – biomass

How to store and utilize more solar energy? – by increasing the photo-active area of plants and solar energy conversion efficiency

Research: engineering higher photosynthetic energy conversion efficiency (anticipated progress in 10-30 ys),
either by

- improved canopy architecture (estimated potential up to 40%)
- improvement and modification of plant metabolism (up to 60%)
- engineering C4 photosynthesis mechanism into C3 crops (up to 30%)

or

- maintaining high photosynthetic conversion efficiency under stress environmental conditions (drought., flooding)

How to reduce water use?

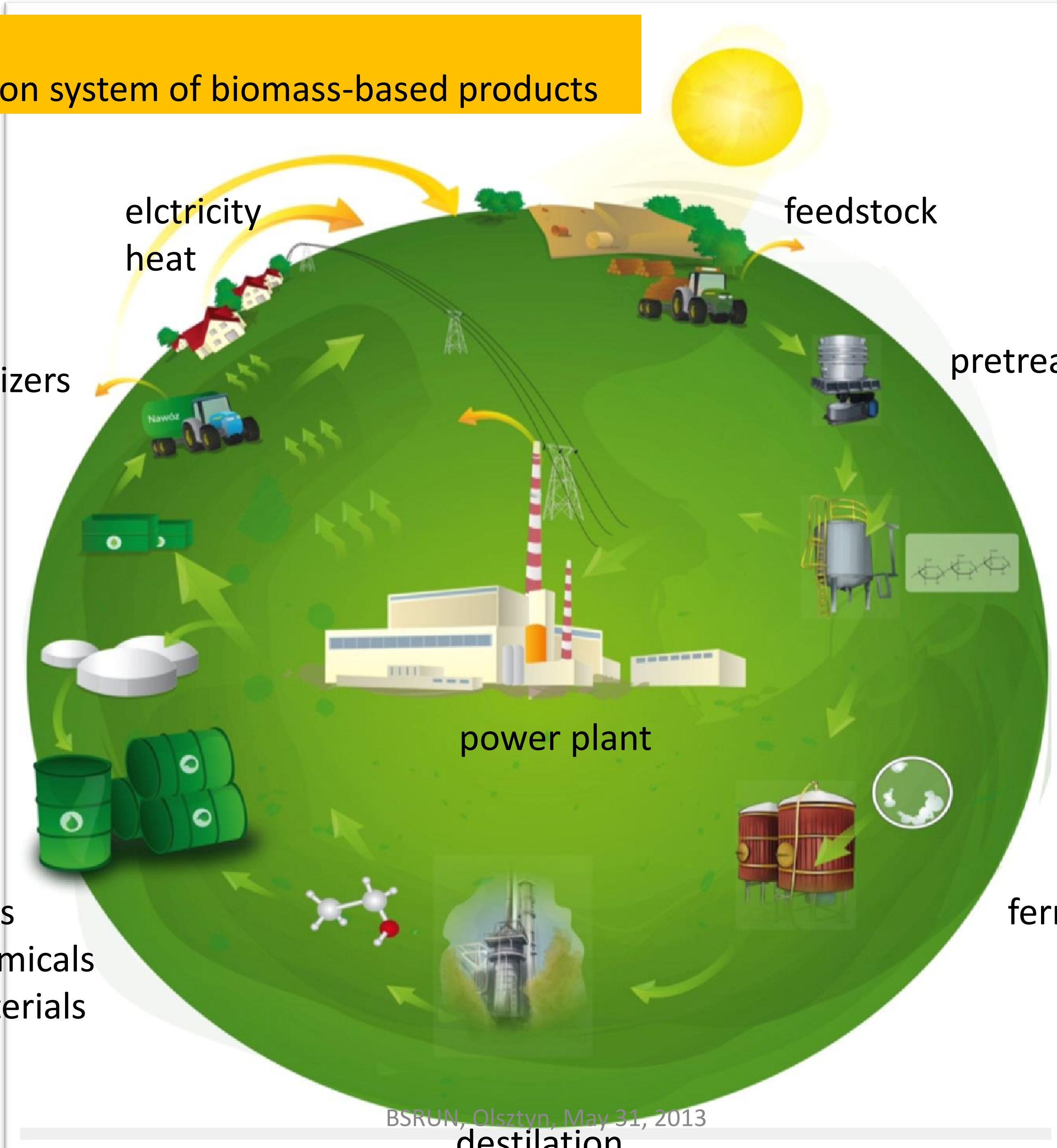
Research in biology, plant biochemistry and physiology of energy crops, incl. identification and transferring genes by means of genetic engineering, application of comparative genomics and bioinformatics, new crop production technologies with efficient water economy, and others

How to balance the uptake of nutrients?

Research on efficiency of economic and energy inputs for energy crop cultivation and on efficient accumulation of nutrients in DM (today it accounts for 5-10% of biomass)

Klass D. Biomass for renewable energy and fuels. Encyclopedia of Energy. Oxford: Elsevier Inc.; 2004
Zhu X-G., Stephen P. Long S.P., Ort D.R. 2010. Improving Photosynthetic Efficiency for Greater Yield Annual Review of Plant Biology Vol. 61: 235-261

Biorefinery
– a production system of biomass-based products



Biorefinery -> New Research Opportunities

Genetic engineering

Green (agriculture) and red (medicine) biotechnology

(market of food and feed, human health)

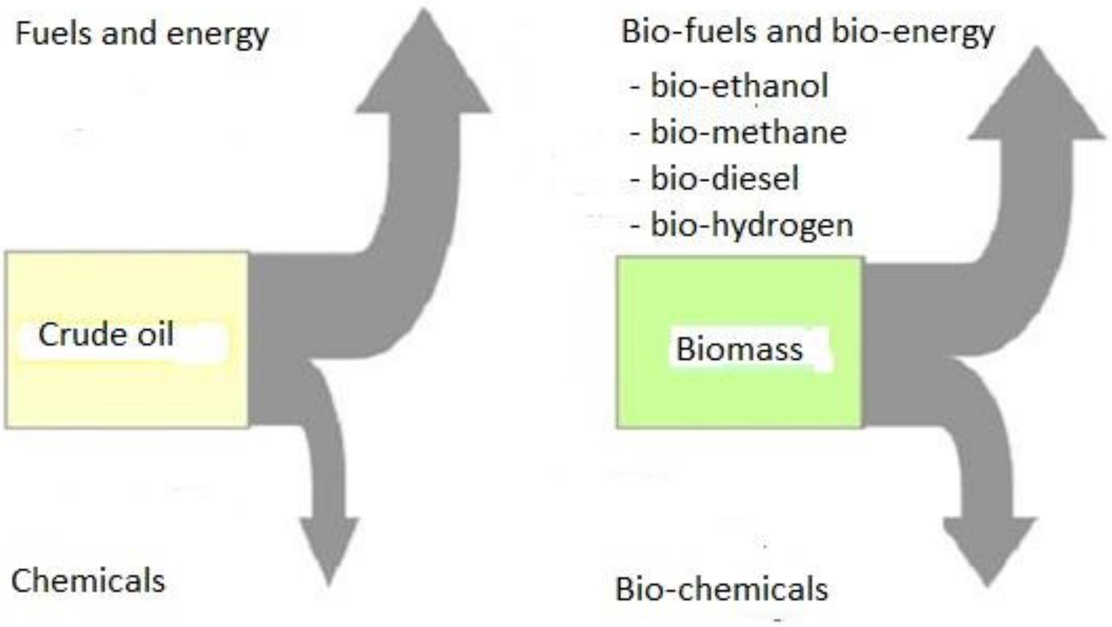
White biotechnology → industrial chemistry

(bioproducts / byproducts which are derived with the use of microorganisms or enzymes)

Biorefinery (integration in a production system)

- core intermediates (C5-C6 sugars, syngas, etc.)
- bioproducts (materials, chemicals, energy carriers, etc.)
- feedstock (raw material from agriculture, forestry, aquaculture, etc.
- conversion processes (bio, chemical, thermochemical, etc.)

