Life cycle assessment of biochar production from corn stover, yard waste, and switchgrass

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What is biochar?

without biochar with biochar

- Inspired by Terra Preta soils, or Amazonian Dark Earths, in regions of high soil fertility in the rainforest
- Biomass derived black carbon
- Co-product of low temperature pyrolysis

- Biochar co-benefits:
  - Soil amendment
  - Carbon sequestration mechanism
  - Bioenergy
  - Waste management

www.biochar-international.org

Biochar as a soil amendment

- Increasing the efficiency of traditional crop fertilizers, with an associated reduction of fertilizer use, nutrient runoff, and leaching [Lehmann *et al.*, Plant and Soil 249, 343 (2003)].
- Improving nutrient availability and soil water-holding capacity [Lehmann *et al.*, 2003].
- Avoiding and reversing soil degradation associated with long-term cultivation [Kimetu *et al.*, Ecosystem 11, 726 (2008)].
- Improving soil biological health through proliferation of beneficial microorganisms [Pietikäinen *et al*., Oikos 89, 231 (2000)].
- Offering sustainable benefits to soil health due to the long half-life of biochar, estimated to exceed one thousand years [Cheng *et al*., J. Geophys. Res. 113, G02027 (2008)].

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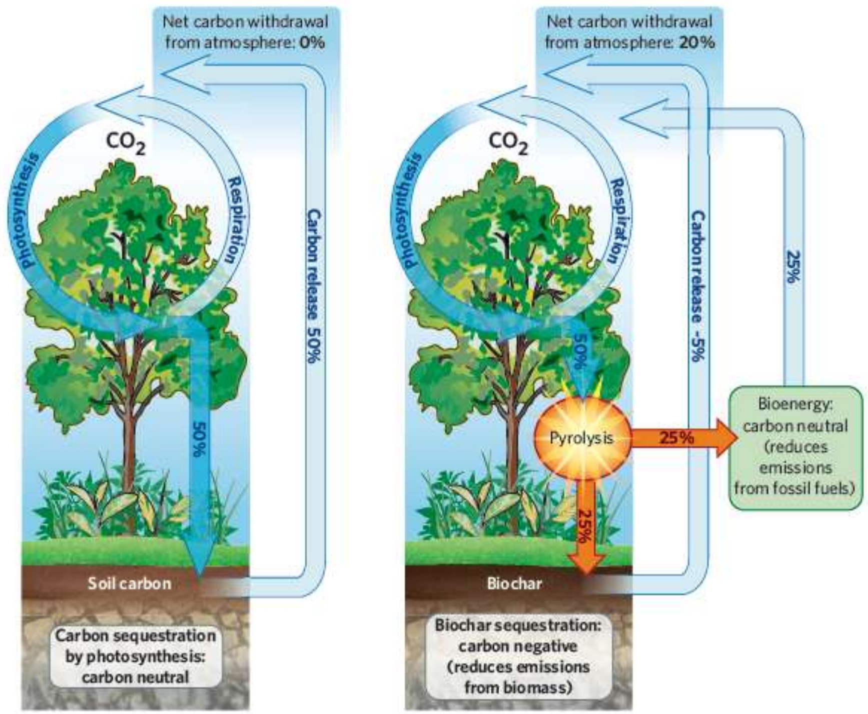
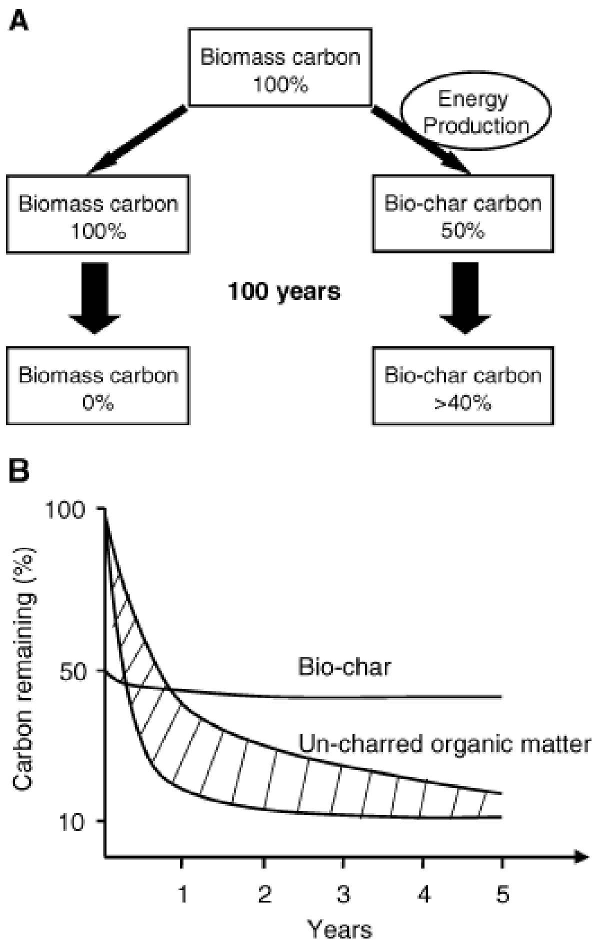
Biochar for carbon sequestration



