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Bio-based polymers – A sustainable solution for the next decades

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Contents

- Truly needed?
- Measuring environmental sustainability
- Bifurcation
- More evidence
- Limits to growth
- Building block for sustainable development

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Bio-based polymers - Truly needed?

The cons:

- Material performance often lower
- High costs for production and processing
- Total energy (= NREU + REU) often higher than for conventional
- Small share of fossil fuels
- Last drops of oil for high value added products
- (Potential) Competition with food
- Threat to biodiversity
- Biodegradable polymers
  - May cause additional GHG (methane!)
  - Carbon sequestration in compost is low
  - No solution for littering

Bio-based polymers - Truly needed?

Pros:

- World Energy Outlook by the International Energy Agency (IEA):
  - Oil price in 2030: **29 $/bbl** (IEA, 2004) → **120 $/bbl** (Nov. 2008)
- IPCC, Feb. 2007: Evidence now “unequivocal” that global warming is man-made

Bio-based polymers - Truly needed?

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- Chem. ind. sector by far largest industrial energy user

Bio-based polymers - Truly needed?

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  - Oil price in 2030: **29 $/bbl** (IEA, 2004) → **120 $/bbl** (Nov. 2008)
- IPCC, Feb. 2007: Evidence now "unequivocal" that global warming is man-made
- Chem. ind. sector by far largest industrial energy user
- Large-scale investments in renewables and energy efficiency, while more oil available for chemicals → pressure GHG policy,
  image loss
- Innovation, rejuvenation of sector

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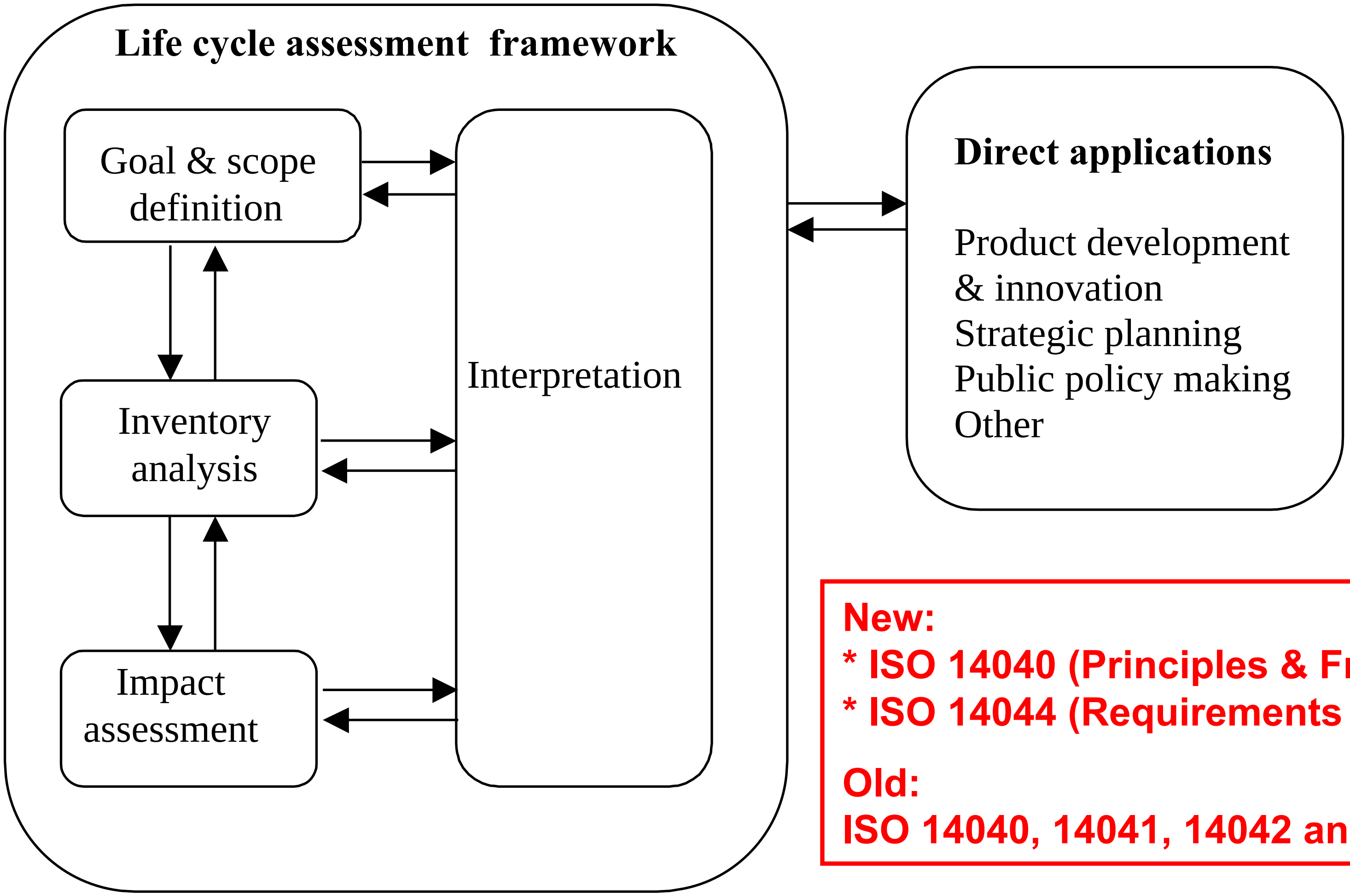
Life cycle assessment (LCA) is the only comprehensive way of assessing the environmental impacts of a product or a service.

