Measuring carbon neutrality:
Is my bioenergy system carbon neutral?

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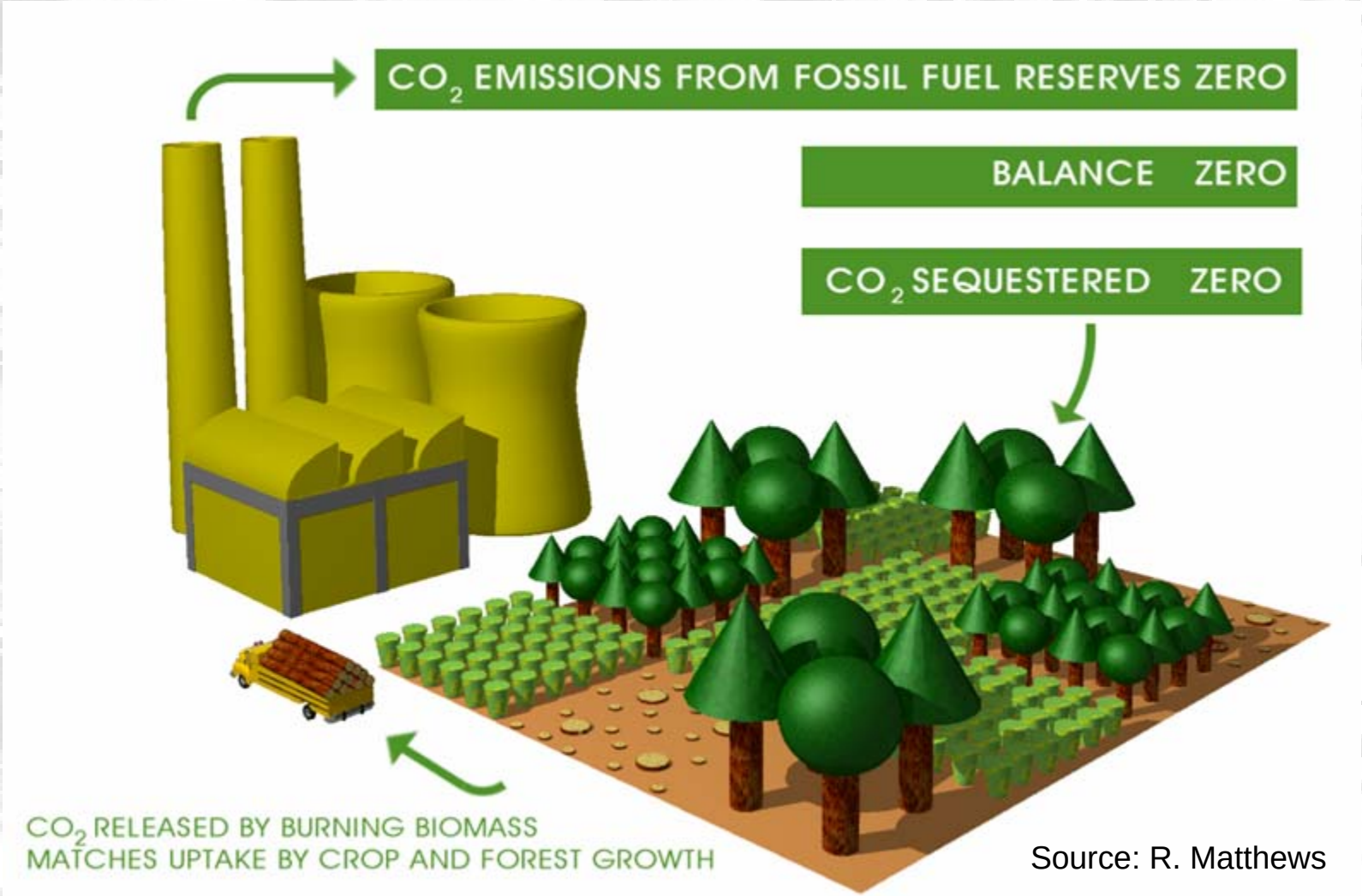
Bioenergy: carbon neutral ?



Source: R. Matthews

Fossil-fuel inputs

- Energy inputs for biomass fuels from ag or forestry residues: 2-5% of energy content
- Dedicated energy crops and refined fuels (e.g., pellets): around 10%
- Liquid biofuels significantly higher, studies differ considerably (15 – 70%)
- How close to carbon neutral is my system?

Calculating the benefits of bioenergy

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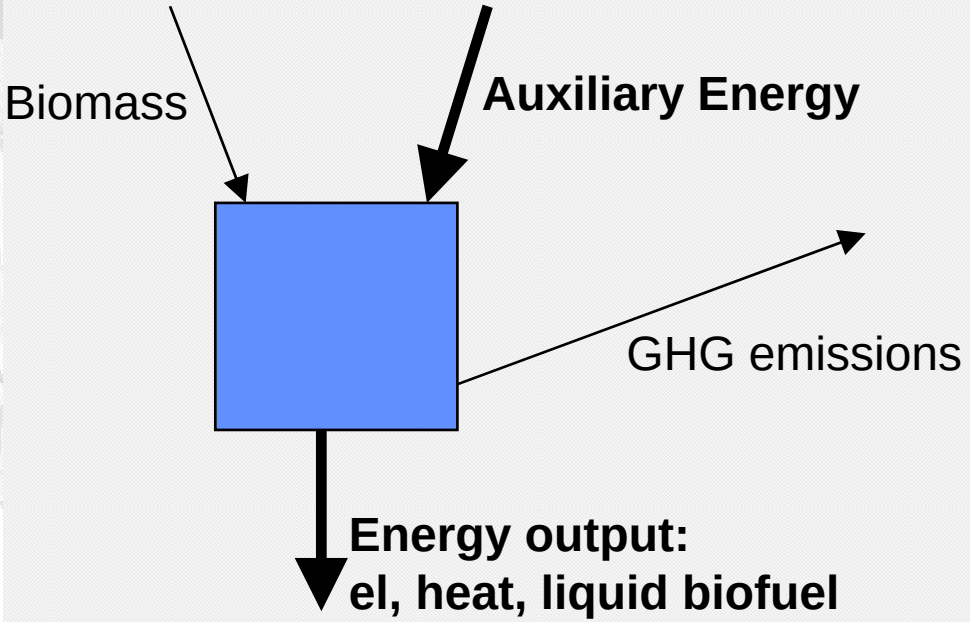
- input-output ratio -
  energy invested per unit energy delivered