Biorefinery
analogy to petrochemical refinery



REFINERY

BIOREFINERY

- **a stand-alone agriculture-base facility (with integrated food and/or feed production)**
- **coupled to a petrochemical refinery**
- **coupled to a chemical plant**

Kamm B., Gruber P.R., Kamm M. 2010. Biorefineries – Industrial Processes and Products. Status Quo and Future Directions. Wiley-VCH Verlag GmBH & Co. KGaA.

Complementary energy facilities of biorefinery

- Local CHP unit
  - energy is produced from own fuel
  - scale: farm, local public sector, …

Bio Machines, Poland

Dranko-Farm. Spain

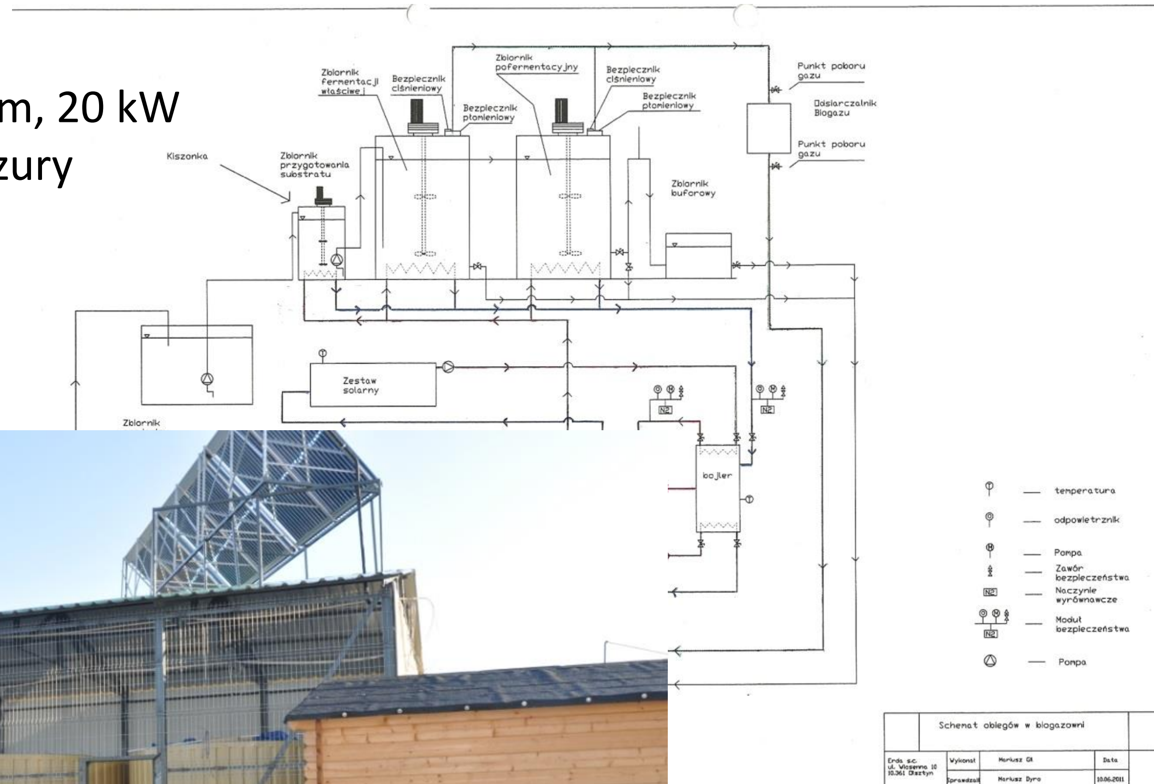
- Pellet and bricket production lines (fixed and mobile)
  - densification of energy per unit of biomass
  - scale: farm, local company

http://cnr.ncsu.edu

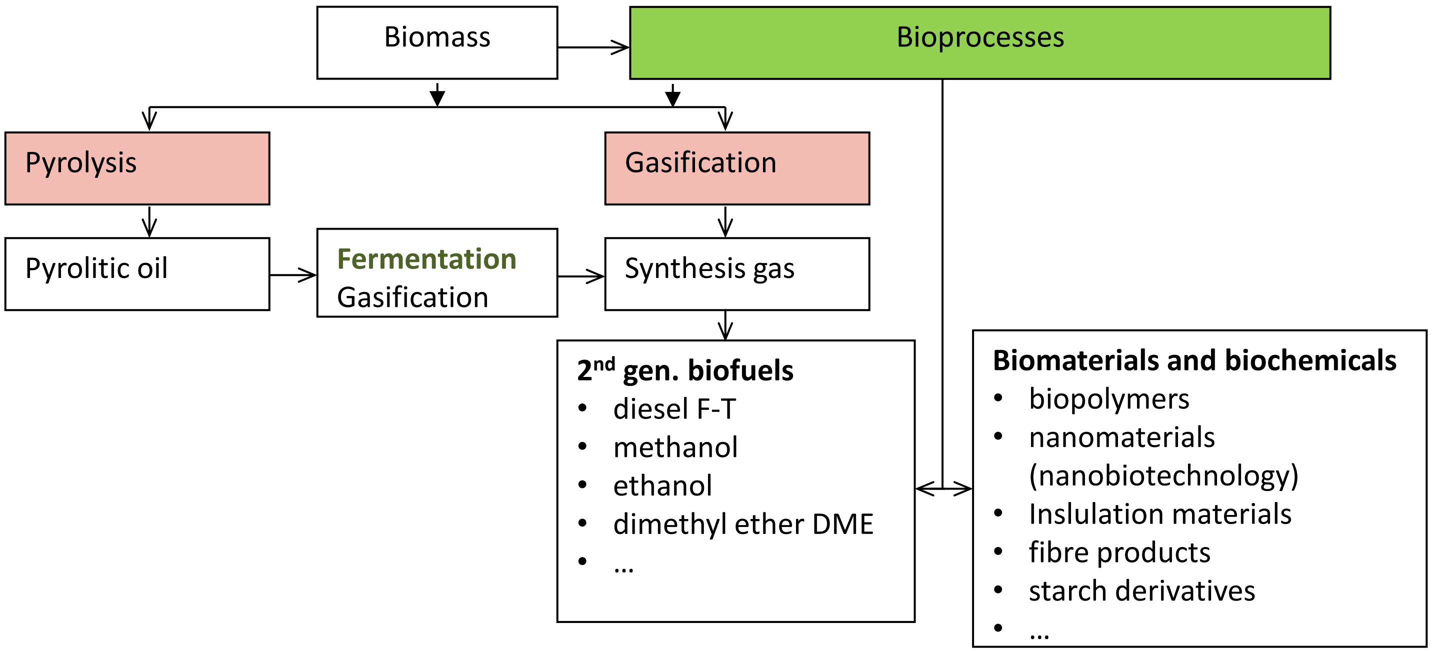
- Biomass „roasting” unit – torrefaction plant or other thermal/ thermochemical biomass conversion facility
  - energy densification
  - scale: farm, local company

Complementary energy facilities of biorefinery

Pilot micro-biogas plant in dairy farm, 20 kW
Univesrity of Warmia and Mazury



Biorefinery – integration of bio- and other biomass conversion processes



Biomaterials – few facts:

- any matter that interacts with biological systems
- biomaterials production combines elements of medicine, biology, chemistry, tissue engineering, and material sciences
- in the world estimated share of biomass-based chemicals is about 5%
- at present only in the USA the target for production of biochemicals was declared (25% by 2030)