Steps of an LCA



Life cycle assessment framework

Goal & scope definition

Inventory analysis

Impact assessment

Interpretation

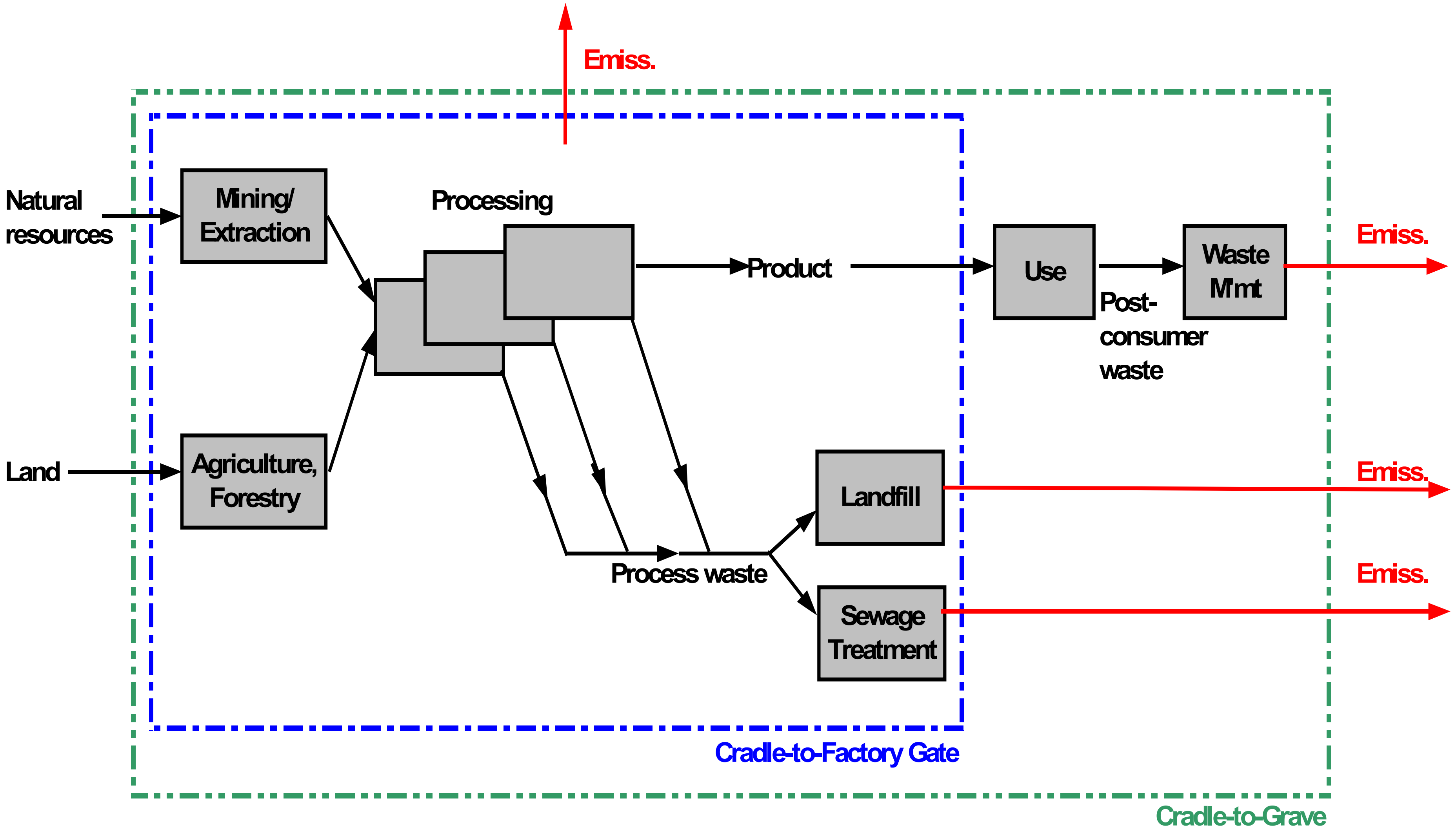
Direct applications

Product development & innovation
Strategic planning
Public policy making
Other

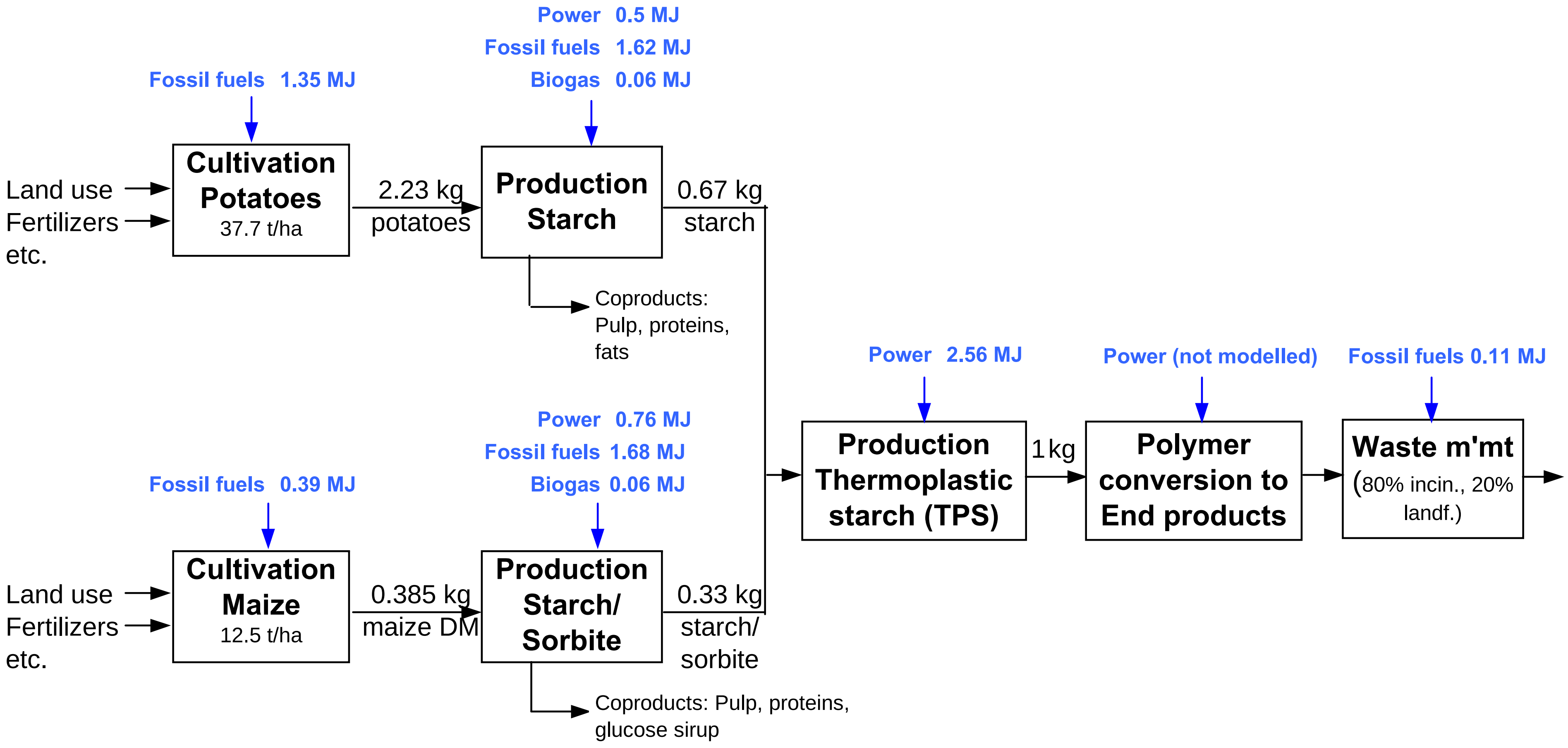
New:
*** ISO 14040 (Principles & Framework)**
*** ISO 14044 (Requirements & Guidelines)**

Old:
ISO 14040, 14041, 14042 and 14043

System boundaries



Thermoplastic starch - Flow diagramme



Fossil fuels 1.35 MJ

Land use
Fertilizers
etc.

Cultivation Potatoes
37.7 t/ha

2.23 kg potatoes

Power 0.5 MJ
Fossil fuels 1.62 MJ
Biogas 0.06 MJ

Production Starch

0.67 kg starch

Coproducts: Pulp, proteins, fats

Fossil fuels 0.39 MJ

Land use
Fertilizers
etc.

Cultivation Maize
12.5 t/ha

0.385 kg maize DM

Power 0.76 MJ
Fossil fuels 1.68 MJ
Biogas 0.06 MJ

Production Starch/ Sorbite

0.33 kg starch/ sorbite

Coproducts: Pulp, proteins, glucose sirup

Power 2.56 MJ

Production Thermoplastic starch (TPS)

1 kg

Power (not modelled)

Polymer conversion to End products

Fossil fuels 0.11 MJ

Waste m'mt
(80% incin., 20% landf.)

Source: CARBOTECH, 1996

Important Environmental Impact Categories

- Non-renewable energy use (NREU)
- Renewable energy use (REU)
- Total energy use (TEU = NREU + REU)
- Land use
- CO_2 equivalents (CO2)
- Abiotic Depletion (ADP)
- Ozone Layer Depletion (ODP)
- Photochemical oxidant formation (smog precursor) (POF)
- Water use (process, cooling) (PW, CW)
- Acidification (ACID)
- Eutrophication (EUTRO)
- Human toxicity
- Aquatic toxicity
- Terrestrial ecotoxicity

Caveats w.r.t. Environmental Impact Categories

- There is no pre-defined, standardized list.
- The list is incomplete, important missing categories are:
  - Biodiversity
  - GMO
  - Water (aggregated assessment)
  - Soil erosion
  - Soil fertility and carbon content of soil
  - Types of land use (agriculture, forest; climate zone)
- Toxicity impacts are highly uncertain; improvement of methodology and data is subject to continuous improvement.

