Energy and CO_2 balance of bio-energy plants and of various forms of bio-energy

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Contents

- Methodology of the balance calculations
- Energy and CO_2 balance of cop production
  (basis of the calculations: field trials)
- Energy and CO_2 balance of the conversion of the crop biomass into different bio-energy forms
  (based on literature review)

Energy- and CO_2-balance in arable production

- Life cycle analysis approach (LCA): System definition und system boundaries

Exploration of raw materials

Production & Transport:
- Fertilizers
- Plant protection substances
- Machinery und seeds

On-field activities:
- Soil preparation
- Plant nutrition
- Plant protection
- Harvest

Biomass

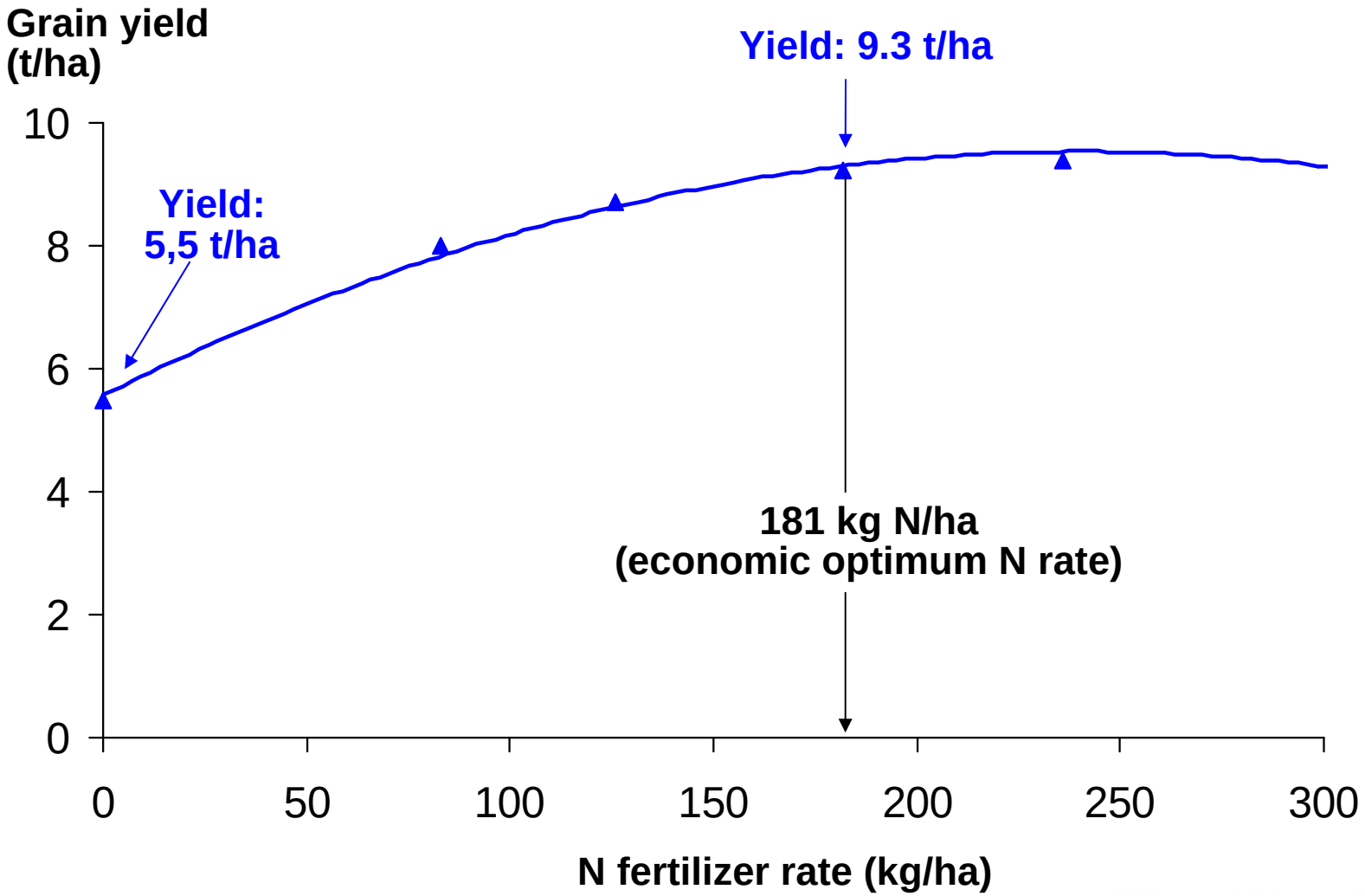
Energy input and CO_2 equivalent emissions [1)]

Energy yield and CO_2 fixation (in the biomass)

Energy balance and CO_2 balance

[1)] **1 kg N_2O = 310 kg CO_2**

Calculation of the economic optimum grain yield
- Example: winter wheat, average of 139 one-year field trials, Yara, 96-07