Scenario for development of research on biofuels

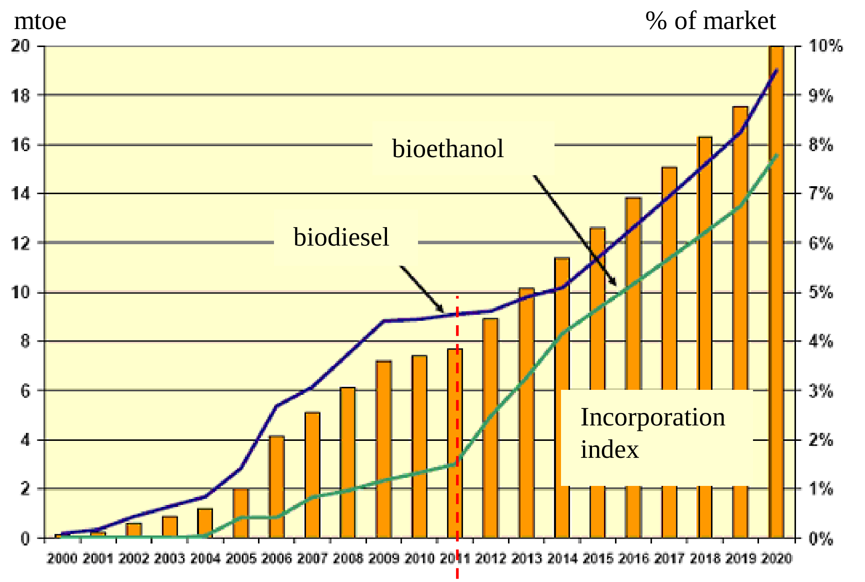
Universal energy carrier
(hydrogen, electricity)

2020

2010

II[nd] generation:
from lignocellulosic biomass: EtOH (ethanol), SynDiesel (F-T diesel), DME (dimethyl ether), SNG (synthetic natural gas), etc.

I[st] generation
improvement of the processes of biofuel production EtOH (ethanol), ETBE (Ethyl Tert-Butyl Ether) FAME (Fatty Acid Methyl Esters) i FAEE (Fatty Acid Ethyl Esters), etc.



Demand for biodiesel and bioethanol and incorporation index in the fuel market in the EU-27 by 2020.

Sources:
1. Gołaszewski J. 2007. Kierunki i perspektywy rozwoju badań nad odnawialnymi źródłami energii. Wyd. UWM Olsztyn.
2. The impact of a minimum 10% obligation for biofuel use in the EU-27 in 2020 on agricultural markets. Impact assessment of the Renewable Energy Roadmap - March 2007. EUROPEAN COMMISSION. DIRECTORATE-GENERAL FOR AGRICULTURE AND RURAL DEVELOPMENT. Directorate G. Economic analysis, perspectives and evaluations. G.2. Economic analysis of EU agriculture. AGRI G-2/WM D(2007)

Biofuels – State of the Art and Research Challenges

<table>
<tr><th>Research/ Technological Stage</th><th>Biodiesel</th><th>Bioethanol</th><th>Biomethan</th><th>Biohydrogen</th><th>Other biofuels, biocomponets of fuels</th></tr>
<tr><td>Fundamental Research (at present weak industrial significance)</td><td>• biooil from algae
• conversion of plant sugars hydrocarbons</td><td rowspan="3">Cellulosic ethanol</td><td rowspan="3">Bio-SG</td><td>New concepts of reforming
• biocatalysed electrolysis
• H_2 fermentation</td><td>New fuels, e.g. furanics</td></tr>
<tr><td>Technological Research - Pilot Plant</td><td>BtL (gasification & F-T)</td><td>• Gasification and reforming
• biogas reforming</td><td>• biobuthanol
• DME
• fuels from pyrolisis process</td></tr>
<tr><td>Implementation - Demonstration Plant</td><td>Hydrogenation of vegetable oils</td><td rowspan="2"></td><td>Methanol</td></tr>
<tr><td>Commercial Plant</td><td>Trans-esterification</td><td>Conversion of sugar and oilseed feedstock</td><td>Anaerobic fermentation</td><td></td></tr>
</table>

Acc. to: Bown A. „Current status and future outlook for biofuels” IEA 2011

Scenario for biorefinery concept development in relation to biofuel generation

Biorefinery – a competitive technology

Tendency to universal energy carrier

– electricity / hydrogen, followed by methanol stage

2020

Integrated biorefinery, 3rd stage – many feedstocks, many bioproducts, many bioprocesses

- incl. agri-energy complex (biochemicals, biomatarials, biofuel and energy)

2010

Biorefinery, 2nd stage – single feedstock, many bioproducts

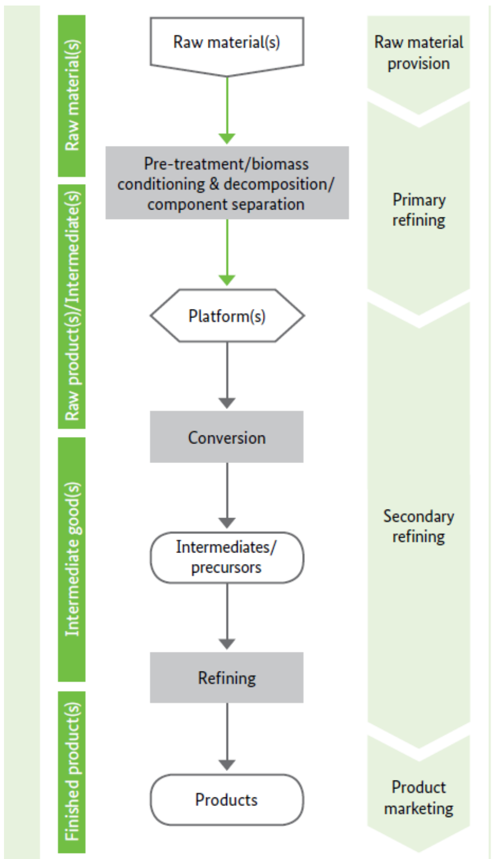
- development of 2nd gen. biofuels, incl. bioethanol, SynDiesel, DME, SNG, etc.