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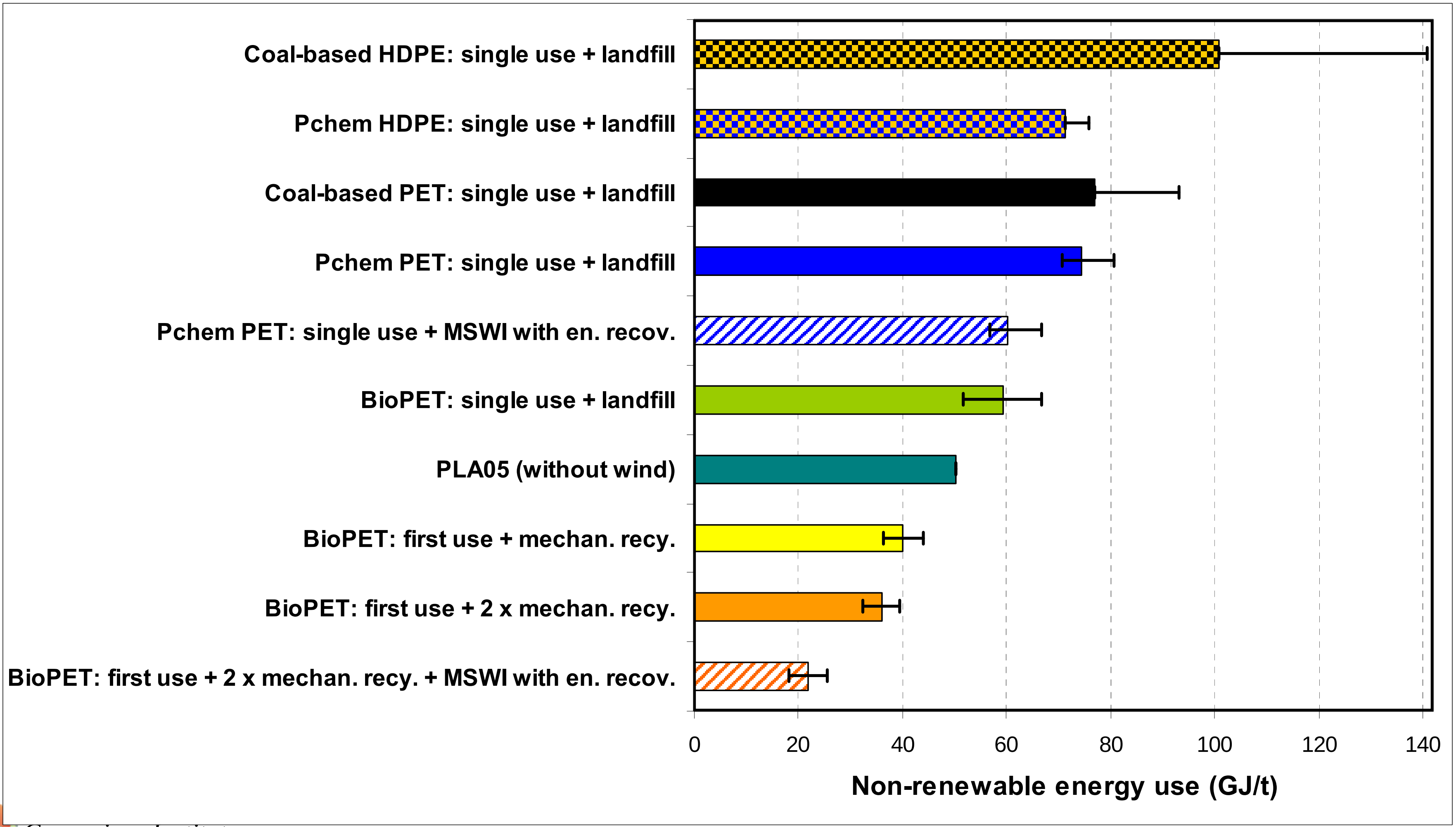
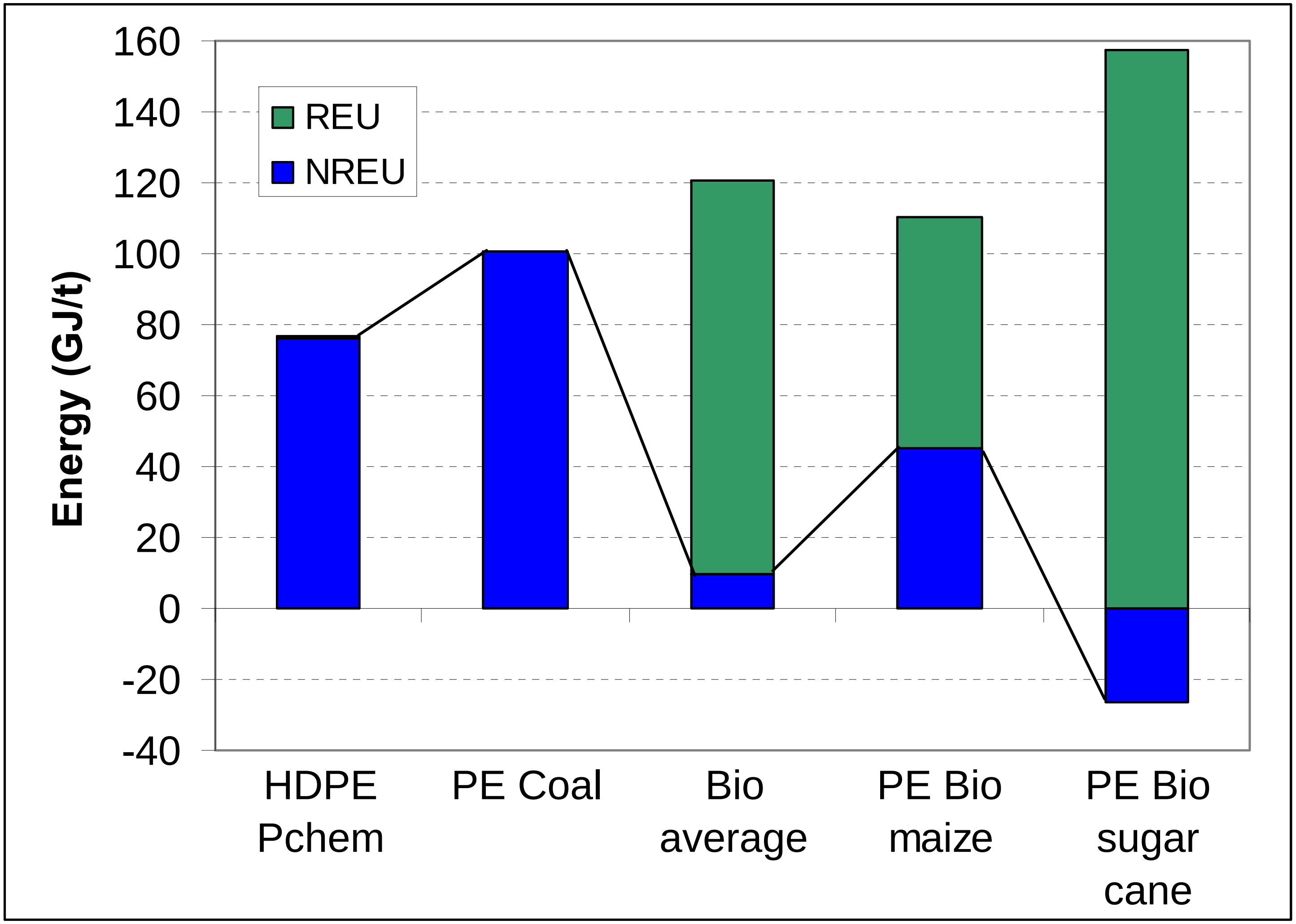
Development potentials of PET in perspective

Preliminary results



Polyethylene from oil, coal and biomass

Preliminary results



Calculations based on BREW Study (2006) and Ph.D. thesis Tao Ren (forthcoming).