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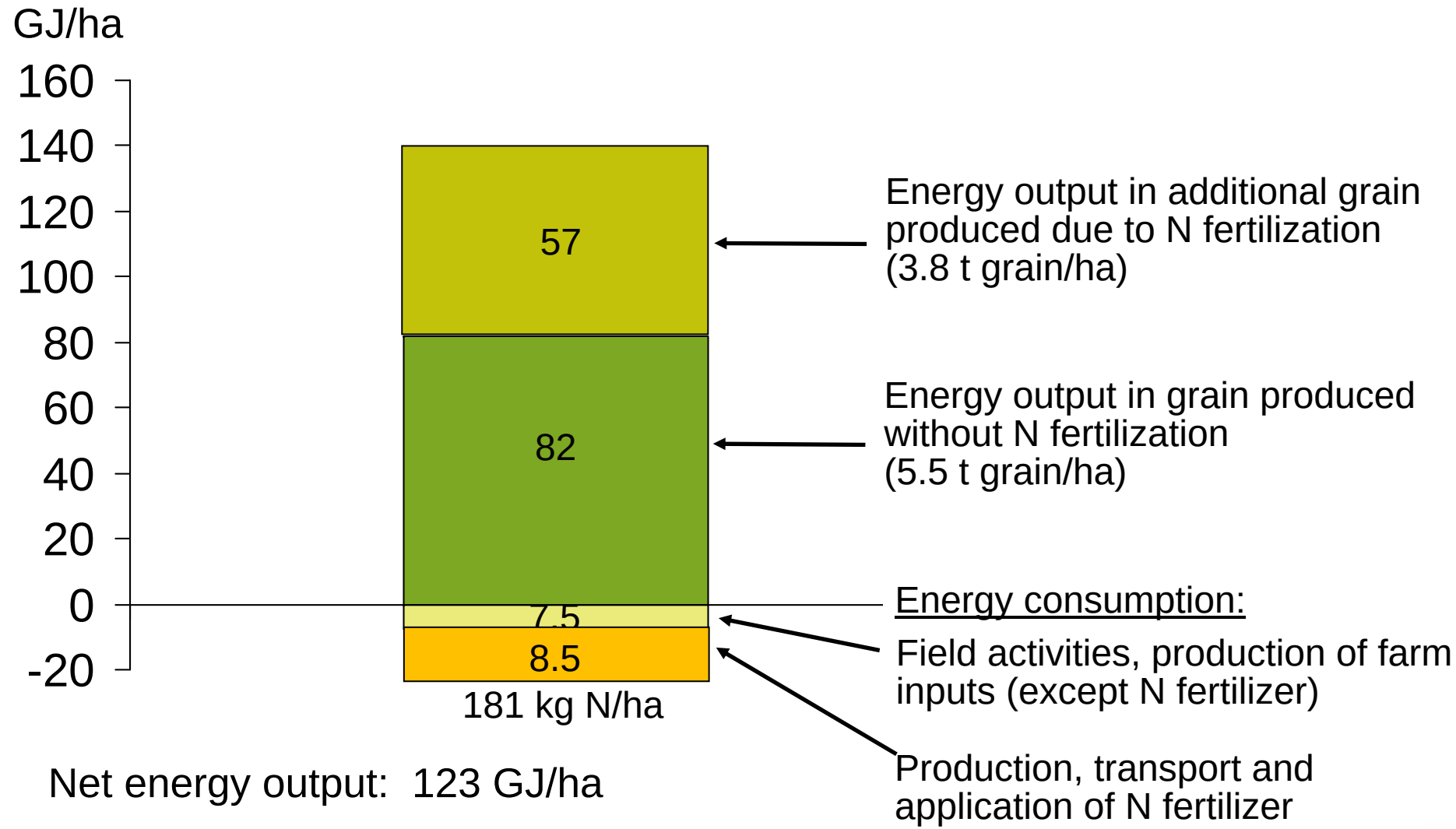
Energy balance of crop production at optimum N fertilizer application

- Example: wheat, data from 139 annual Yara field trials (Western Europe)

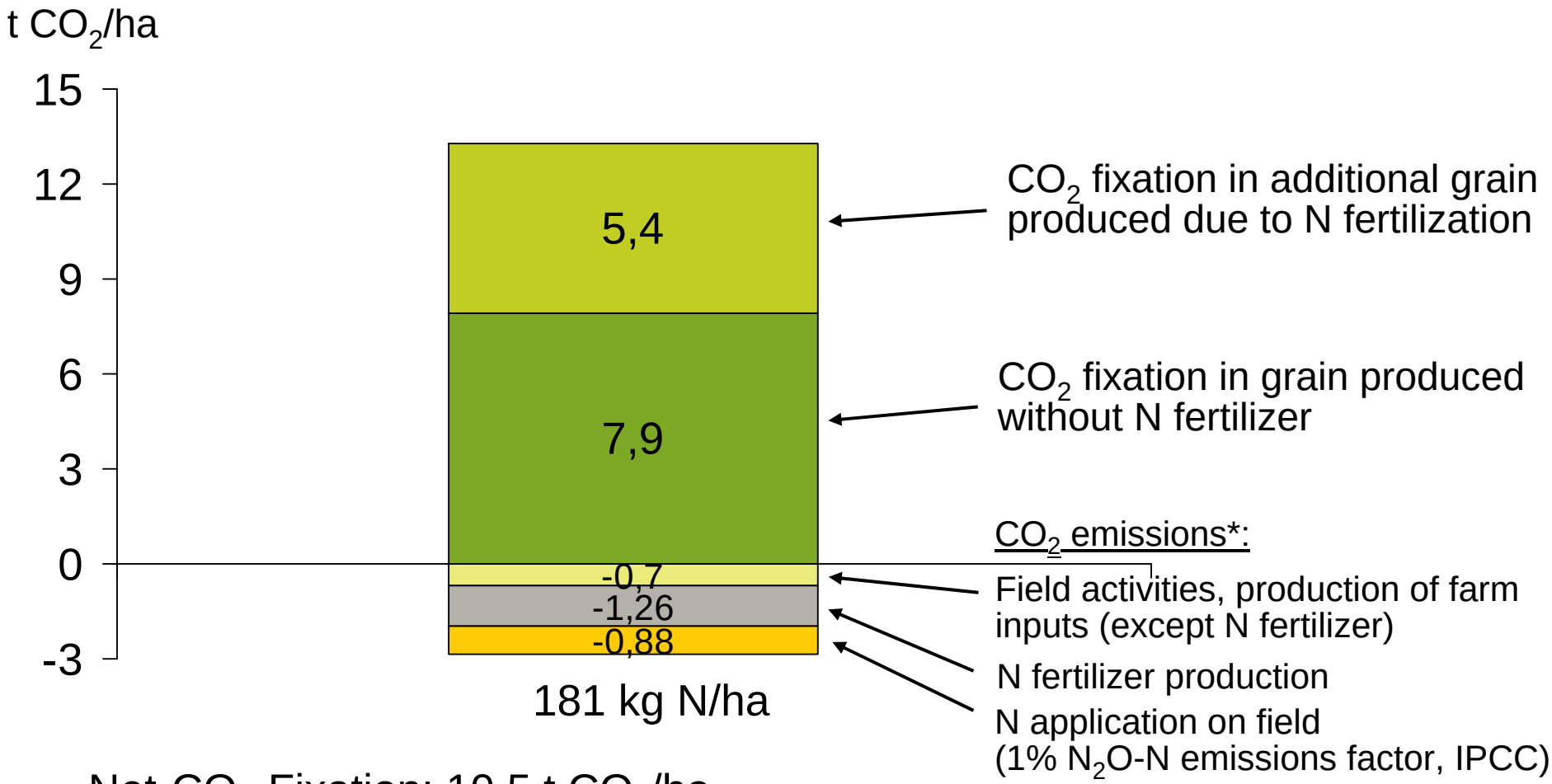


Net energy output: 123 GJ/ha

CO_2 balance of crop production at optimum N fertilizer application

- Example: wheat, data from 139 annual Yara field trials (Western Europe)

One ton of wheat (fm) fixes 1.42 tons of CO_2.