“Net energy yield”
“Energy return on investment”
“Net energy value”



Misleading
Irrelevant

Calculating the benefits of bioenergy

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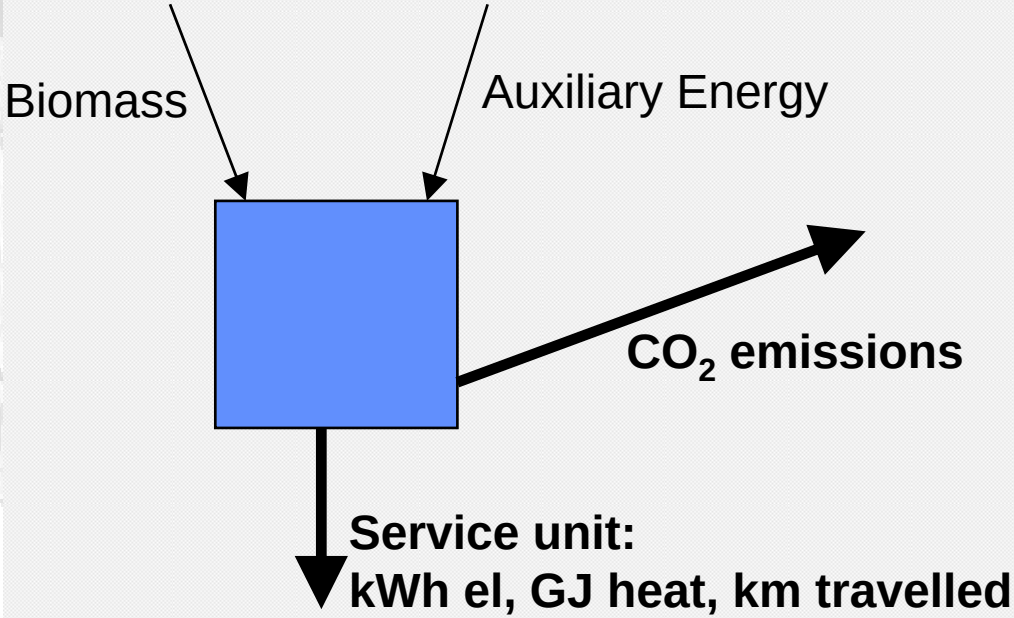
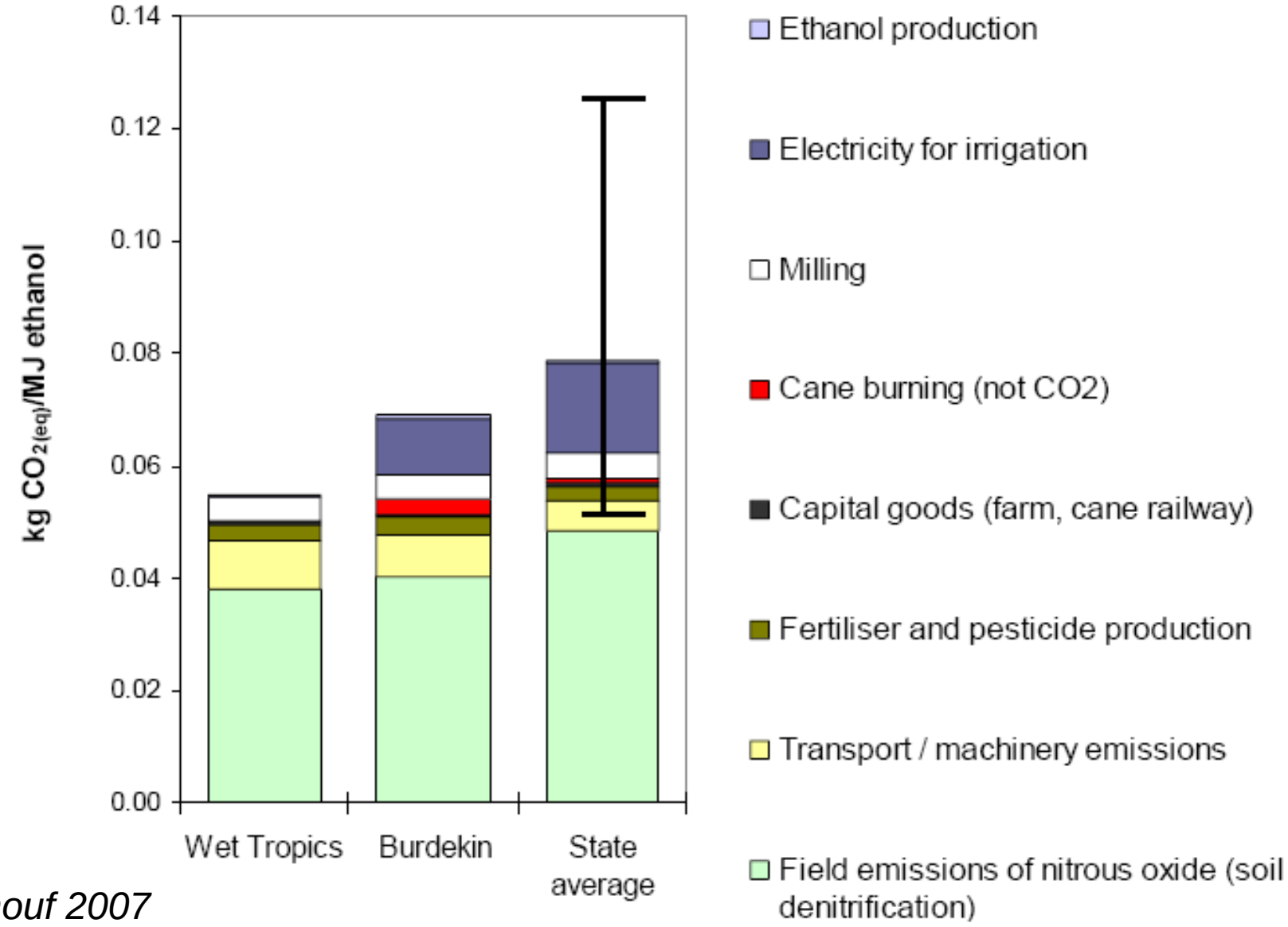
- Emissions intensity:
- CO_2 emissions per unit *useful output* (kWh electricity, GJ heat, GJ biofuel, km travelled)