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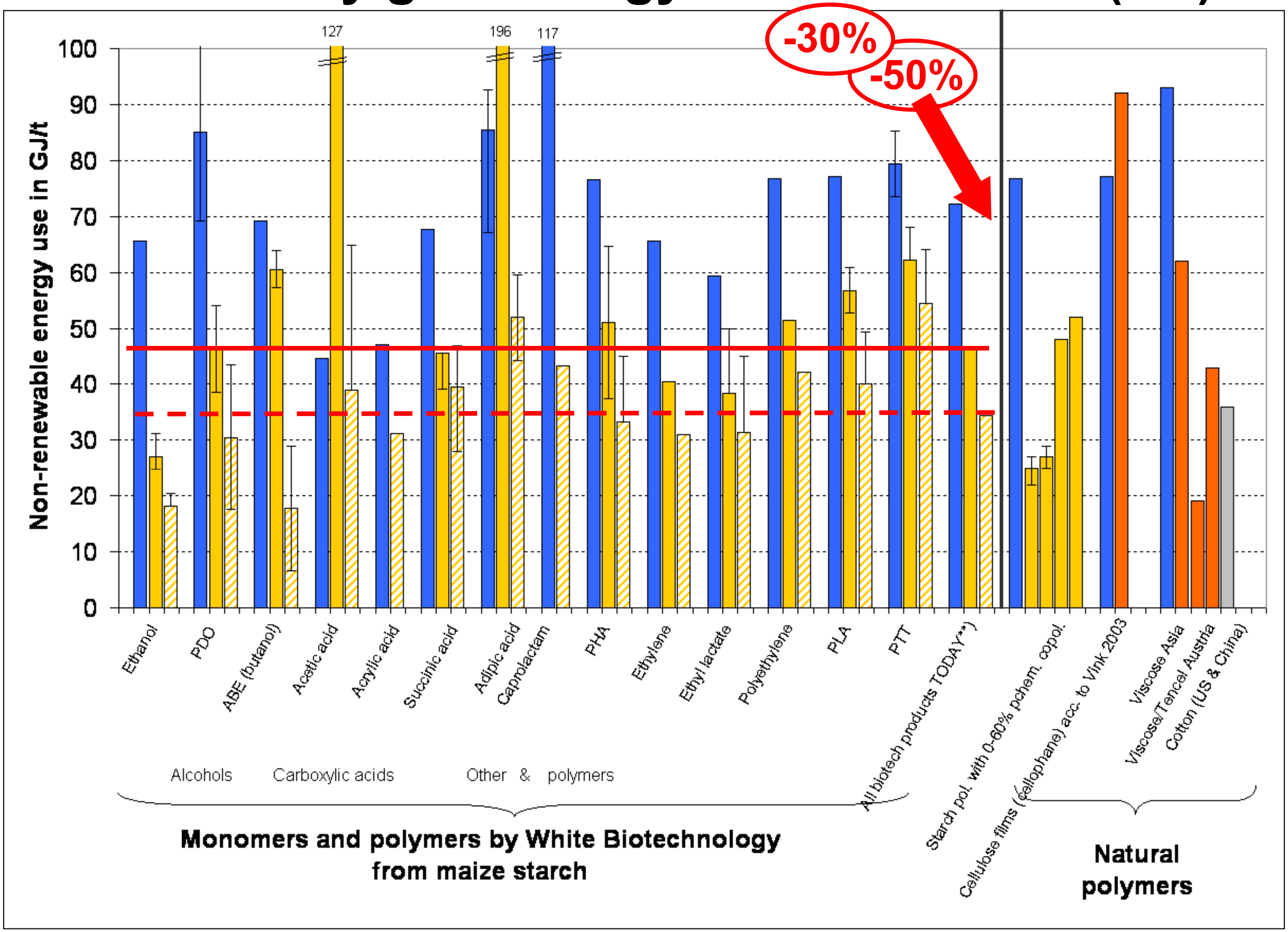
Preliminary results

Cradle-to-factory gate energy use – Overview (2/2)



M. K. Patel, based on several UU studies, 2008

Technology perspective vs. company perspective

PLA with and without wind energy

		2005 without wind energy	2006 with wind energy
NREU	MJ/kg PLA	50.2	27.2
GWP	kg CO_2 eq/kg PLA	2.0	0.3

Is in line with EU goals for 2020:
Reduce overall emissions to at least 20% below 1990 levels, save 20% energy, and reach 20% renewables.

Source: PLA data from Ingeo/NatureWorks LLC, Vink et al. 2007

Comparison of PLA with PET, per kg

		PLA **without** wind energy 2005	PLA **with** wind energy 2006	PET
NREU	MJ/kg	50.2	27.2	80.8
GWP	kg CO_2 eq./kg	2.0	0.3	3.3

Critical factor for material use (dies): If 1.6 more PLA than PET (possible for diverse commercial products)

Density PET: 1.35 – 1.39 kg/litre
Density PLA: 1.25 kg/litre

Sources: PLA data from Ingeo/NatureWorks LLC, Vink et al. 2007; PET data from PlasticsEurope

Food company project (1/2)

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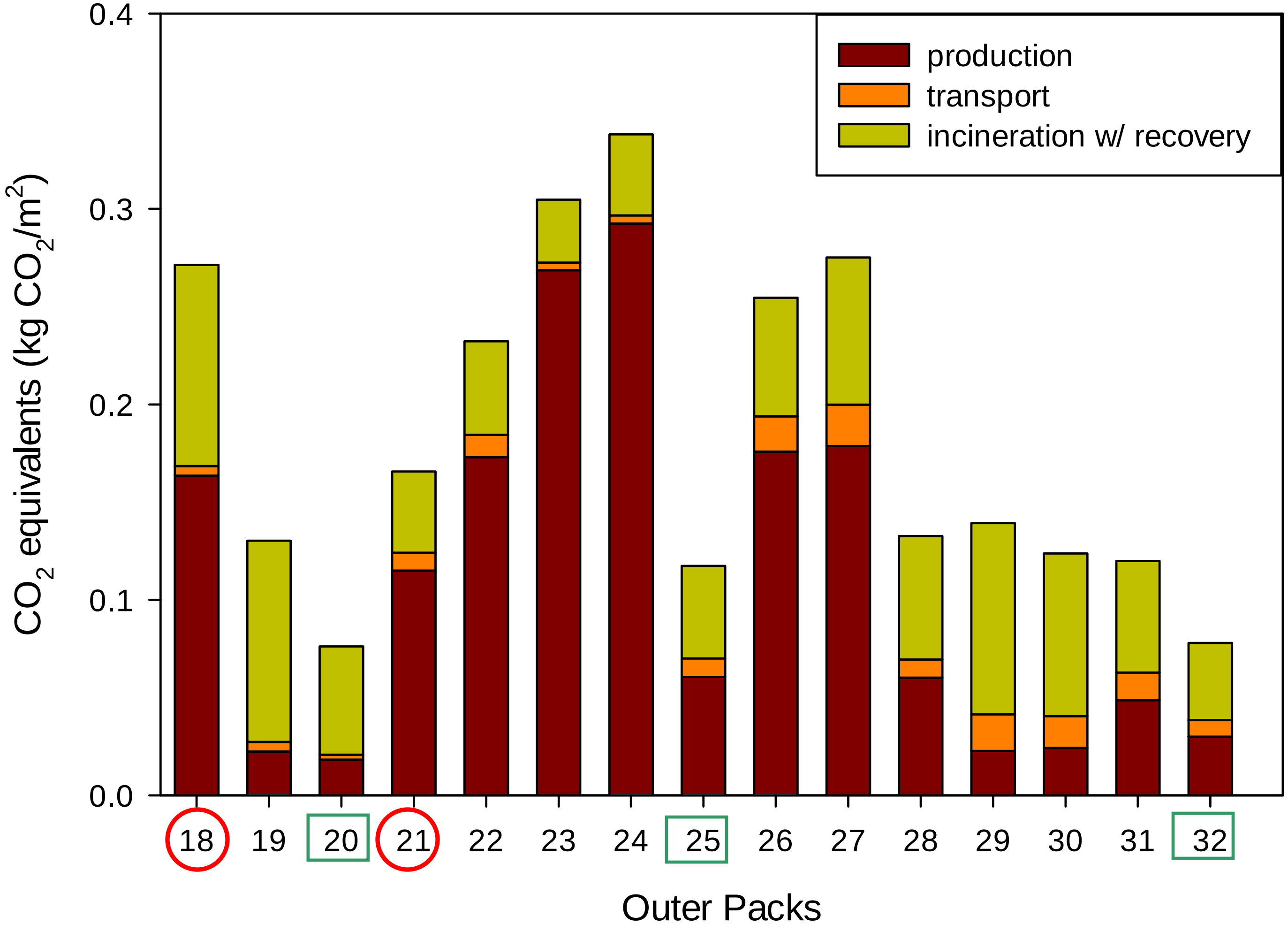
Bio-based materials for Outer packaging films