Lehmann, Nature 447, 143 (2007)



Lehmann, Mitigation and Adaptation Strategies for Global Change 11, 403 (2006)

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Goals of the LCA

- To conduct a cradle-to-grave analysis of the energy, greenhouse gas, and economic inputs and outputs of biochar production at a large-scale facility in the US.
- To compare feedstocks (corn stover, yard waste, switchgrass).

Functional unit

- The management of one tonne of dry biomass.

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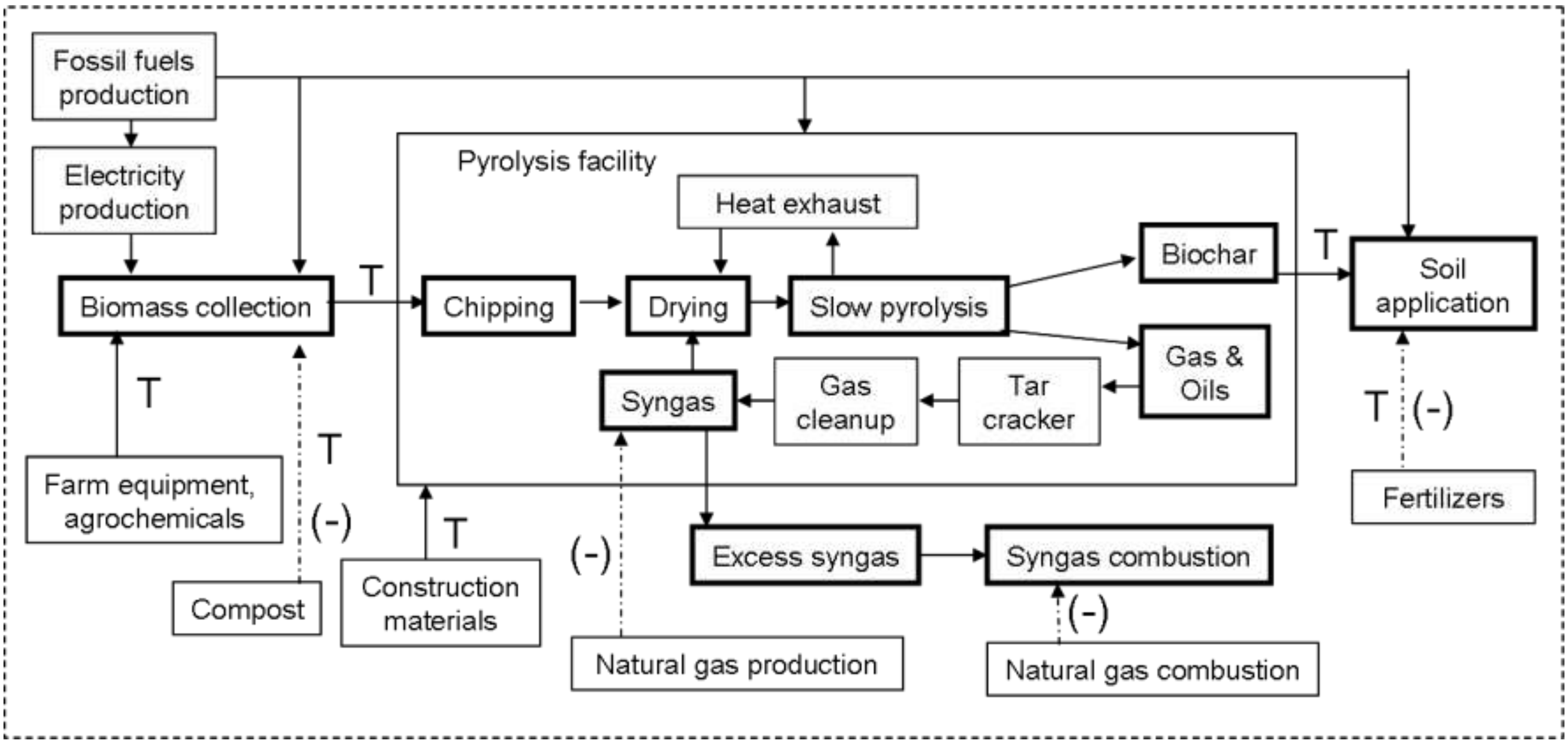
System boundaries