CO_2 is not the whole story

- Non-CO_2 GHG can be significant

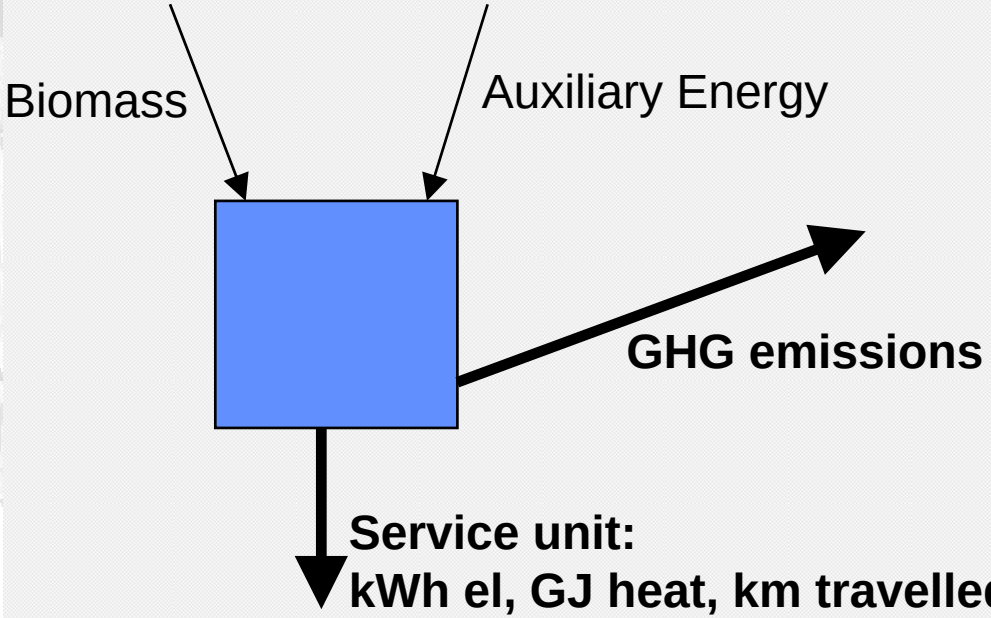
Greenhouse gas emissions



Renouf 2007

CO_2 is not the whole story

- Non-CO_2 GHG can be significant
- Emissions intensity: *GHG emissions* per unit output



Consider carbon stock change

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- Adjust emissions intensity for C stock change in biomass or soil
- GHG emissions & removals per unit output
- Approaches 0 if carbon neutral
- <0 if C stocks increasing

Carbon quotient

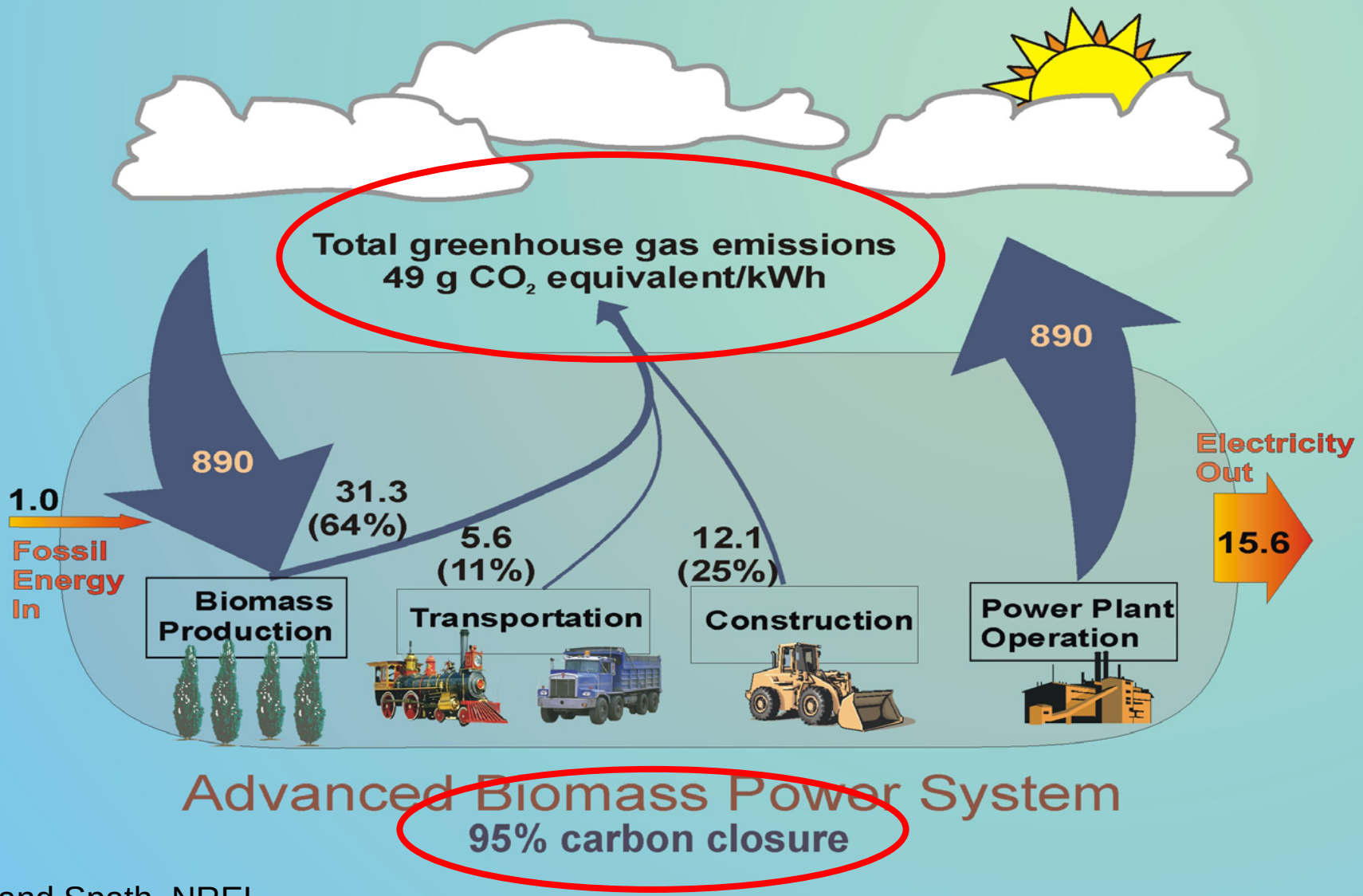
- Carbon quotient = $\frac{\text{C sequestered}}{\text{GHG emitted}}$
- Approaches 1 if carbon neutral
- Includes stock change in biomass and soil
- Exceeds 1 if biomass or soil pools increasing