Net-CO_2-Fixation: 10.5 t CO_2/ha

* inkl. N_2O (1 kg N_2O = 310 kg CO_2)

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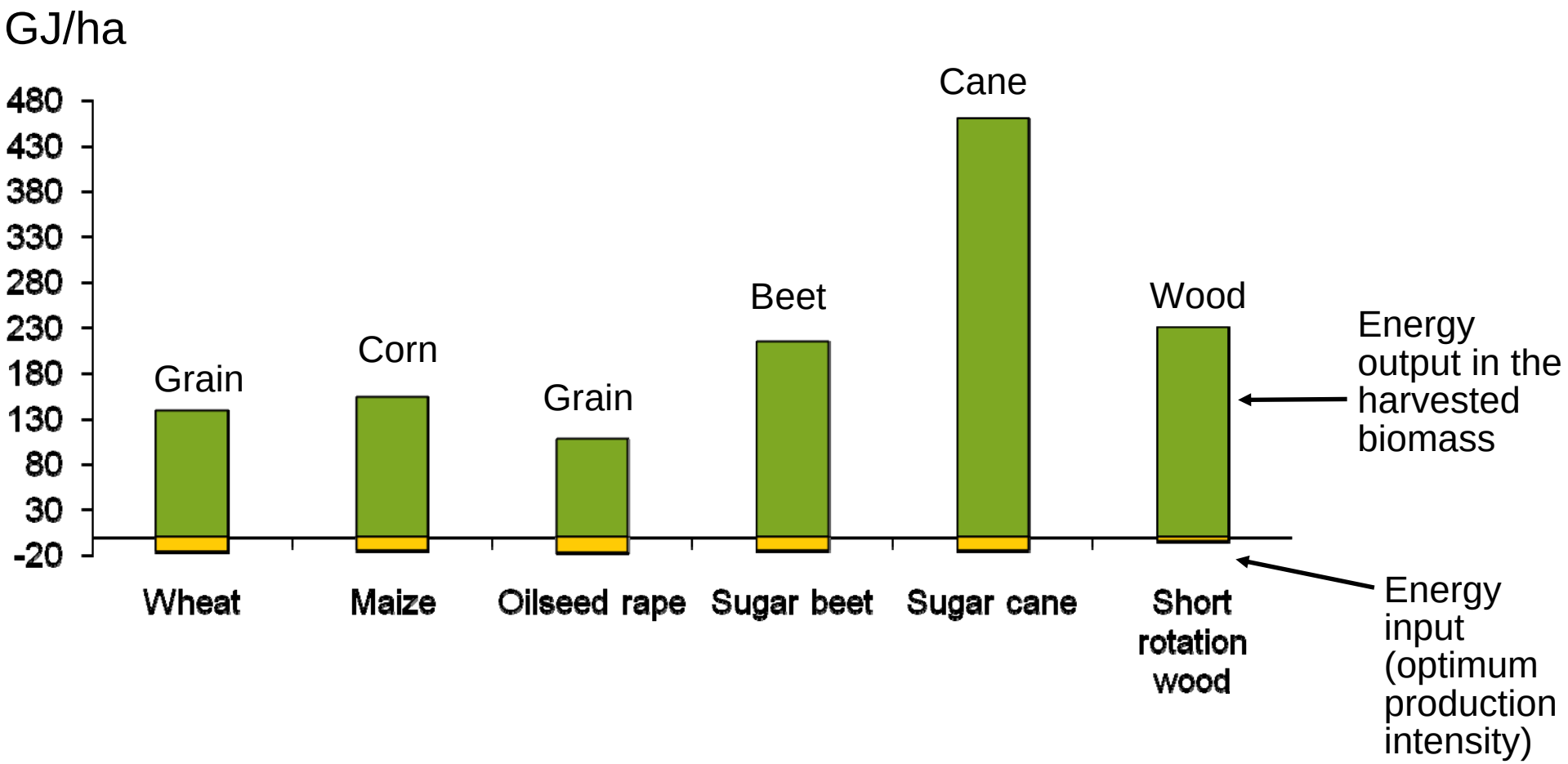
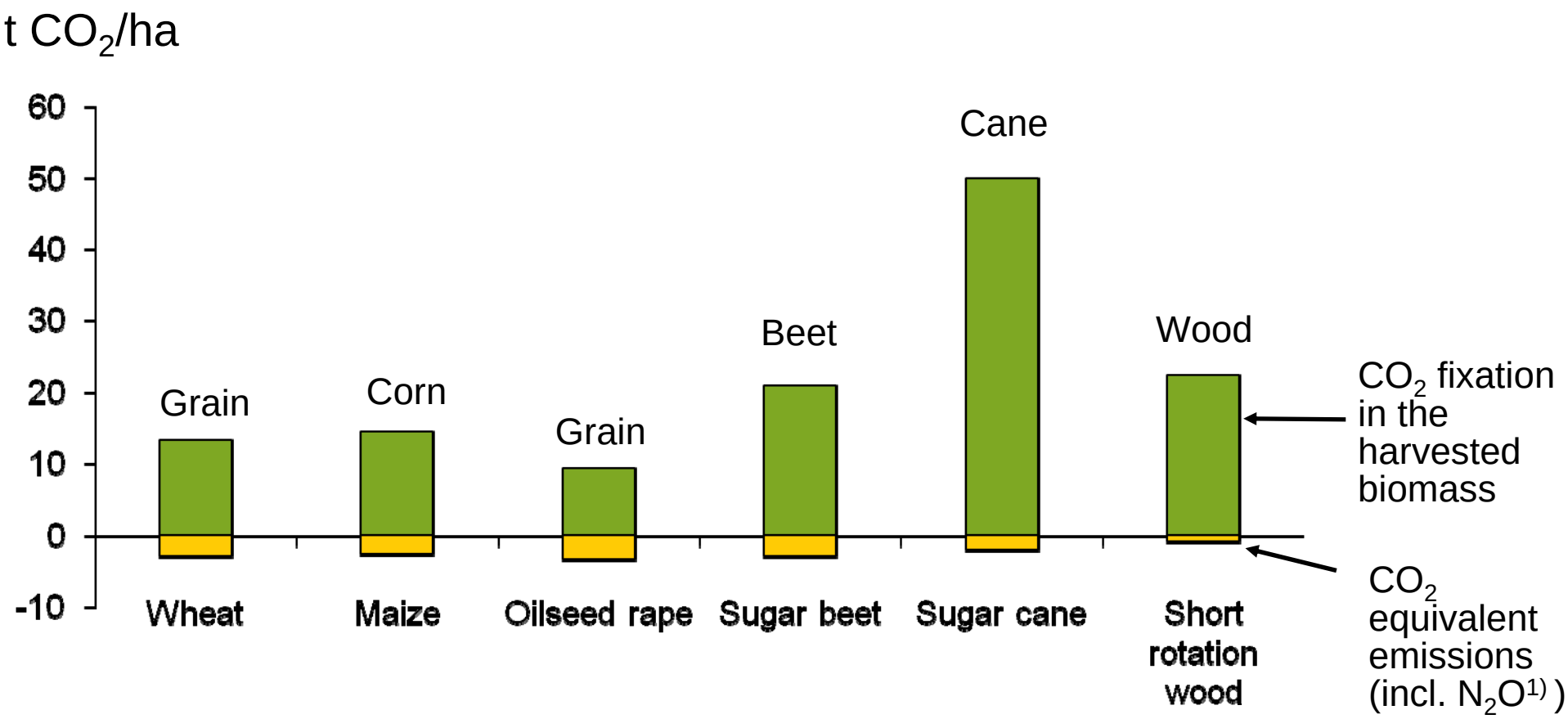
Comparison of the energy balance of the production of different crops