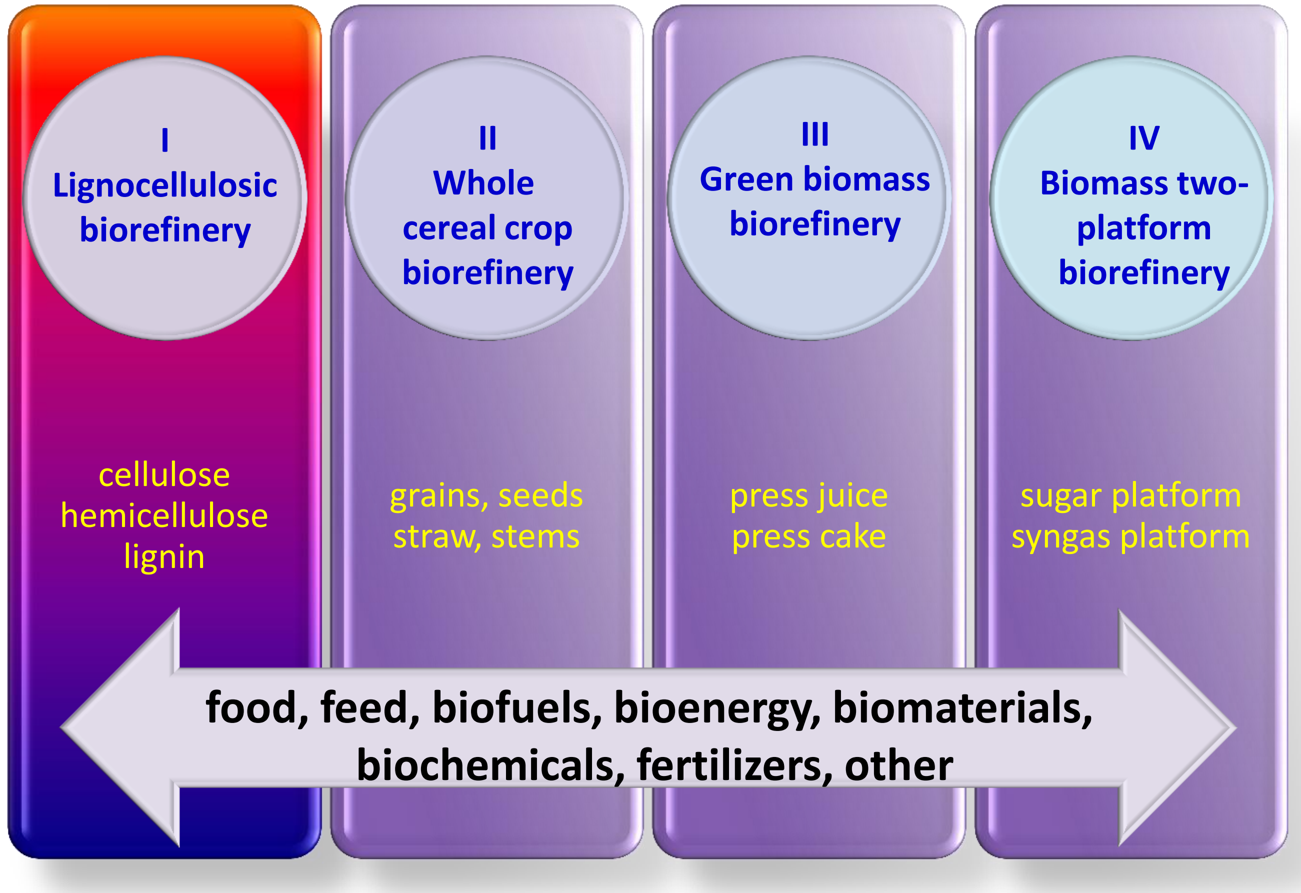
Biorafienery, 1st stage – single feedstock, single bioproducts

– incl. 1st generation biofuels; development of technologies for production of bioethanol and esters

Gołaszewski J. 2011. Biorefinery, conversion processes of lignocellulosic biomass to bioethanol and other bioproducts. (in press)

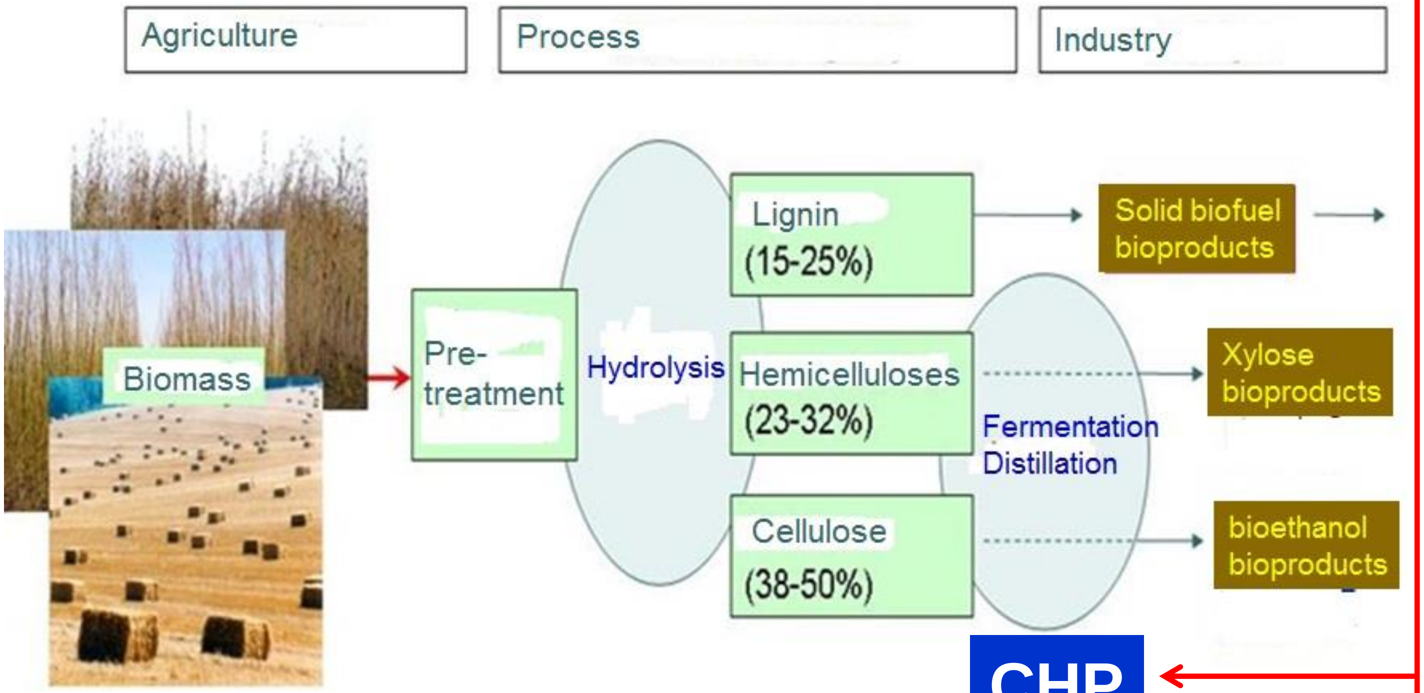
General biorefinery process, types of biorefineries – 3rd stage of development