Carbon closure

- *Mann and Spath NREL*
- Includes avoided emissions
- Carbon closure = $\frac{CO_2 \text{ sequestered } \textit{or avoided}}{CO_2 \text{ emitted}}$

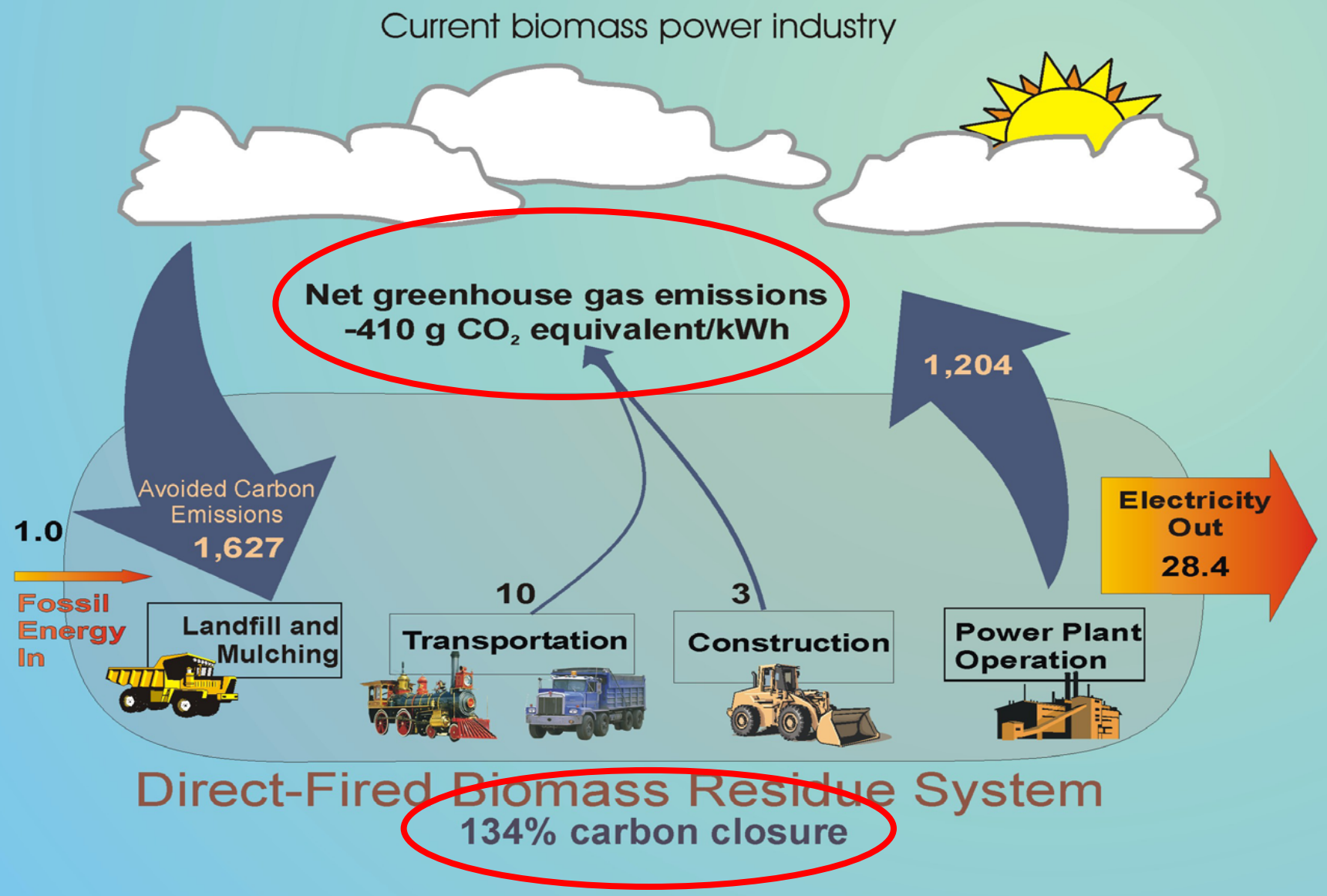
Life Cycle GWP and Energy Balance for Advanced IGCC Technology using Energy Crop Biomass