Source: Calculations from field trial data and literature

Comparison of the CO_2 balance of the production of different crops



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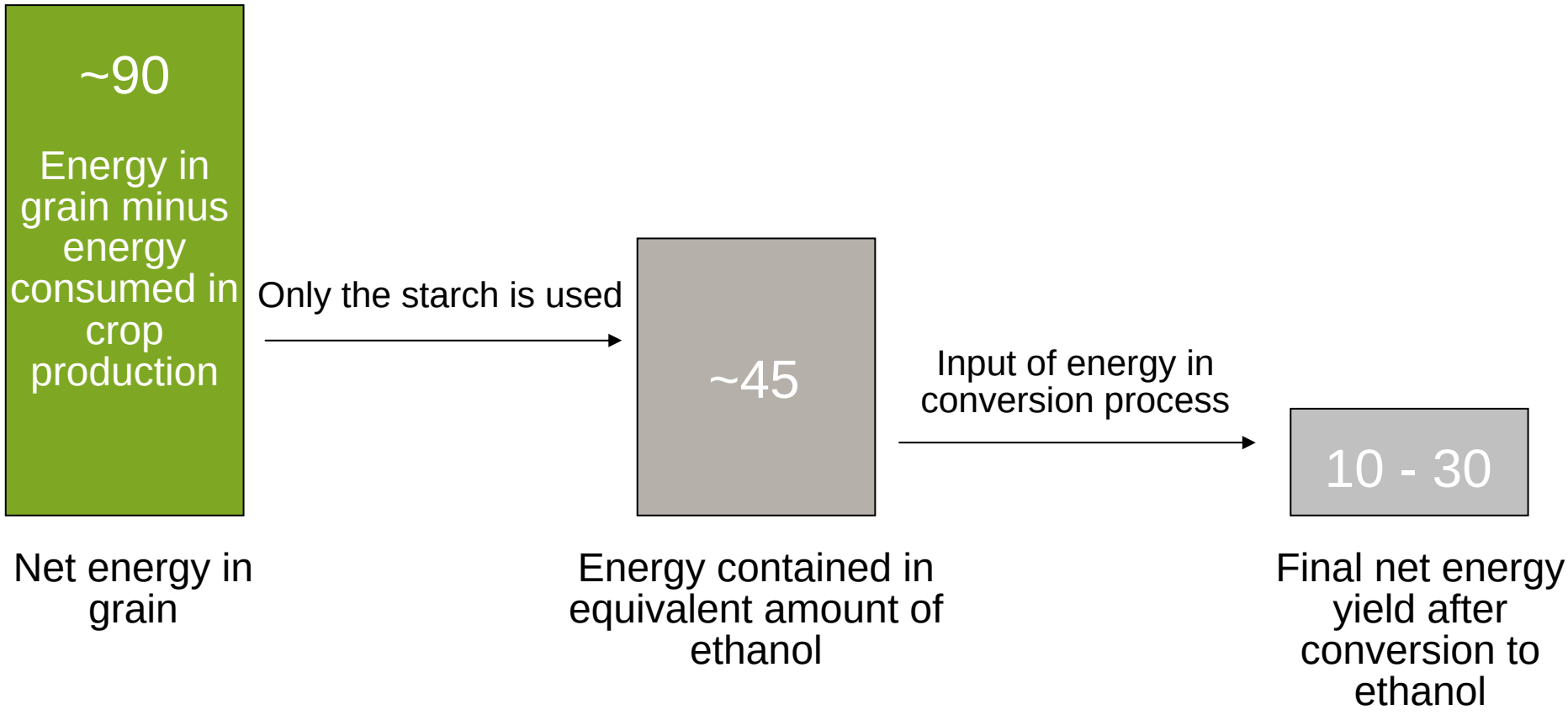
Theoretical gross energy yield of bio-fuels
- in l fossil fuel equivalents per ha

	Biomass yield (t/ha)	Yield of fossil fuel equivalents (l/ha)
Bio-ethanol		
Cereals	6 – 10 t grain	1500 – 2500
Sugar beet	50 – 70 t beet	3500 – 4900
Sugar cane	70 – 110 t cane	4000 – 6300
Bio-diesel		
Oil seed rape	3 – 5 t grain	1250 – 2100
Oil palm	20 – 25 t FFB [1)]	2500 - 4000