Cradle-to-grave: incineration with energy recovery



18) PE
20) bio-based PE
21) PP
22) PLA
23) Cellulose
25) Paper/PP
26) Paper/PLA
28) Paper/PE
31) Paper/BBP
32) Paper/EVA

Caveat: Snapshot for current technology.

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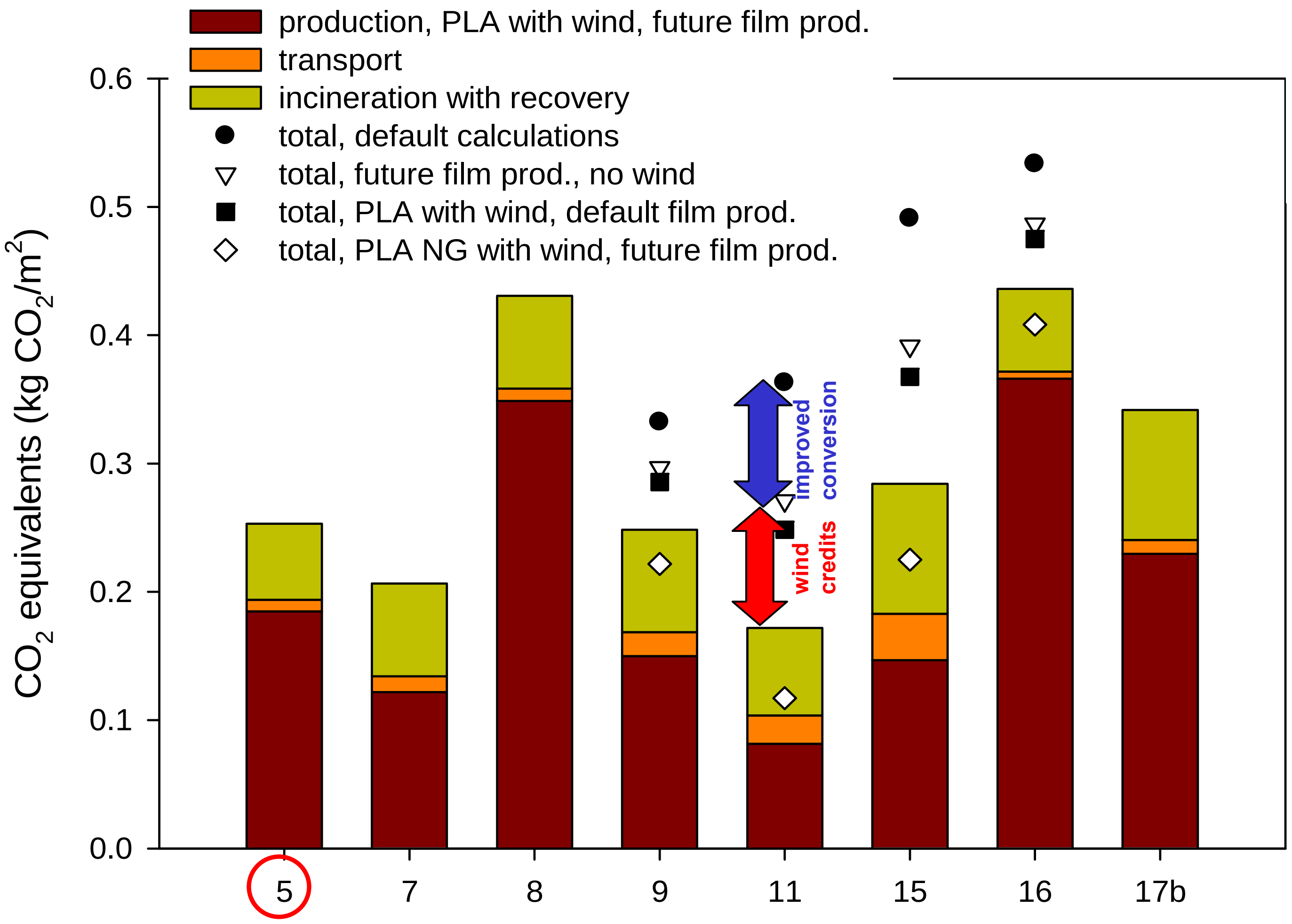
Bio-based materials for <u>high-barrier</u> food packaging films

Global warming potential of Inner Packs including wind credits and future technology for PLA film production; *cradle-to-grave*: incineration with energy recovery



5) PP/PP

7) Paper/PP

8) Cellulose/PP

9) PLA/PP

11) PLA/PLA

15) Paper/PLA

16) Paper/PLA/Alu

17) Paper/PET/PE

PaperFoam project (1/2)

Energy and GHG emissions in perspective

Jewelcase

(polystyrene tray
+ polystyrene cover)

PaperFoam

(PaperFoam tray
+ cardboard cover)

DigiPack

(polystyrene tray
+ cardboard cover)

PaperFoam project (2/2)