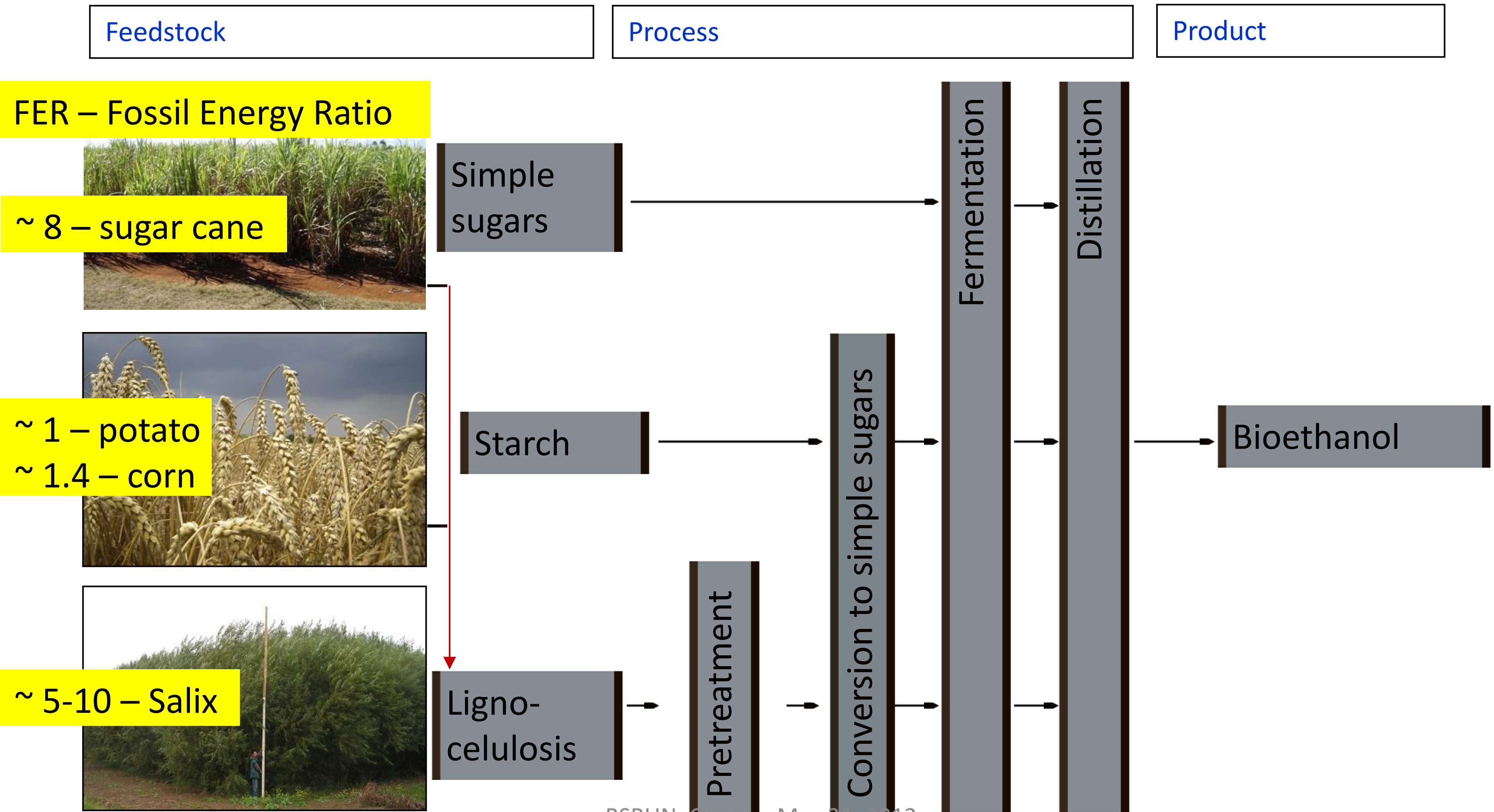
Biorefineries Roadmapas part of the German Federal Government action plans for the material and energetic utilisation of renewable raw materials
Gołaszewski J. 2011. Biorefinery, conversion processes of lignocellulosic biomass to bioethanol and other bioproducts. (in press)

Lignocellulosic biorefinery process



Bioethanol – from sugar and starch to lignocellulose conversion

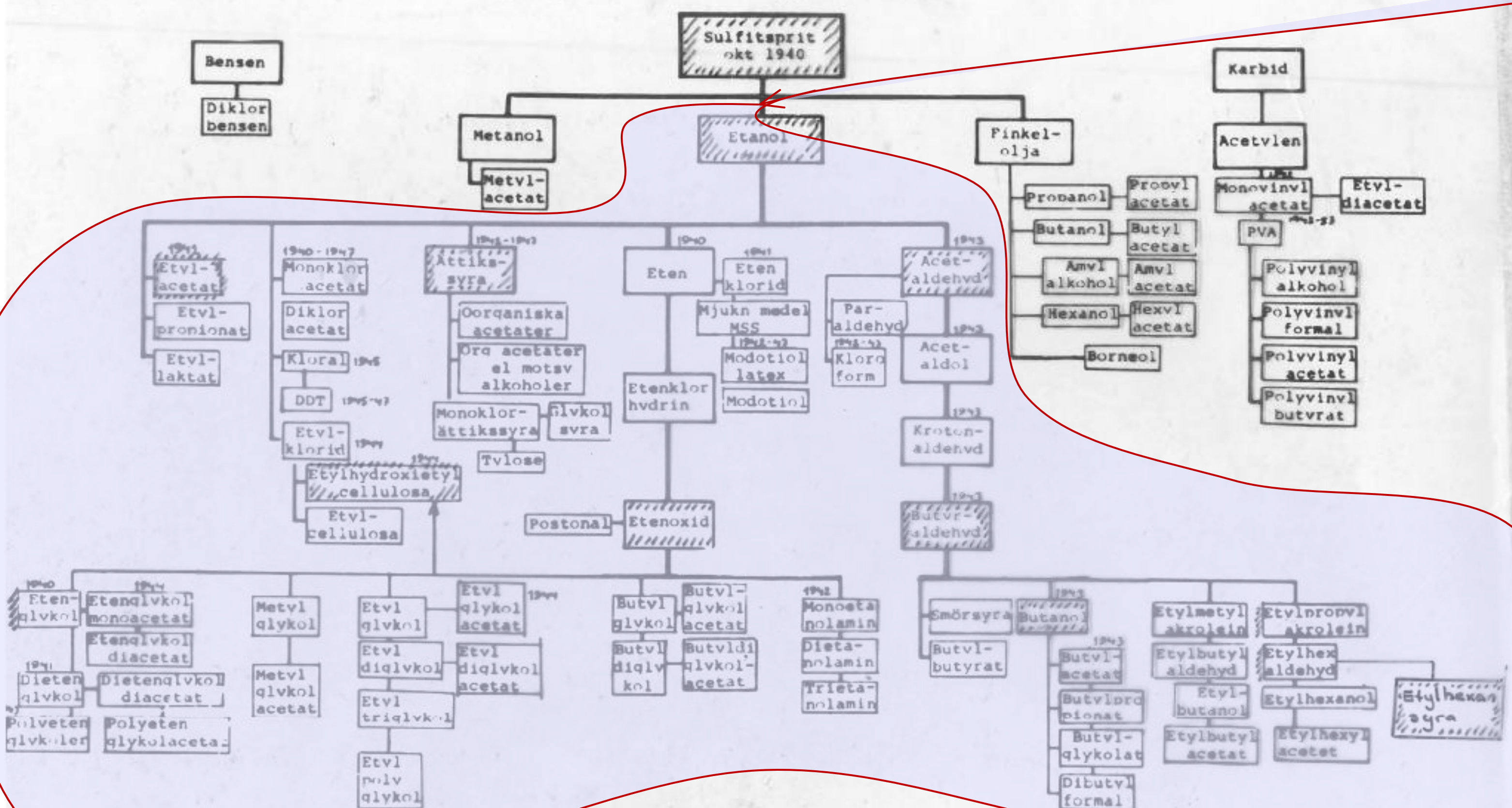
– quality jump from the 1st to the 2nd generation biofuels
– integration of lignocellulosic resources



Gołaszewski J. 2011. Biorefineries, processes of biomass conversion to biofuels, bioenergy and bioproducts. (in press)