1) FFB = Fresh fruit bunches
2) Short rotation wood

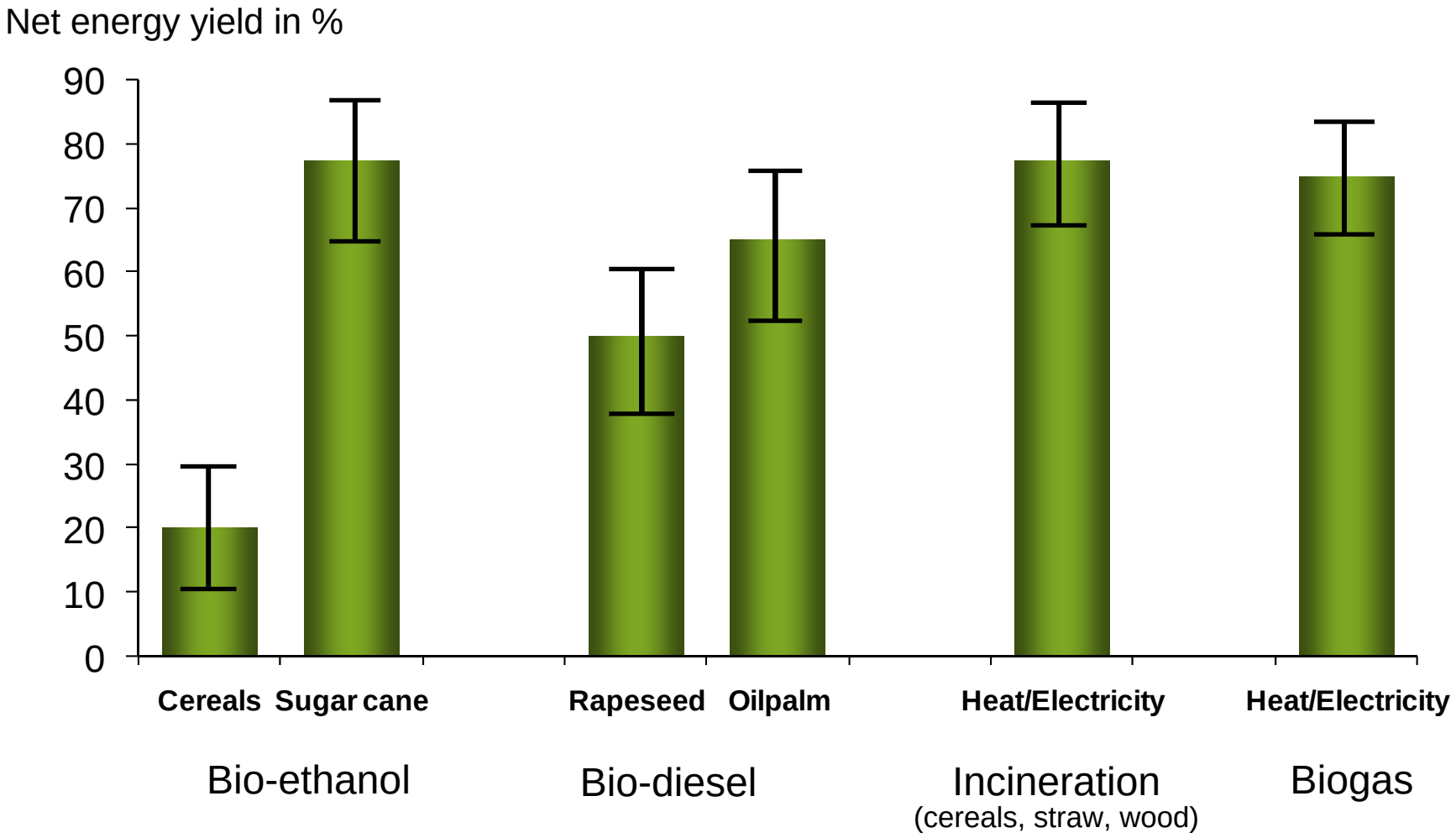
Net energy yield of the production of bio-ethanol

- Example: Conversion of wheat grain into bio-ethanol (relative, total energy in grain = 100)

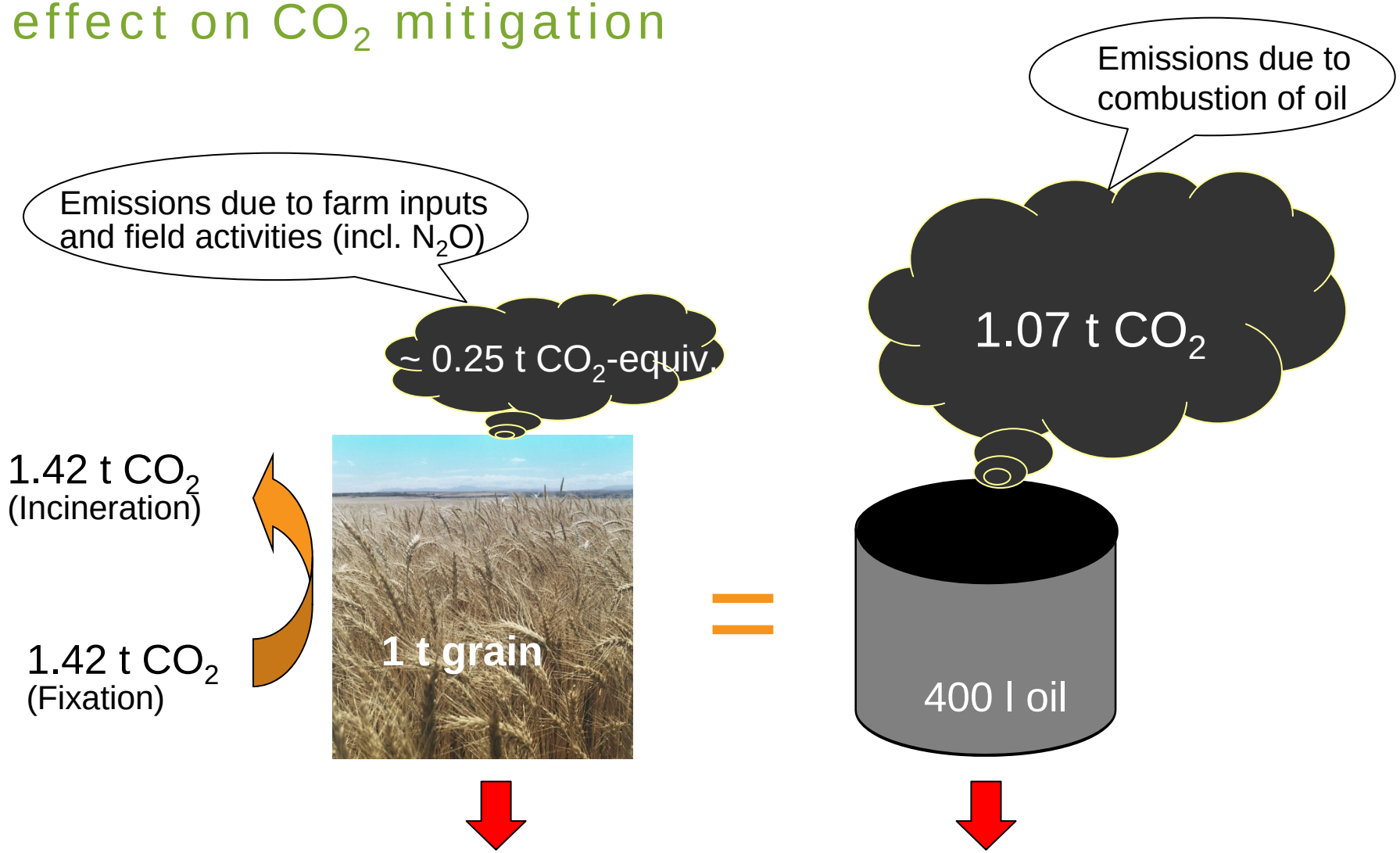


Net energy yield of different bio-energy forms

(relative, energy in biomass minus energy input in agriculture and conversion)