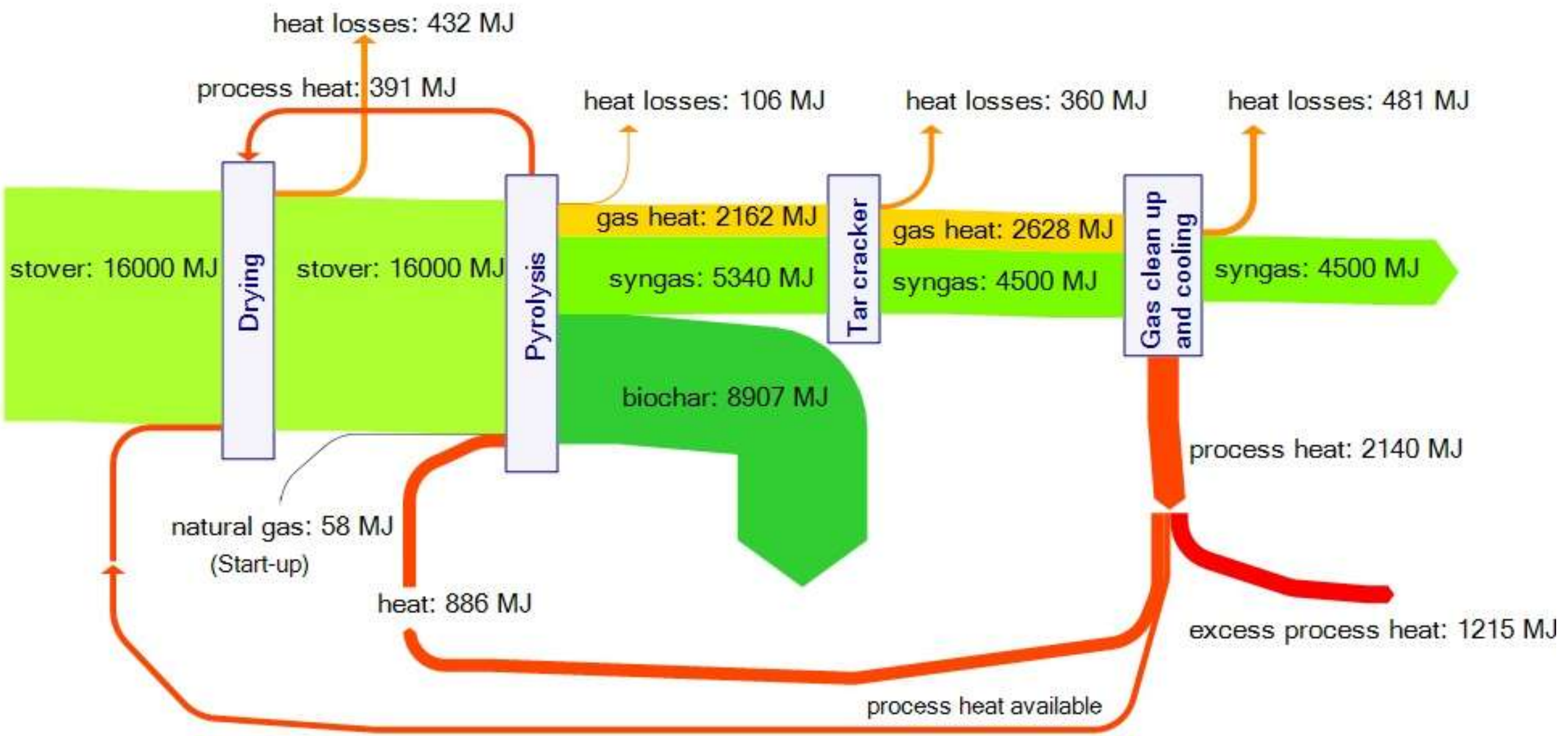


Dashed arrows with (-) indicate avoided processes.
The "T" represents transportation.

LCA of biochar – industrial scale

- The slow pyrolysis process has four co-products:
  - Biomass waste management
  - Biochar soil amendment
  - Bioenergy production
  - Carbon sequestration

Energy flows: feedstock to products



Sankey diagram, per dry tonne stover

Feedstocks

- Corn stover
  - Late and early harvest (15% and 30% mcwb).
  - Second pass collection, harvest 50% above ground biomass.
- Yard waste
  - 45% mcwb
  - No environmental burden for production.
  - Assumed to be diverted from large-scale composting facility.
- Switchgrass
  - 12% mcwb
  - Scenarios A and B to capture range of GHG flows associated with land-use change

Feedstocks (cont.)