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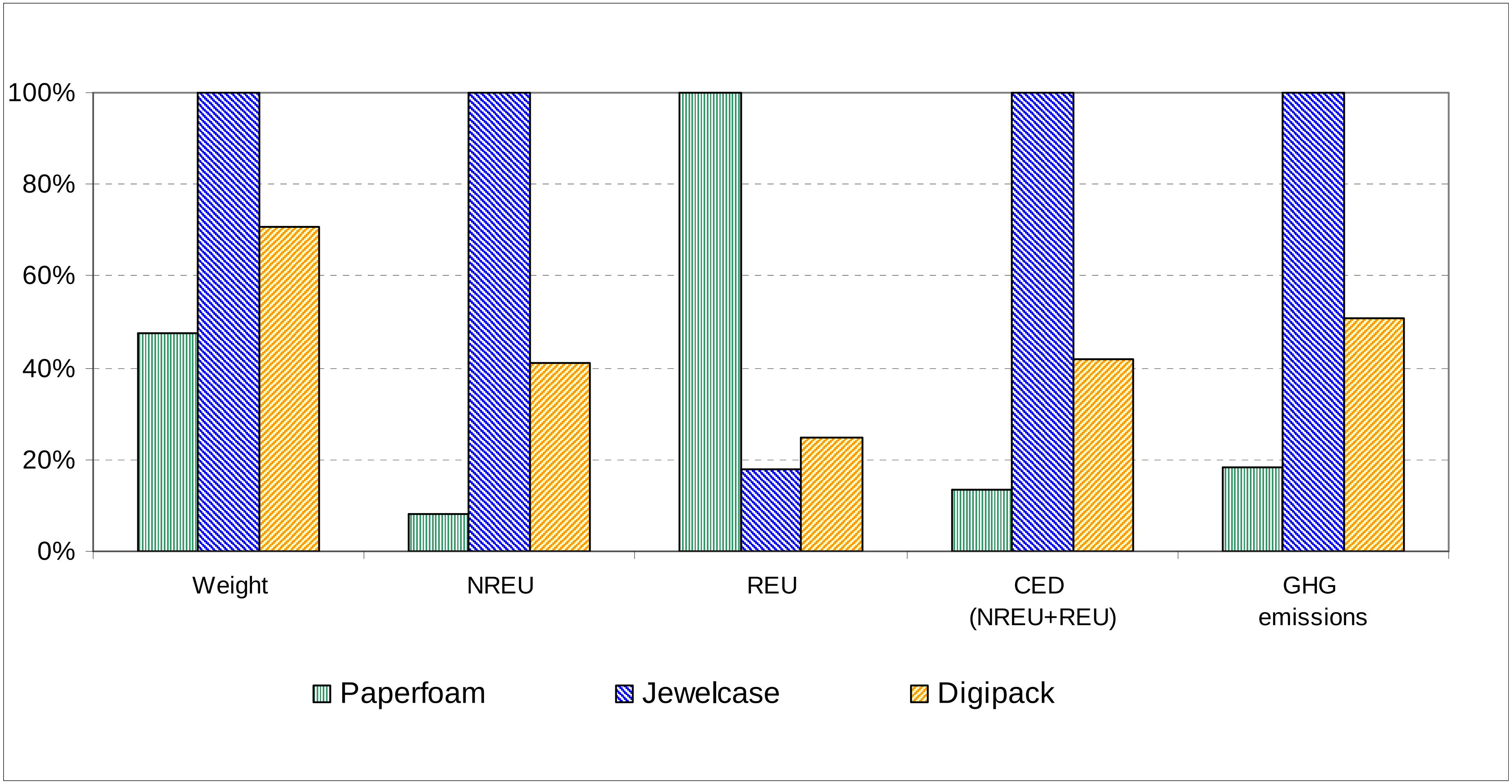
Energy and GHG emissions in perspective

Cradle-to-grave (MSW incineration plant with energy recovery)



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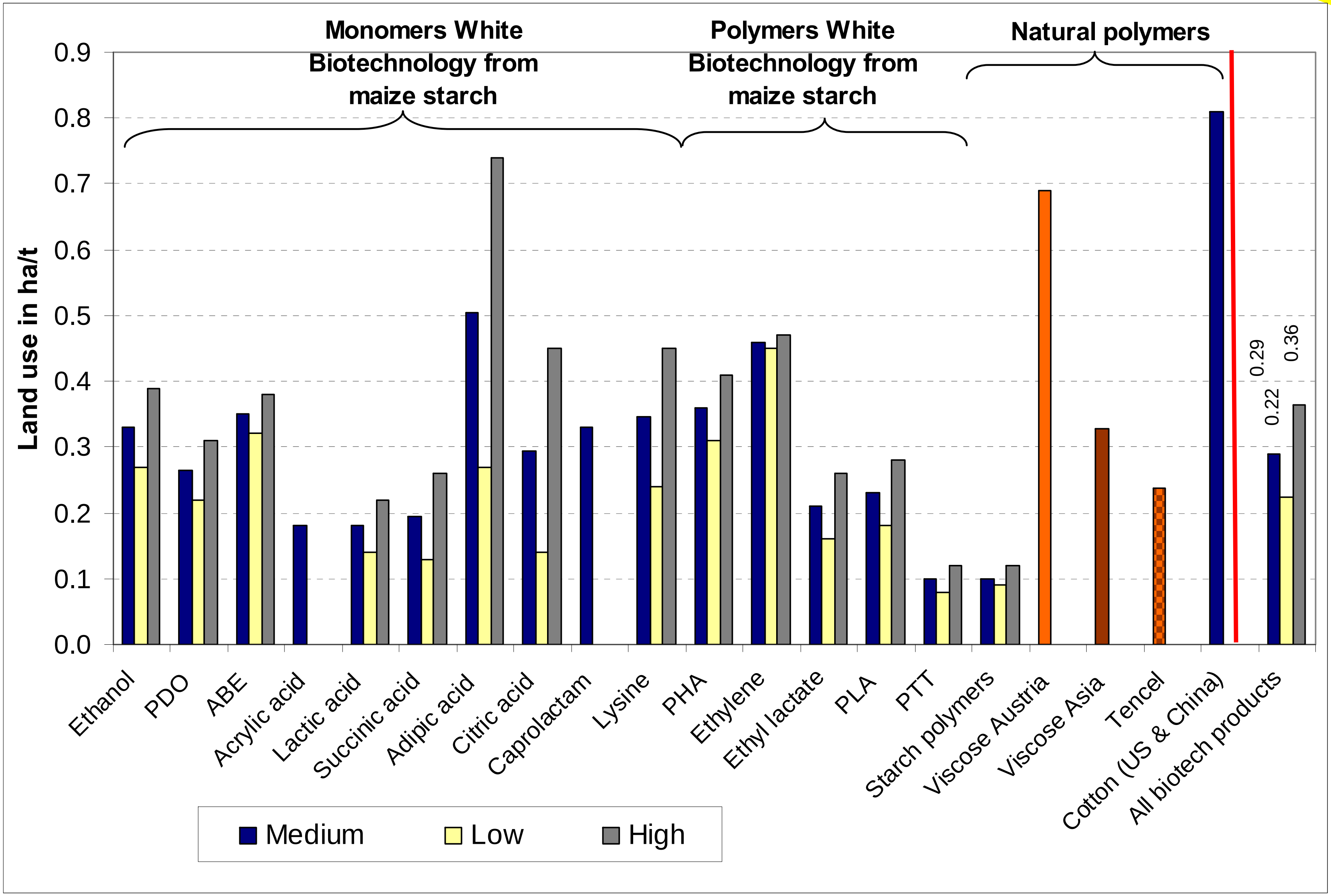
Land use (2/2)