Future, wide-spread potential



Mann and Spath, NREL

Life Cycle GWP and Energy Balance for a Direct-Fired Residue-Biomass Power System



Mann and Spath, NREL

Simple measures can be misleading:

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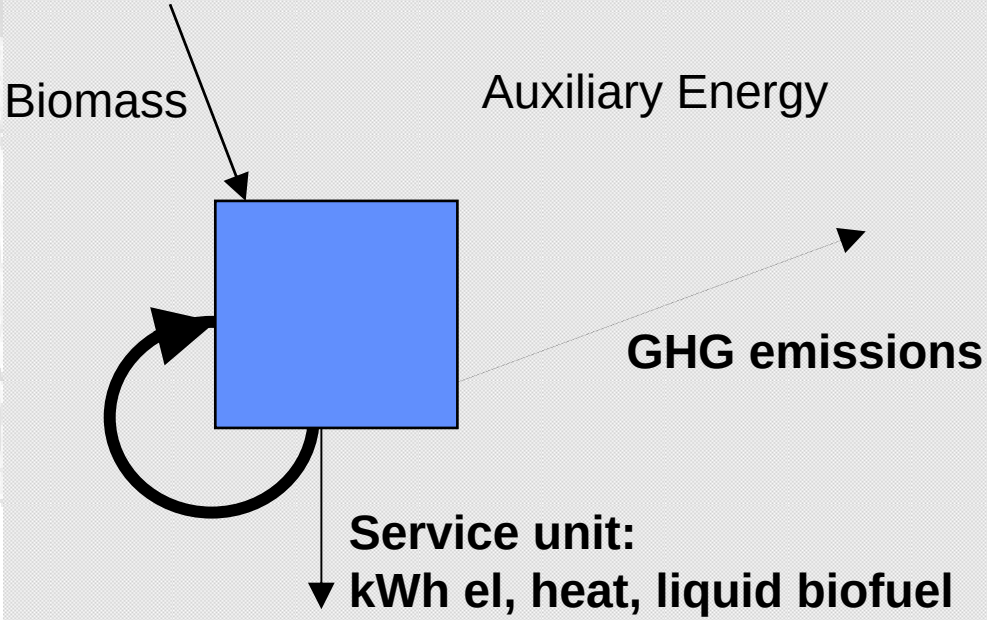
- emissions per unit output can be manipulated



Expand system boundary: consider fossil reference system

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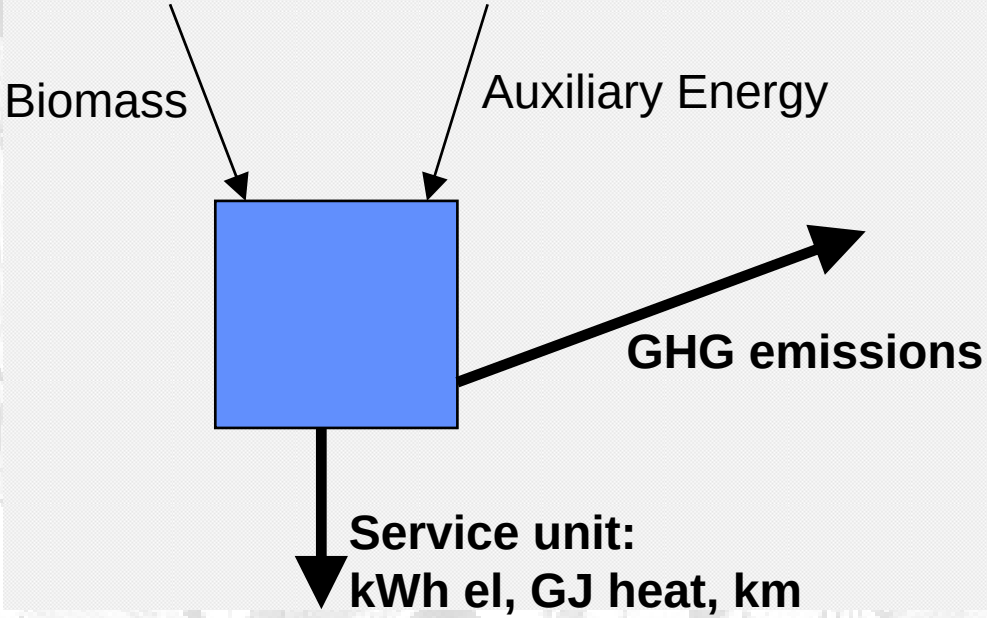
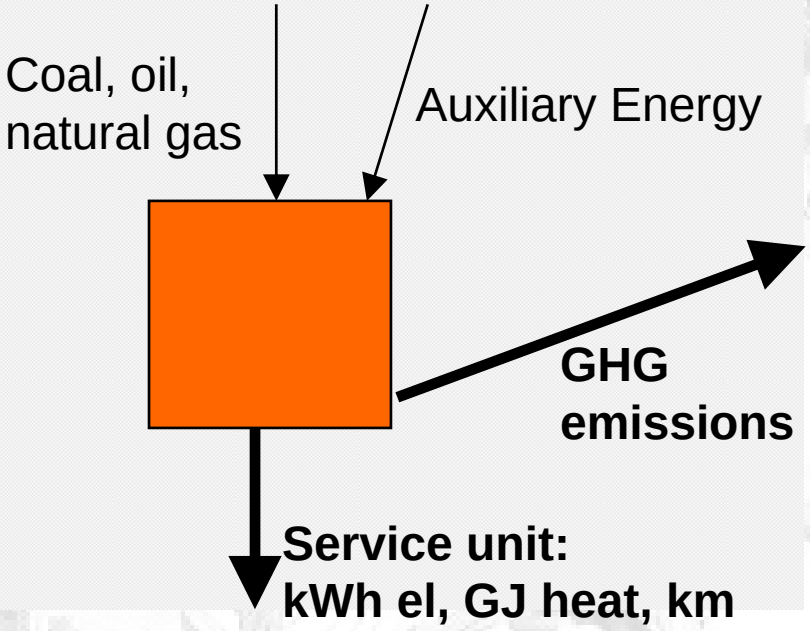
- *Emission reduction* per unit useful output