A spectrum of chemicals from lignocellulosic bioethanol

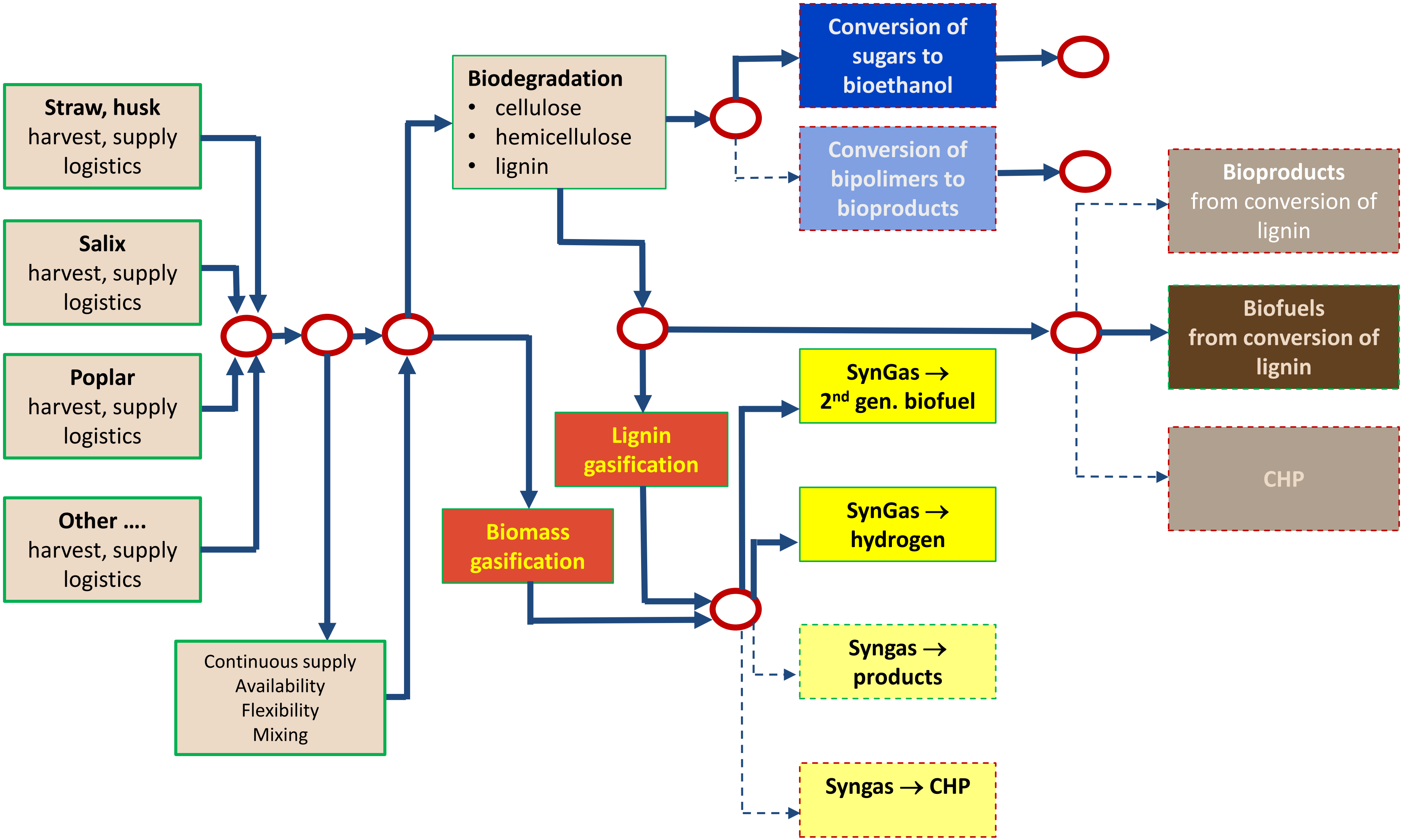
Figur 13. Mo och Domsjös uppbyggnad av organisk kemisk industri under 2:a världskriget. I vissa fall anges även nedläggningsår. Produktträdet gäller år 1945.



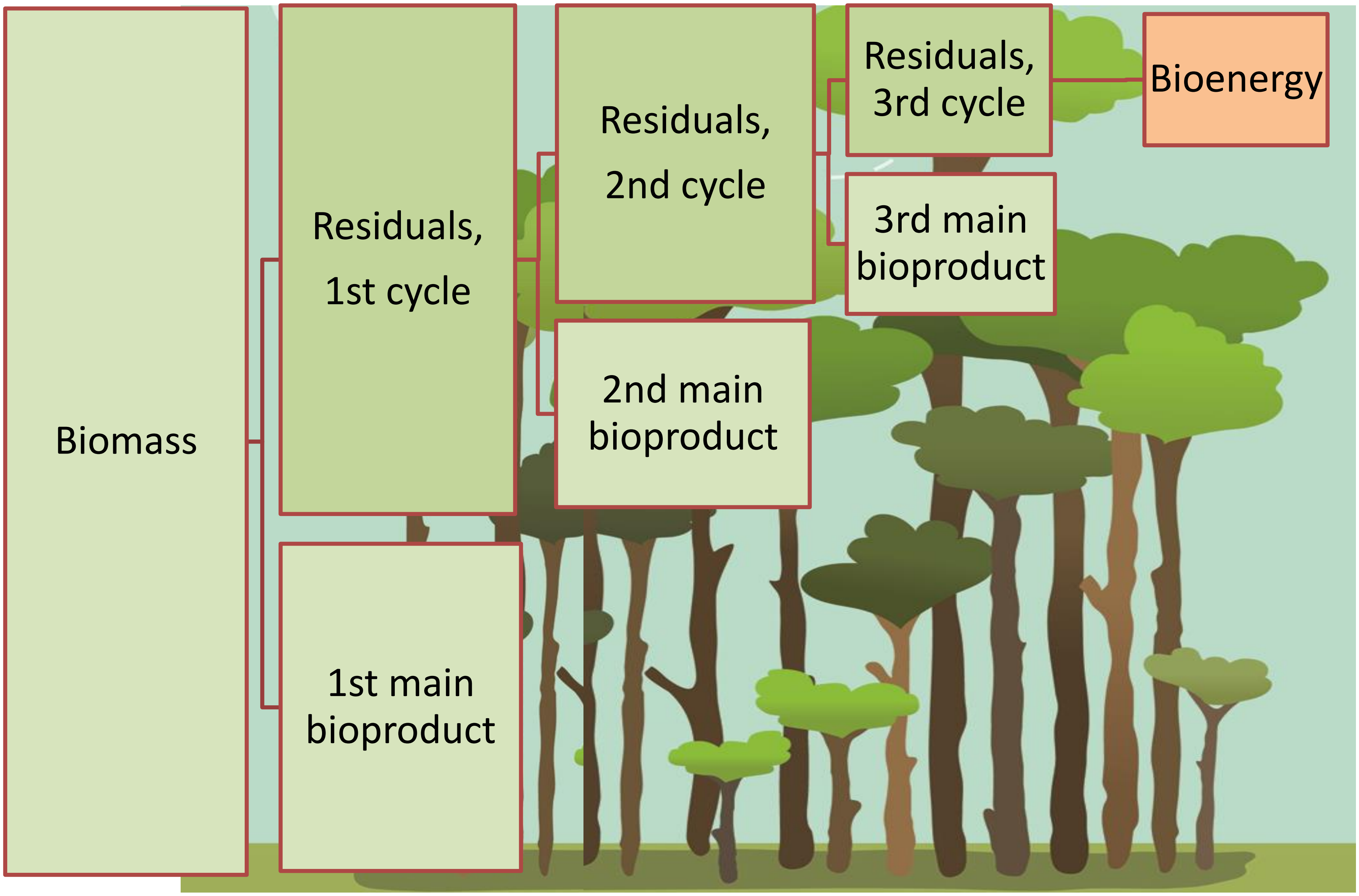
Källor: Skogen ger. Stockholm 1945. Svensk Trävaru och Pappersmassetidning årsnummer 1943. Svensk Kemisk Tidskrift 1962 s. 132. Festskrift till Carl Kempe Uppsala 1964.