Preliminary results



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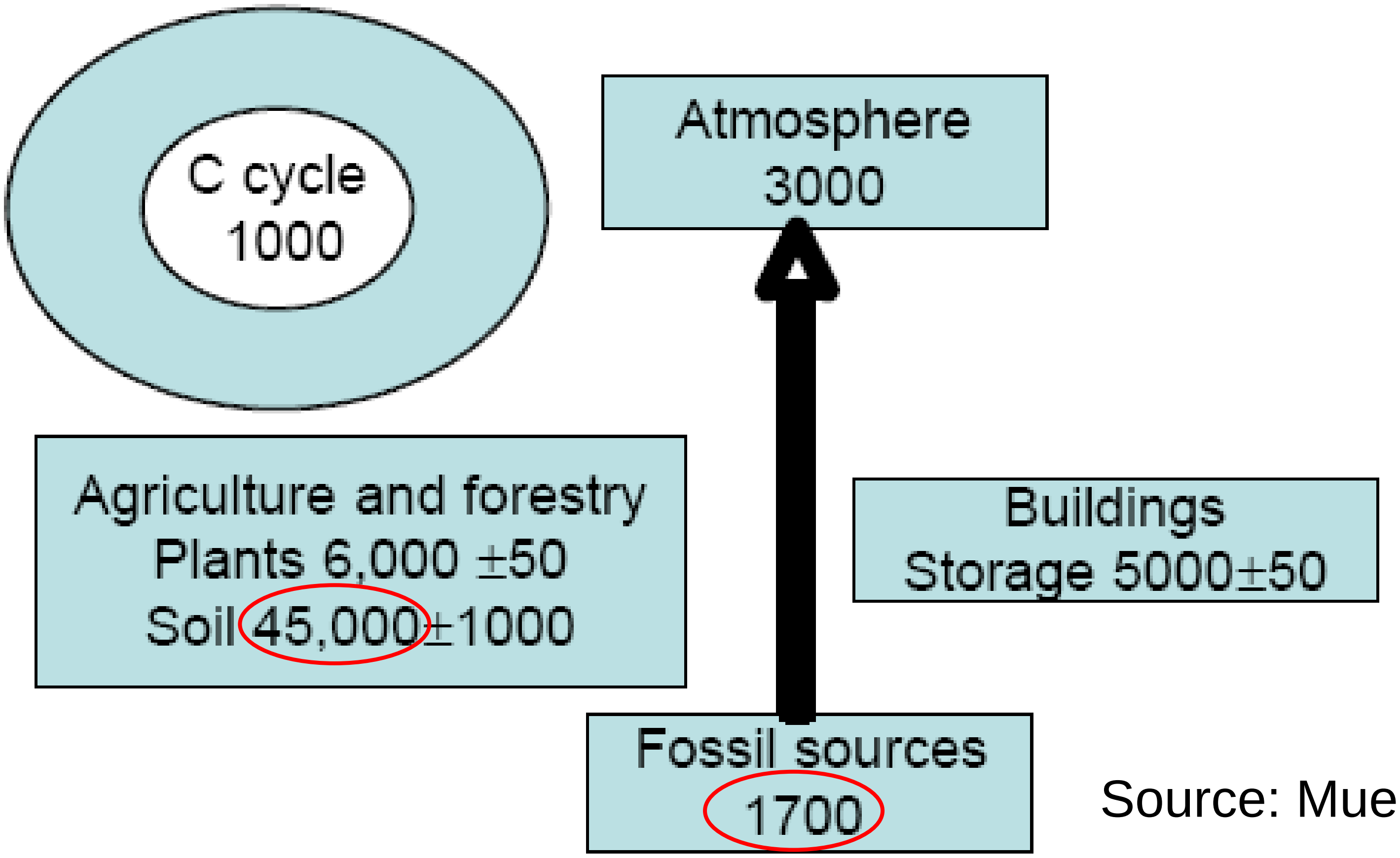
Carbon flux in CH in 2005



C cycle
1000

Atmosphere
3000

Agriculture and forestry
Plants 6,000 ±50
Soil 45,000±1000

Buildings
Storage 5000±50

Fossil sources
1700

Source: Mueller & Baccini

UK soils have lost 15% of carbon in 1978-2003, equals 15 million tonnes (Bellamy, 2005)

Global ethanol production and conclusions for bio-based polymers (1/2)

Preliminary results

39	**million t EtOH**
↓	
24	**million t ethylene**
37%	of all polyethyene
10%	of all thermoplastics
8%	of all polymers

Global ethanol production and conclusions for bio-based polymers (2/2)

Preliminary results

39 **million t EtOH**

↓

24 **million t ethylene**

37% of all polyethylene

10% of all thermoplastics

8% of all polymers

Land use million ha

14

---

125 **million t EtOH**

↓

76 **million t ethylene**

119% of all polyethylene

31% of all thermoplastics

25% of all polymers

Land use million ha

45

For comparison:

*** USA: 165 million ha arable land**

*** World: 1,550 million ha arable land, under cultivation**

3,100 million ha total arable land

Rethinking demand

77 grammes almond bread

= 355 kcal

≈ 1.5 MJ (without processing)

14 grammes PET

Total NREU
(material + processing)

≈ 1.4 MJ (with processing)

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Biodegradable vs. Bio-based

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Biodegradability

	Fully fossil-based	***Partially Biobased***	***Fully Biobased***
Fully Biodegradable	-PBS -PBSL -PBSA	-Starch blends (with biodegradable fossil-based coplymers) -Vegetable-oil based polyesters	-TPS -Starch blends (with biobased and biodegradable copolymers) -PLA -PHA/PHB -Cellulose film
Partially Biodegradable		- Starch blends (with polyolefins)	
Non-Biodegradable	-PE -PP -PET -PVC -PUR -ABS -Epoxy resin -Synthetic rubber	-Biobased PTT, PBT -Biobased PET -Biobased PVC -Biobased PUR -Biobased polyacrylates -Biobased ABS -Biobased Epoxy resin -Biobased SBR -Alkyd resin	-Biobased PE -Biobased PP -Biobased PA -Biobased PB -PO3G

Biobased raw material

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Technical Substitution Potential

Preliminary results

All values in 1000 tonnes	PE-LD	PE-HD	PP	PVC	PS [1]	PET	PUR	PA	ABS [2]	PC	PBT	PMMA	Other Polyacrylates	Epoxy resin	Synthetic rubber	Other	Total	% subst
Consumption in W. Europe [5]	8,415	5,940	9,405	6,435	3,465	3,465	2,970	863	646	336	180	204	205	370	1,810	4,790	49,500	100
Starch polymers	673	475	752	0	277	0	238	0	0	0	0	8	0	0	0	0	2,424	5
PLA	0	594	941	0	347	693	0	86	0	0	0	10	0	0	0	0	2,671	5
PHA	1,683	1,188	941	644	693	347	297	0	65	0	0	10	0	0	0	0	5,866	12
Vegetable oil-based polyesters	168	119	188	0	69	0	59	0	0	0	0	2	0	0	0	0	606	1
Cellulose films	0	0	9												0	0	2,450	5
Biobased PE	5,891	3,564													0	0	9,455	19
Biobased PP	0	0	5,												0	0	5,173	10
Biobased PVC [4]	0	0													0	0	5,148	10
Biobased PET [4]	0	0													0	0	1,213	2
Biobased PTT [3]	0	0	4												0	0	1,680	3
Biobased PUR [4]	0	0													0	0	2,376	5
Biobased PA	0	0													0	0	259	1
Biobased Polyacrylates [4]	0	0													0	0	205	0
Biobased Epoxy resins [4]	0	0													0	0	278	1
Biobased ABS [4]	0	0	0	0	0	0	0	0	581	0	0	0	0	0	0	0	581	1
Biobased Synthetic rubber [4]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,448	0	1,448	3
Sum volumes	8,415	5,940	9,405	6,435	1,733	3,465	2,970	604	646	67	180	41	205	278	1,448	0	**41,832**	**85**

Total polymer cons. Western Europe:
~50 million t p.a.

Technical potential bio-based:
~42 million t p.a. (85%)

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[1] PS (all types) and EPS

[2] ABS/SAN

[3] Including other partially biobased polyesters

[4] Partially biobased polymers

[5] For PE, PP, PVC, PS, PET and PA, consumption data are for 2006 (PlasticsEurope, 2008); For ABS, PBT, PMMA and other polyacrylates, consumption data are for 2003 (PlasticsEurope, 2004); For Epoxy resin and synthetic rubber, consumption data are for 2000 (Ullmanns, 2007)