Carbon neutrality

- *Schlamadinger et al 1995*
- CN = $\frac{\text{Reference emissions} - \text{Bioenergy emissions}}{\text{Reference emissions}}$
- Approaches 1 if carbon neutral
- Exceeds 1 with sequestration or avoided emissions

Consider limiting resource

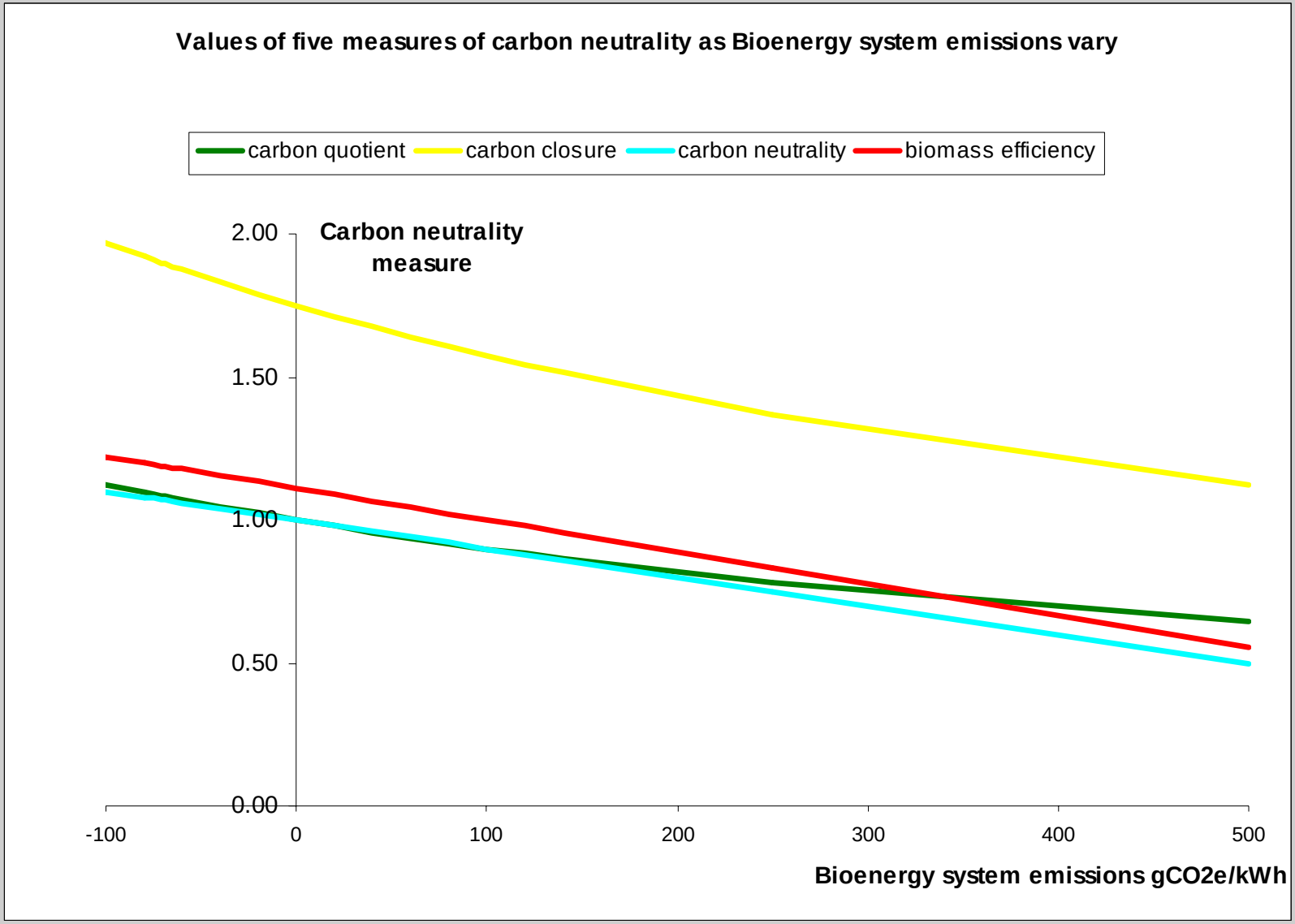
- Biomass
- Land
- Dollars

- Emission reduction per unit limiting input

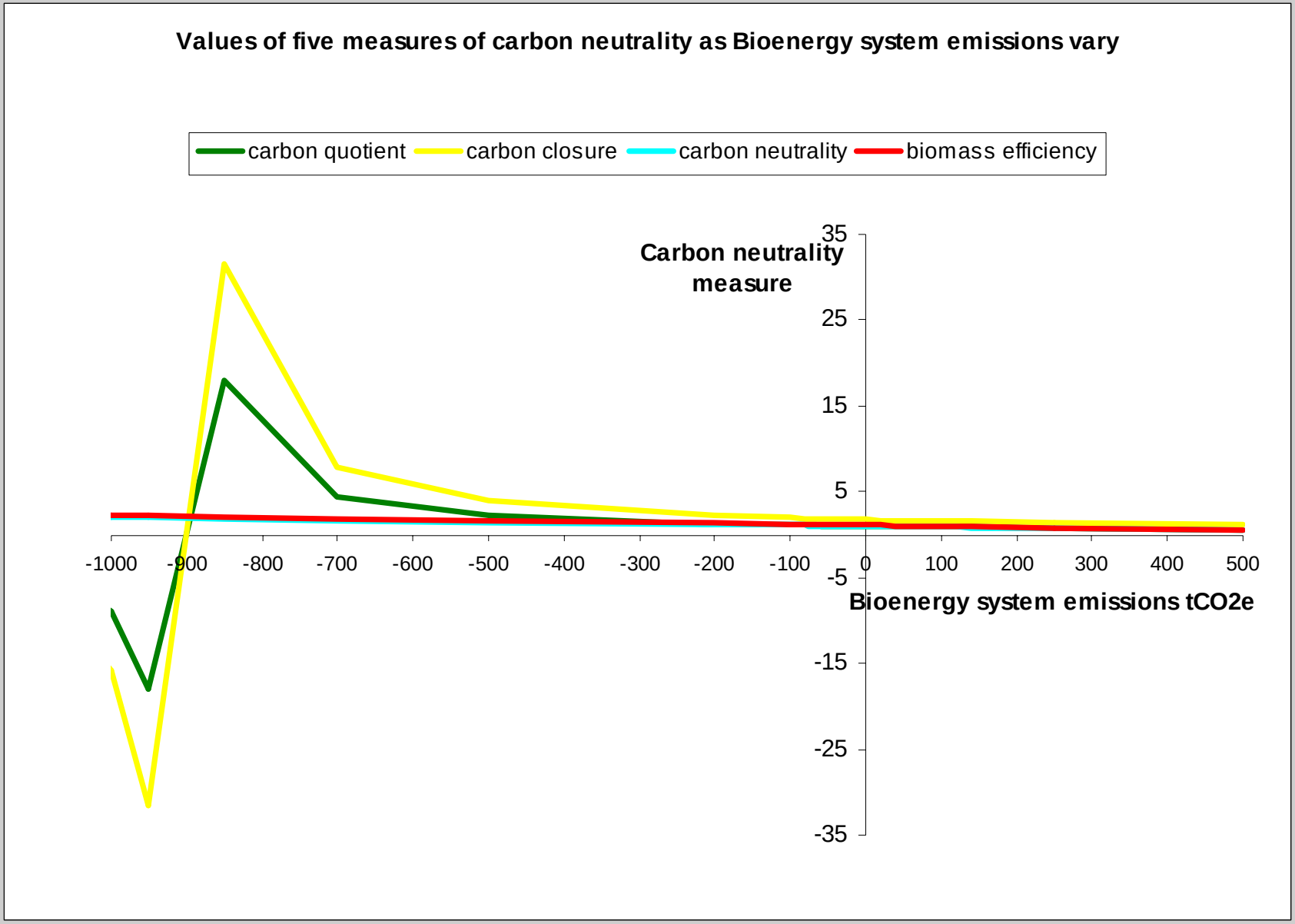
- Biomass efficiency = $\frac{\text{Emissions reduction}}{\text{Biomass C (as CO2e)}}$

A theoretical example:

1 kWh electricity from 900g CO_2e biomass combusted,
cf reference system 1000g CO_2 e
landfill emission 675 gCO_2e



Testing the logic



Measuring carbon neutrality?

- Simple metrics are not useful
- Can be misleading
- Don’t tell whole story
- “Is my bioenergy system carbon neutral?”
- Wrong question!