Research Challenges

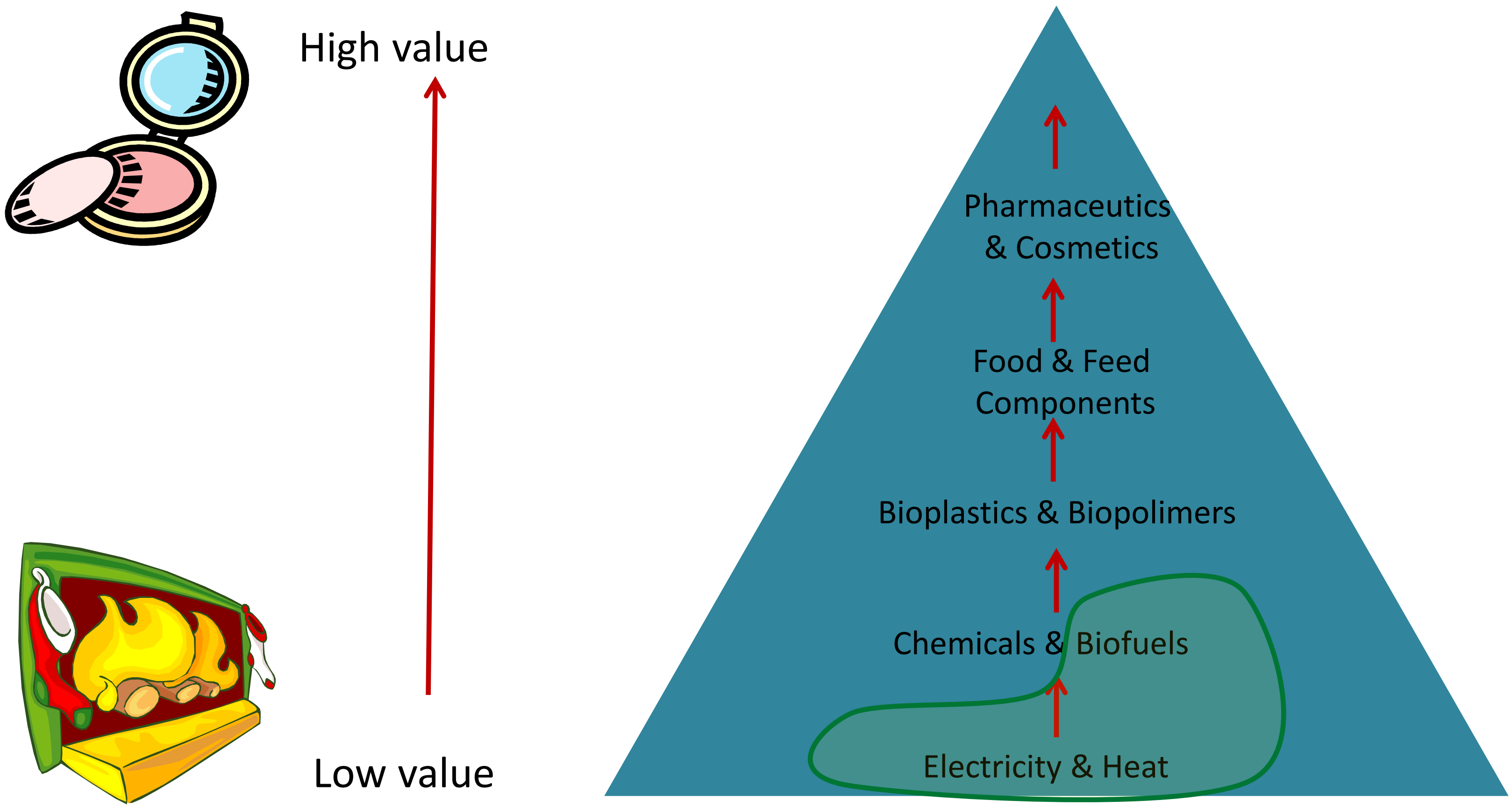
– Integration of Lignocellulosic Feedstock, Biomass Pretreatment and Conversion Processes



Cascading use of biomass



Biorefinery: Eco-pyramid of Cascading Biomass Use
Research challenge: implementation of optimal bio-based products value chain



acc. to Sanders J. Sustainability and climate protection, the role of bio fuels and biorefineries in Europe. Biomotion. Hannover, 12 November 2009.

Biochemicals – two obvious facts

- from a technical point of view almost all industrial materials made from fossils (today ca. 330 mil. t) could be substituted by their bio-based counterparts (today ca. 50 mil. t).

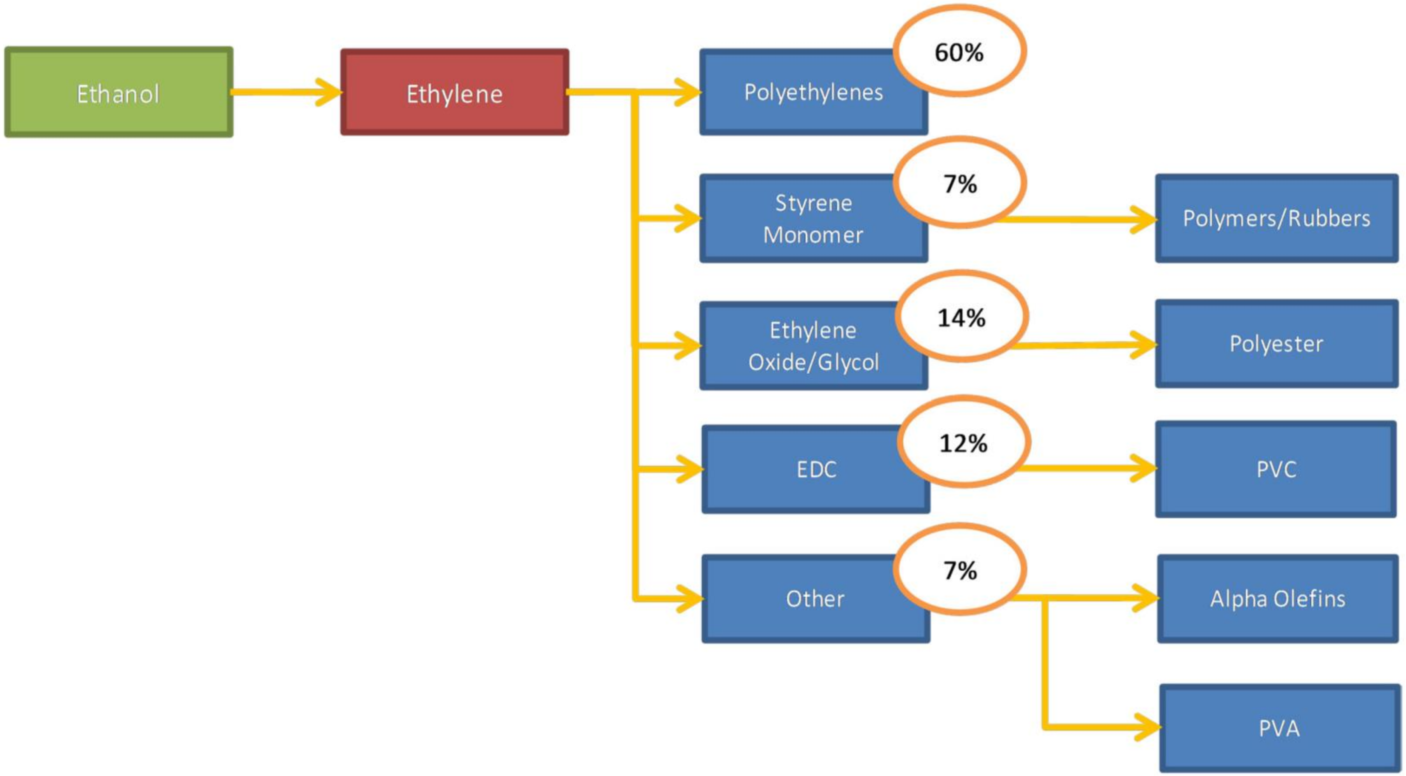
- cost of bio-based production in many cases exceeds the cost of petrochemical production but at the lower environmental impact

Acc. to: Bio-based Chemicals. Value Added Products from Biorefineries. Report of IEA Bioenergy. 2011.