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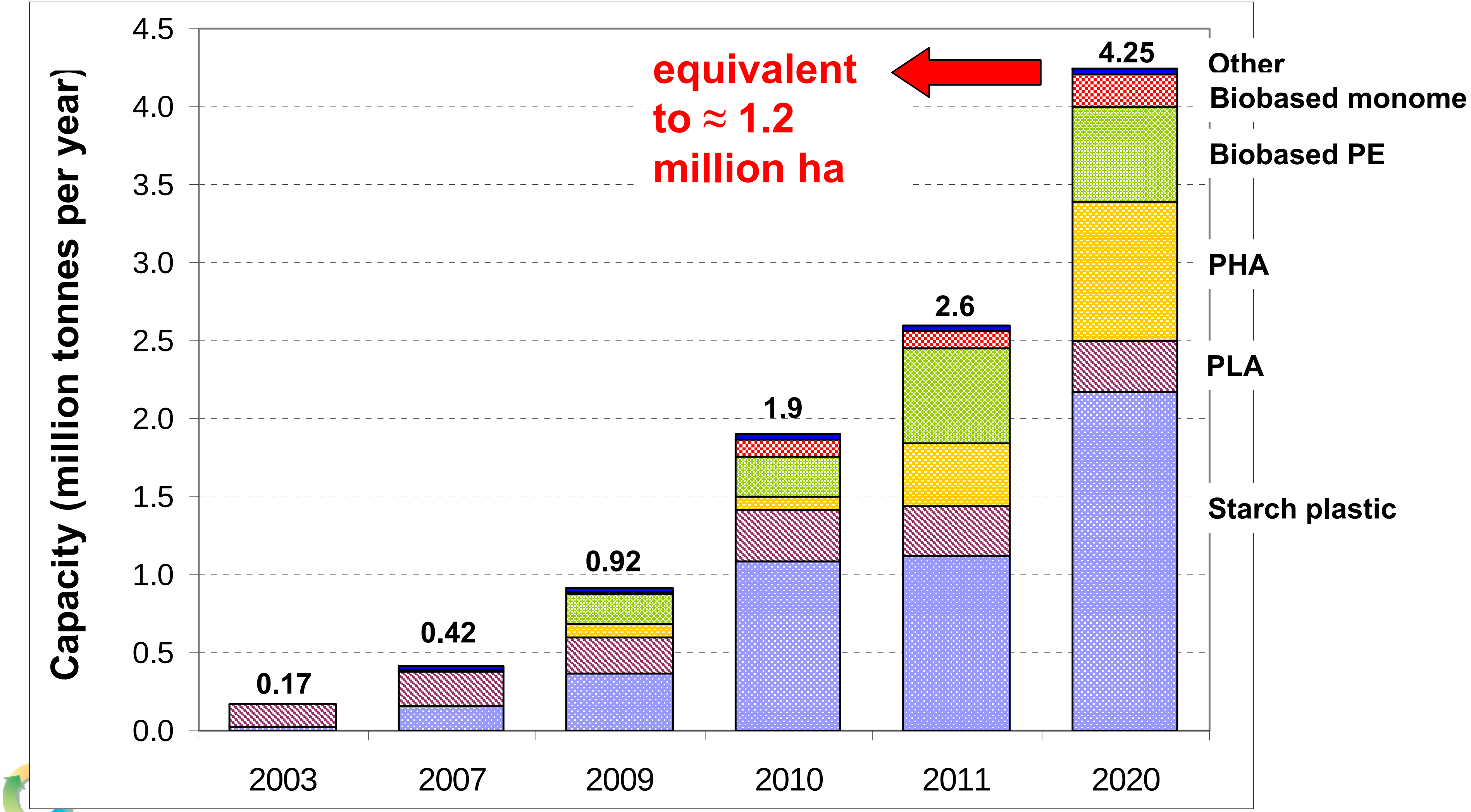
Global capacities of bio-based polymers (in kt)

(historical data for 2003-2007; announcements for >2007)

Preliminary results



equivalent to ≈ 1.2 million ha

Bio-based chemicals or biofuels?

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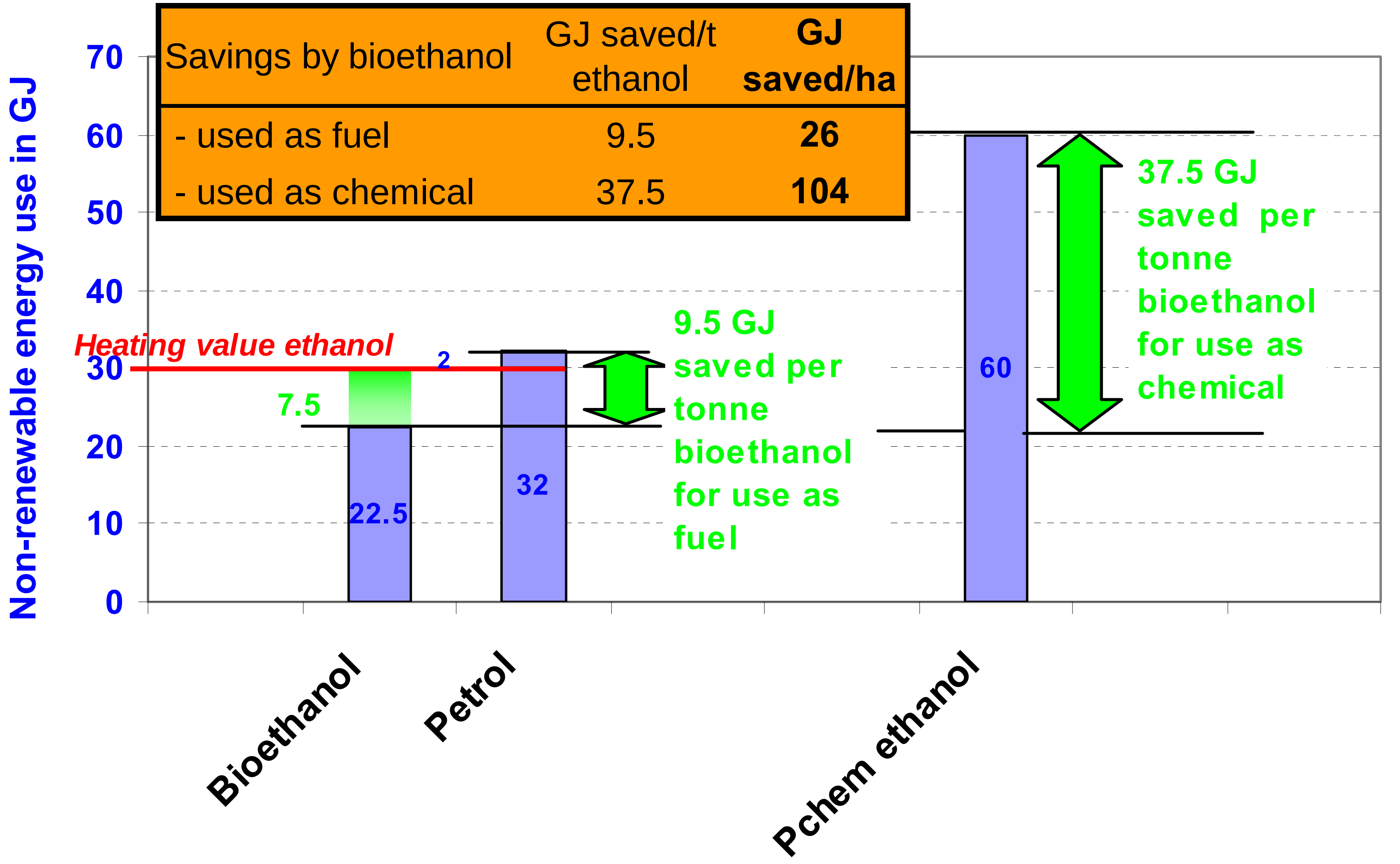
Production of 1 tonne ethanol (on 0.36 ha)

Savings by bioethanol	GJ saved/t ethanol	**GJ saved/ha**
- used as fuel	9.5	**26**
- used as chemical	37.5	**104**



M.K. Patel: Understanding bio-economics. European Plastics News, March 2008, pp.28-29

Conclusions

- **Important opportunities** for reducing environmental impacts (esp. NREU and GHG)
- Likely to be **needed** (policy?)
- Substantial **differences** across the polymers and final products
- Some **drawbacks** still not fully understood (soil, toxicity of agricultural chain)
- Challenge: **Maximize (environmental) benefits** by
  - optimal portfolio of bio-based polymers
  - closing loops by reuse and recycling
  - avoidance of excessive material use

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