Methodology for measuring GHG benefit

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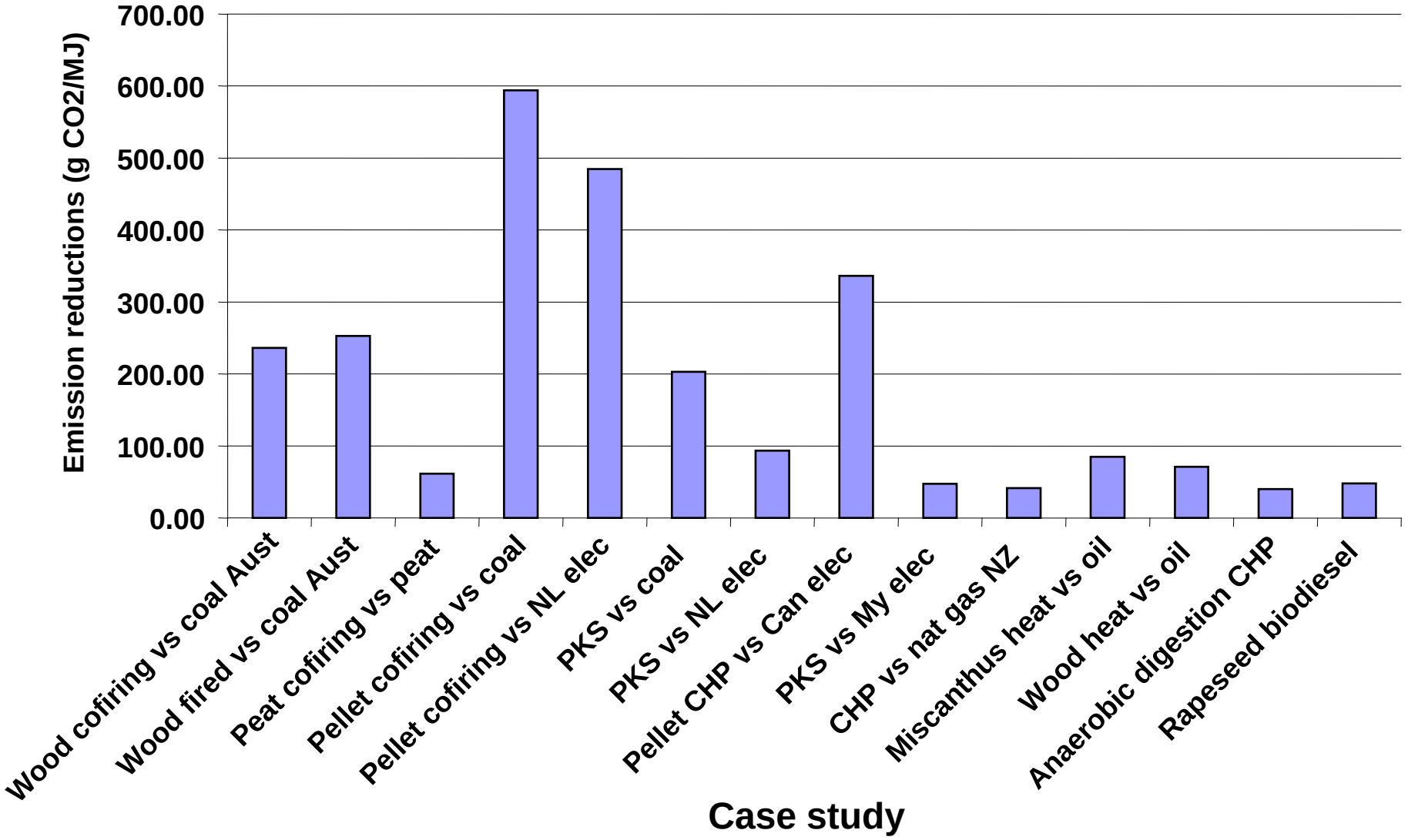
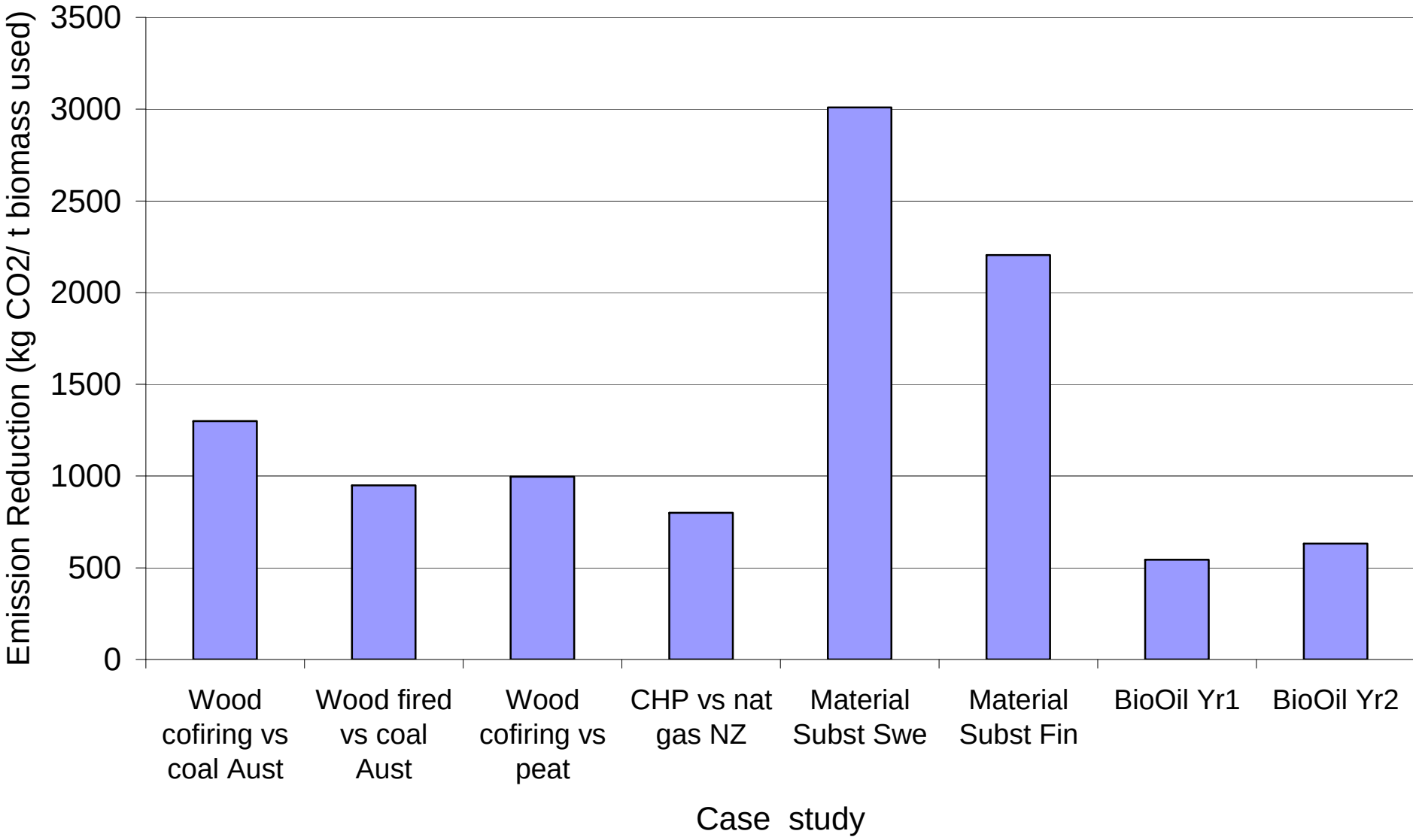
- Compare project with reference
- Consider whole system life cycle
  - Direct and indirect emissions
- System boundary
  - Deliver equivalent service
  - All greenhouse gases CO_2 and non-CO_2
- C stock change in biomass,soil pools
- Emissions reduction per unit limiting resource
- Result is specific to each situation

Task 38 Case studies



Task 38 Case studies



Task 38 LCA paper

Bioenergy system	t CO2-eq. saved/ha
Ethanol - sugar cane	10 - 16
Ethanol - wheat	0.4 - 4.5
Ethanol - lignocellulose	2 - 7
Biodiesel - canola	0.5 - 1.5
Biodiesel - palm oil**	8 - 13
Bioelectricity - Wood chips/pellets	0.5 - 14
Bioelectricity - Giant reed	2 - 33
Heat - Wood chips/pellets	6 - 23
Heat - Giant reed	18 - 58

Task 38 , in prep

Key findings

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- GHG mitigation through bioenergy
  - → technology specific
  - → site specific
- Synergies/Trade-offs in land management
- Materials substitution, heat, CHP or co-firing applications tend to have greater benefits
- Some 1st generation biofuel systems have minimal greenhouse benefits
- Policy measures should distinguish and promote systems with highest mitigation benefit

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Greenhouse Gas Balances of Biomass and Bioenergy Systems

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