Biorefinery – Platforms of Biochemicals Depending on the Main Bioproduct in Value Chain

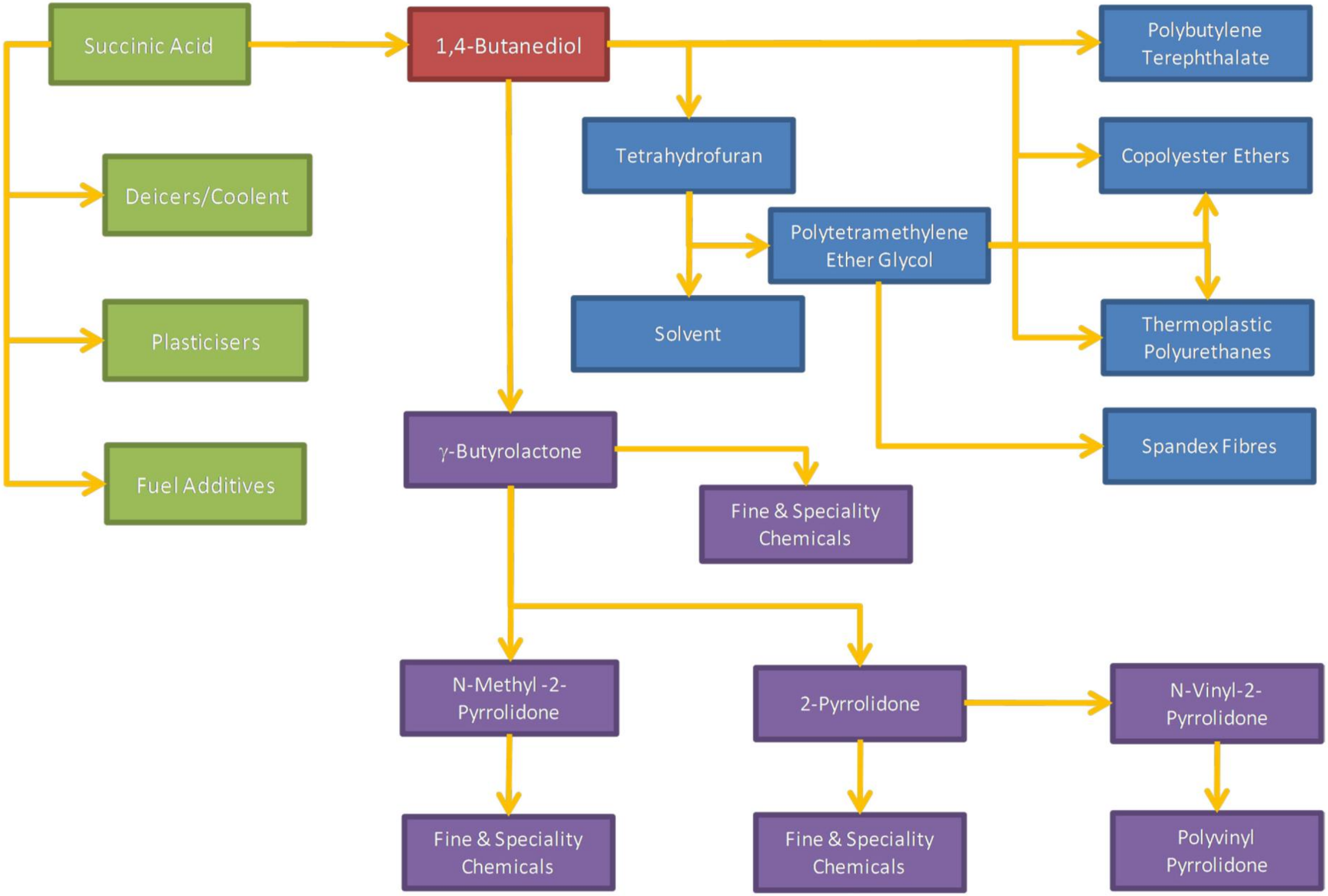
- Syngas
  (methanol, DME (dimethylether), ethanol, Fischer-Tropsch diesel)
- Biogas
  (amino and organic acids (e.g. lactic acid), vitamins, antibiotics, xanthan, and many other promissive chemicals: succinic acid, itaconic acid, adipic acid, 3-hydroxypropionic acid / aldehyde, isoprene/farnesene, glutamic acid, aspartic acid)
- Sugars C5 and C5/C6
  (sorbitol, levulinic acid, glucaric acid, hydroxymethylfurfural 2,5-furan dicarboxylic acid, p-xylene)
- Vegetable oil
  (propylene glycol, epichlorohydrin, 1,3-propanediol, 3-hydroxypropion aldehyde, acrylic acid, propylene, methanol (via syngas)
- Algae oil
  (lipids, pigments, antioxidants, fatty acids, vitamins, sterols)
- Press juice
  (carbohydrates, proteins, free amino acids, organic acids, minerals, hormones and enzymes)
- Lignin
  (syngas products, hydrocarbons, phenols, oxidised products, amcromolecules)
- Pyrolysis oil
  (phenols, organic acids, furfural, HMF and levoglucosan

Acc. to: Bio-based Chemicals. Value Added Products from Biorefineries. Report of IEA Bioenergy. 2011.



Potential Ethylene Value Chain

Source: Bio-based Chemicals. Value Added Products from Biorefineries. Report of IEA Bioenergy. 2011.



Potential Succinic Acid Value Chain

Source: Bio-based Chemicals. Value Added Products from Biorefineries. Report of IEA Bioenergy. 2011.

Biorafinery – Research Challenges - Summary

- ✓ sustainable development is associated with sustainable use of biomass
- ✓ development of biorefinery needs to integrate specialists which represent various scientific disciplines

- ✓ key role in the research progress will have interdisciplinary agro-bio-technological and agro-bio-chemical sciences because
  - ✓ they will create technologies for new bioproducts, incl. biofuels and bioenergy and finally – a portfolio of bioproducts for future market (bioeconomy)
  - ✓ they will contribute to new science - bioeconomics

- ✓ various petrochemical refinery processes and refinery products may be considered in biorefinery processes and bioproducts

Biomass-to-Energy Technologies – Research Challenges - Summary

1. Competitive today:
    - production of bioethanol from sugar cane (Brasil)
    - chosen systems for biowaste utilization,
    - effective boilers and CHP units which use fuels from biomass

2. Competitive in the course of 10-20 years:
    - low-cost agriculturally derived lipid materials such as tallow, greases, and soapstocks
    - lignocellulosic biofuels as a main replacement of fossil fuels
    - advanced technologies of electricity production from biomass
    - biorefineries optimized for a set of bioproducts
    - multi-cycle path for recycling of bio-waste
    - models for integrated economic, energy, and environmental assessment in agreement with energy systems

3. Competitive in the course of 20-30 years:
    - integration of biomass conversion with CCS in the context of significant reduction of GHG emission

4. A biomass potential which is difficult to determine today:
    - advanced biomaterials from biomass
    - effective utilization of energy potential and bioproducts from water biomass
    - economic effectiveness and significant reduction of GHG emission

Economics of biomass conversion requires research oriented on high yield of biomass and effective conversion processes

In general:

- consciousness of research and any other activities in the spirit of sustainable development
- environmental pressure for changes in energetics and transportation
- biomass – is the only renewable resource which is an organic equivalent of the fossils and may replace petrochemical fuels
- biomass conversion technologies to energy are not efficient
- effective biomass use requires research orientated on new high-value bioproducts

BIOMASS HAS THE POTENTIAL TO BE THE KEY RESEARCH TOPIC IN THE 21ST CENTURY

THE TODAY'S RESEARCH CHALLENGES ASSOCIATED WITH BIOMASS WILL RESULT IN NEW MARKET OF BIOPRODUCTS

[1]Best G. 2003. Agro-Energy: A New Function of Agriculture. Lamnet-News, 3rd Issue

Brussels, 17 December 2012

MANIFESTO FOR A RESOURCE-EFFICIENT EUROPE

In a world with growing pressures on resources and the environment, the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy.

It apply to biological and technical materials

Circular economy

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