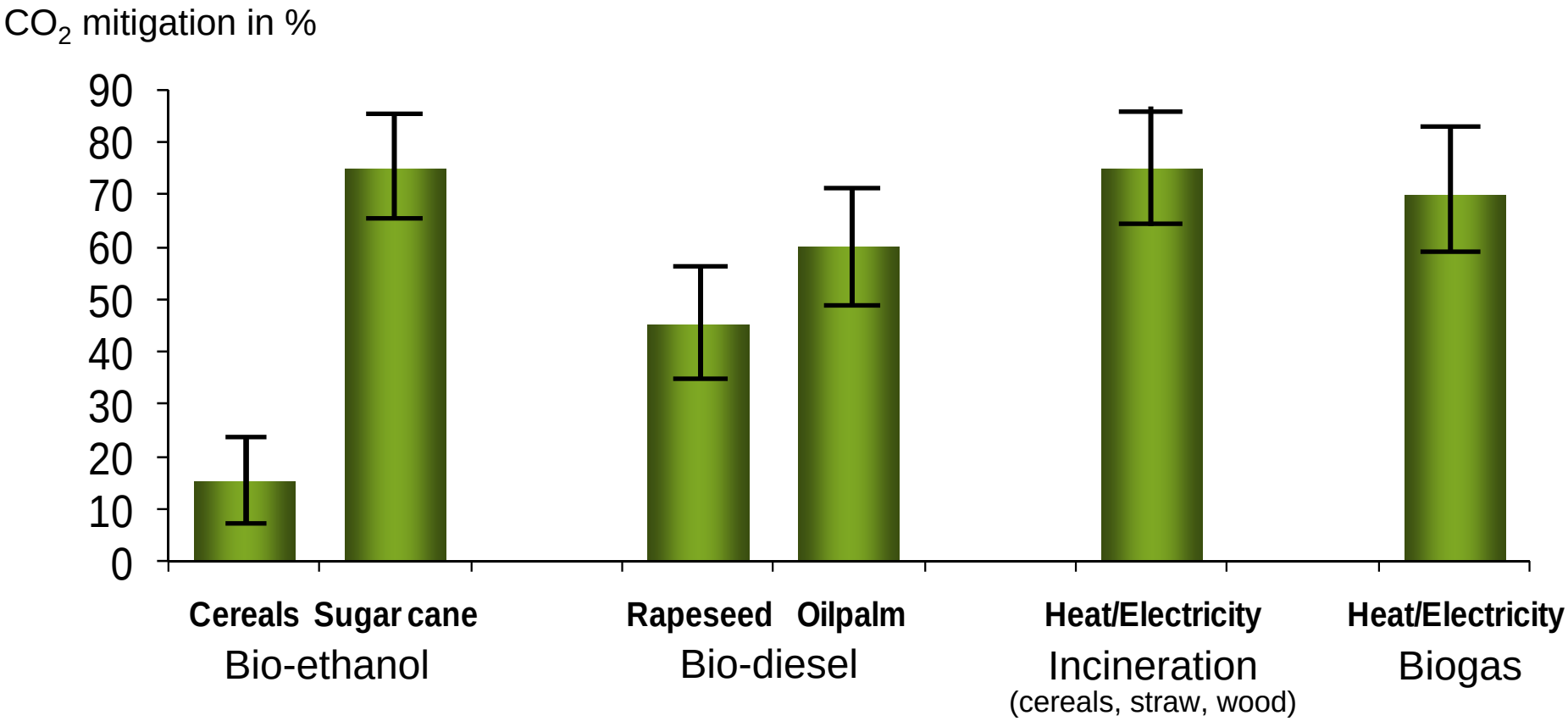
Incineration of wheat grain to produce heat: effect on CO_2 mitigation



Net avoidance: ~0.82 t CO_2 per t of grain (= 77% of fossil CO_2 emissions)

CO_2 mitigation potential of different bio-energy forms

(if bio-energy replaces fossil fuels)



Mitigation potential increases, if by-products were used as animal feed products (e.g. DDGS).

Mitigation potential decreases significantly, if natural eco-systems were taken into production for bio-energy crops (e.g. rainforest clearance for oil palm leads to a negative CO_2 balance).

Summary

- The energy and CO_2 balance of arable crop production is positive.
- The application of mineral fertilizers at optimum rate improves the balance further.
- The energy and CO_2 balance of the bio-fuel production (conversion of crop into fuel) depends on the conversion technology.
- Bio-ethanol from sugar cane and the production of heat and power from the incineration of biomass and biogas have the highest potential to save energy and to mitigate CO_2 emissions.
- The use of by-products (e.g. as animal feed) will improve the energy balance and the CO_2 balance.
- Land use changes (e.g. cutting of rain forest) or burning of the residues (e.g. cane straw) will deteriorate the CO_2 balance.

Backup slides

Harvested biomass contains a considerable amount of energy

- Example wheat grain

Energy yield of 1 t wheat:

15 GJ	~ 400 l oil	~ 4400 kWh

Bio-energy production and food or feed production compete for arable crops and arable land

1 t wheat:

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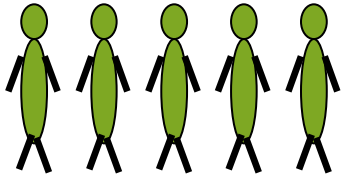

Nutritional energy for 5 persons per year (FAO)

OR

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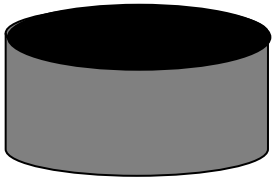
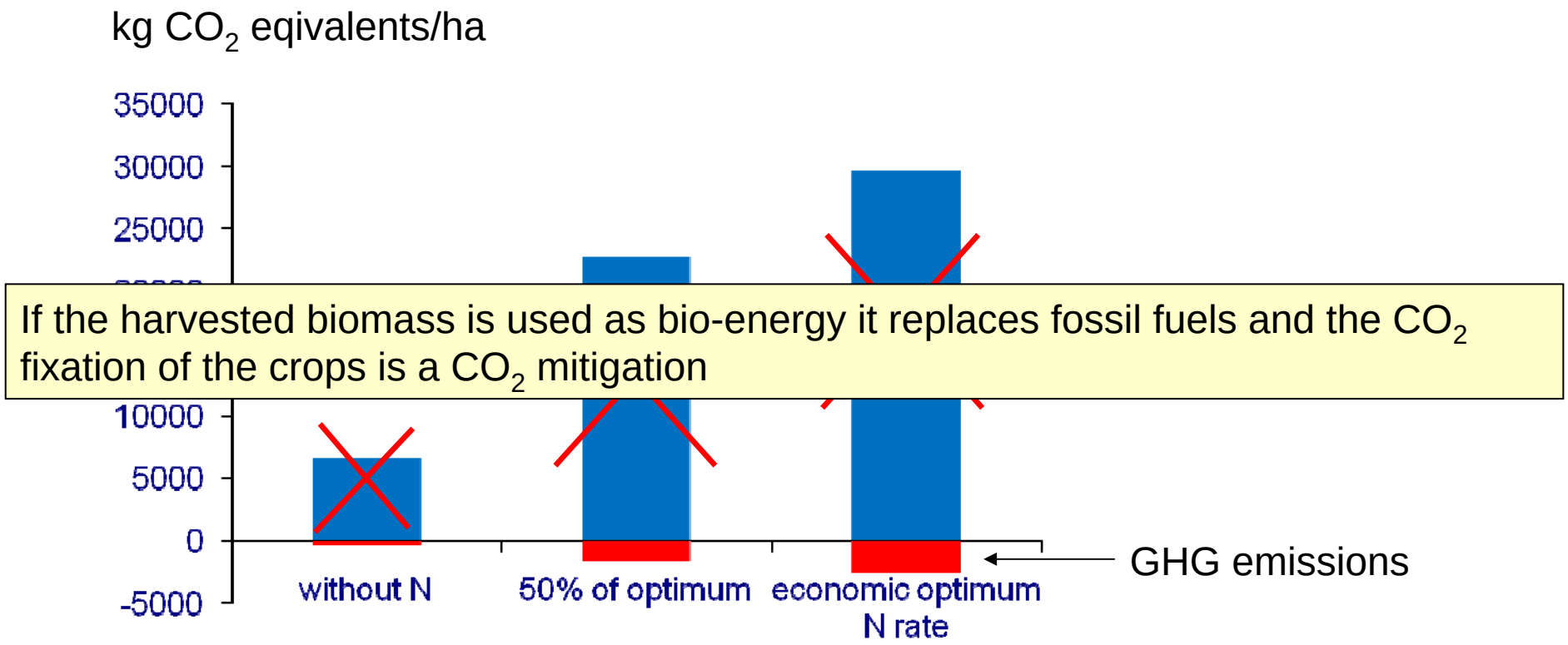


400 liters of oil

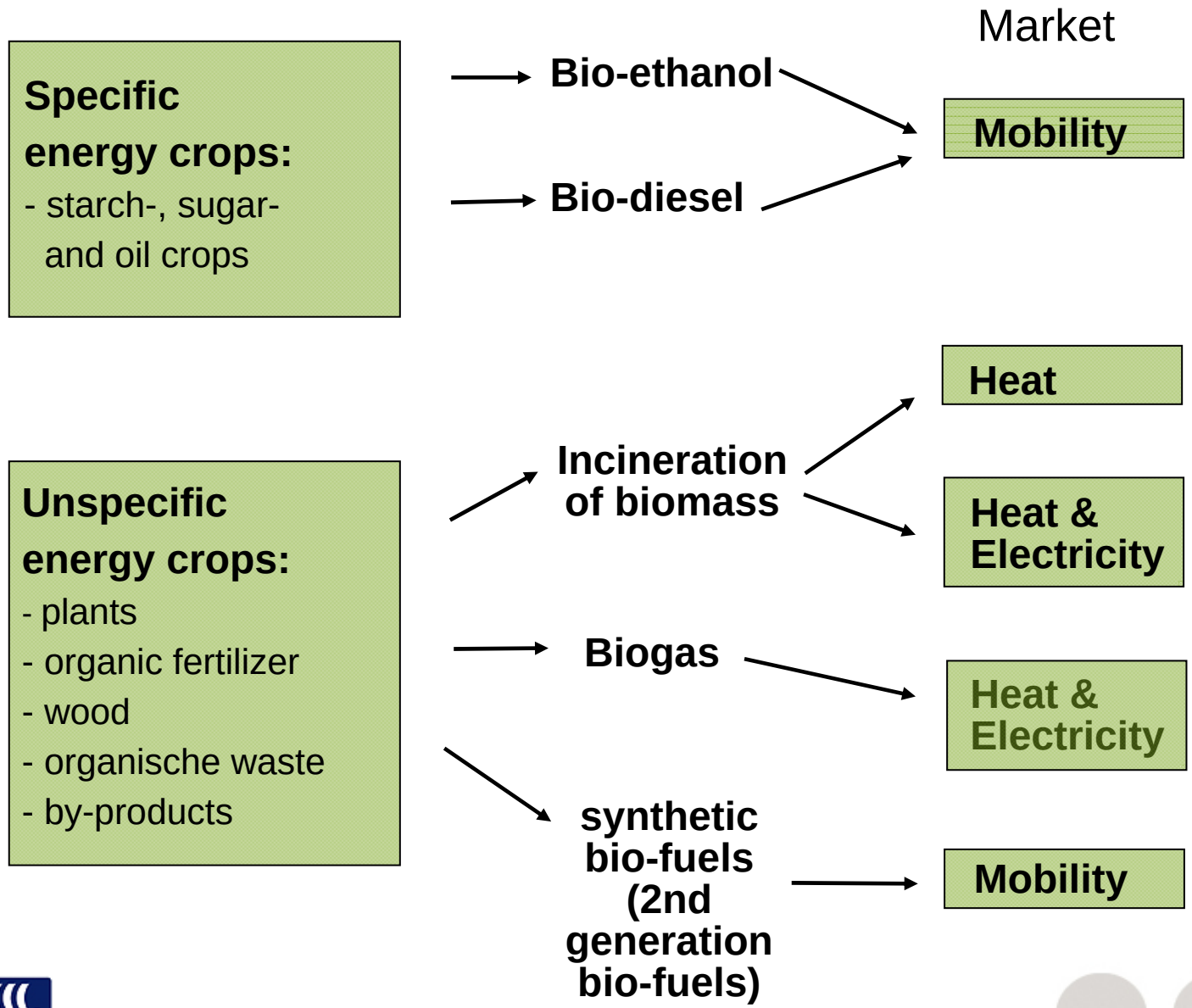
- Arable land is a scarce resource. How can this competition be solved?
  - Improvement of the crop production intensity on the available land
  - Development of 2nd generation bio-fuels that use by-products as feedstock
  - Use of non-agricultural sources such as wood for bio-energy production

Until harvest the CO_2 balance of crop production is positive and enhanced by N fertilizer use



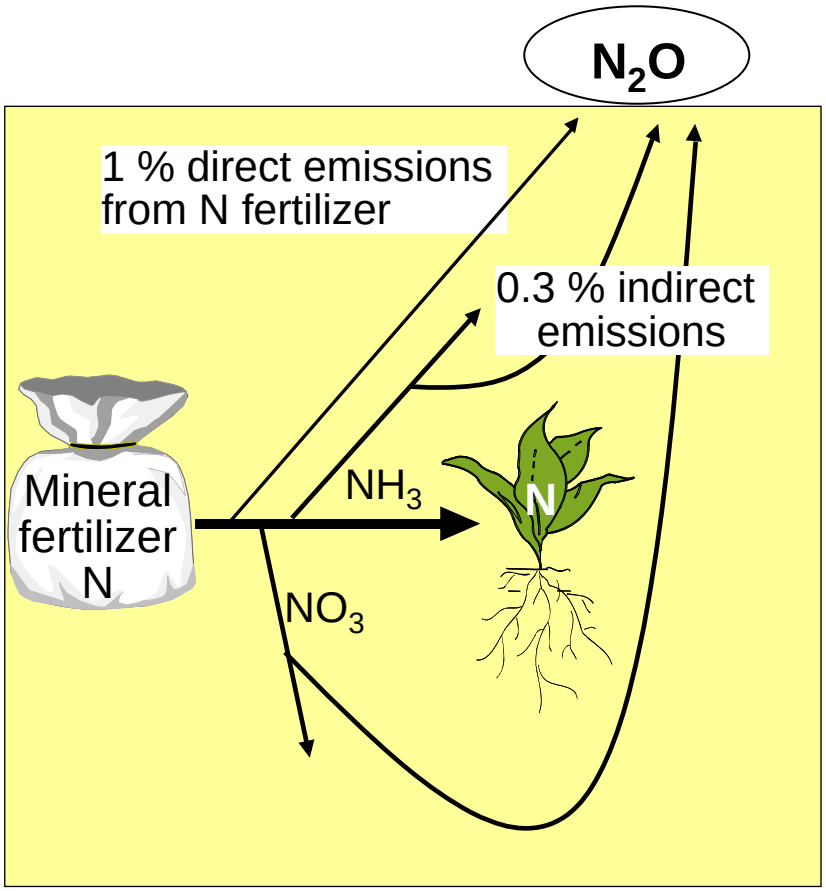
Routes of bio-energy production

- schematic, simplified



N_2O emissions from N fertilizer use in arable production systems

Emissions allocated to N fertilizer (according IPCC-Tier1): 1.3% N_2O-N



Fertilizer specific IPCC emissions factor: 1.0% N_2O-N for calcium ammonium nitrate

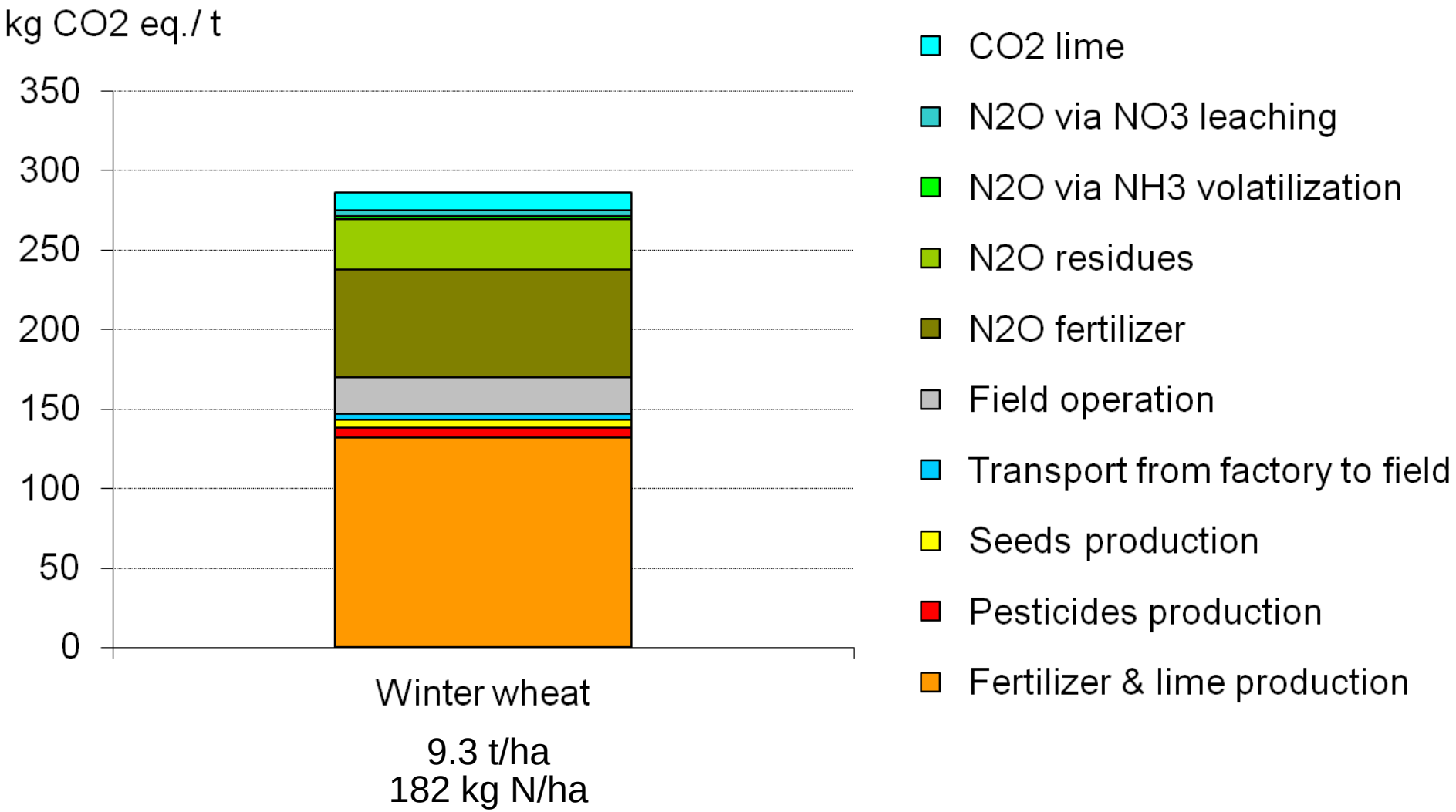
The potential of different bio-energy forms to save energy and to mitigate CO_2

- land use changes and use of by-products not considered

	Energy saving (in %, compared to fossil fuel)	**CO_2 emission savings (in %, compared to fossil fuel)**
Bio-ethanol		
- Cereals	10 – 35 %	max. ~ 30 % [1)]
- Sugar cane	70 – 85 %	70 – 80 %
Bio-diesel		
- Oil seed rape	40 - 60 %	30 – 50 %
- Oil palm	55 - 75 %	50 – 70 %
Incineration of biomass		
- heat or heat/electricity	70 – 85 %	70 – 80 %
Biogas (Silage maize, slurry)		
- heat/electricity or gas fed into public grid	70 – 80 %	~ 70 %

1) Liska et al. (2009): CO_2 mitigation of 48 – 60% in case of using very modern technology and of using by-products as feed products (Maize, USA)

„Carbon footprint“ of 1 ton of winter wheat



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Straw (Cellulose, 2nd gen.)	3 - 4 t straw	670 - 900
Bio-diesel		
Oil seed rape	3 – 5 t grain	1250 – 2100
Oil palm	26 – 25 t FFB 1)	2500 - 4000
Wood 2) (BTL-diesel, 2nd gen.)	10 – 15 t dry wood	2600 – 3900

1) FFB = Fresh fruit bunches
2) Short rotation wood