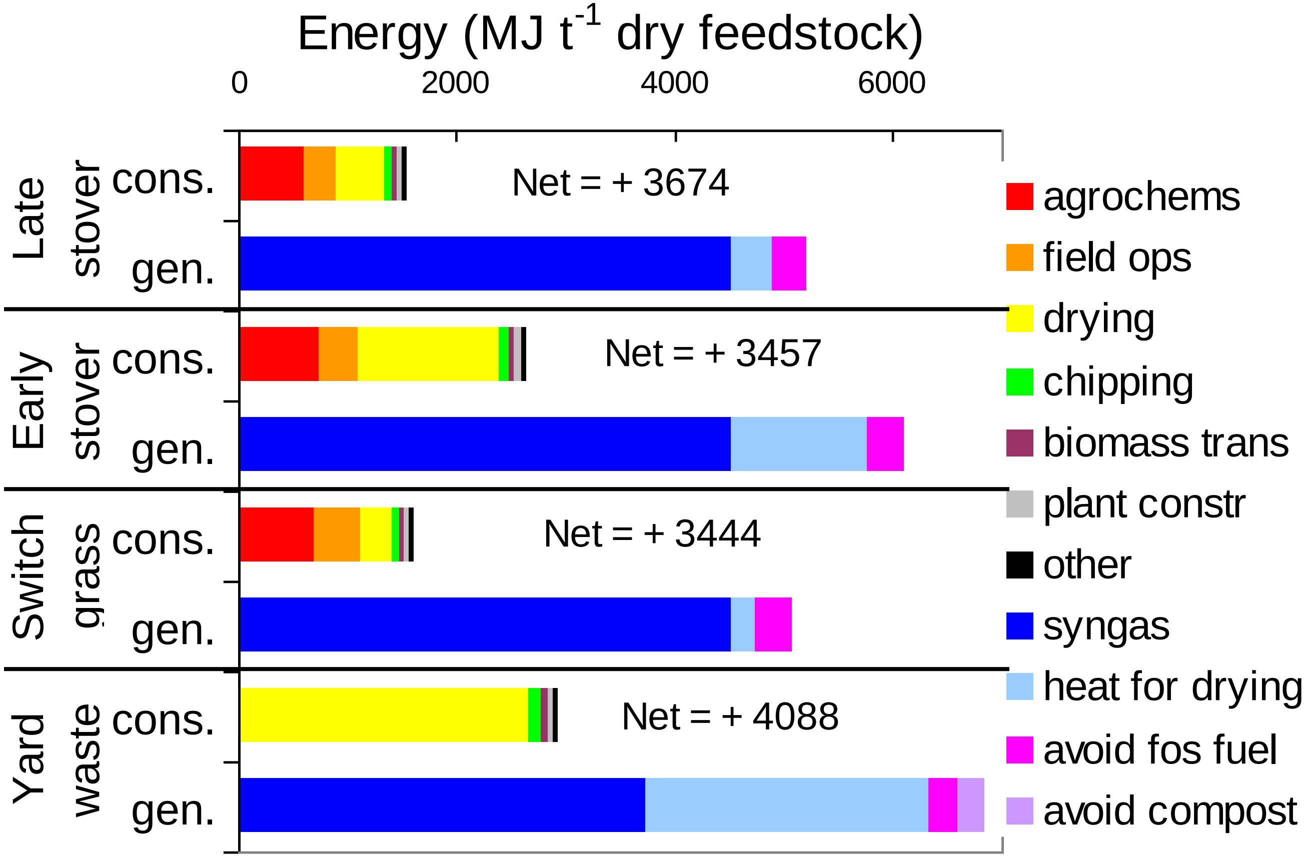
- Switchgrass A
  - Lifecycle emissions model (Deluchi), informally models land-use change.
  - Assumes land conversion predominantly temperate grasses and existing croplands, rather than temperate, tropical or boreal forests.
  - Net GHG of +406.8 kg $CO_2e\ t^{-1}$ dry switchgrass harvested.

- Switchgrass B
  - Searchinger et al (2008) global agricultural model.
  - Assumes land conversion in other countries from forest and pasture to cropland to replace the crops lost to bioenergy crops in the U.S.
  - Net GHG of +886.0 kg $CO_2e\ t^{-1}$ dry switchgrass harvested.

Deluchi, M. "*A lifecycle emissions model (LEM)*"; UCD-ITS-RR-03-17; UC Davis, CA, 2003.

Searchinger, T.; et al. *Science* 2008, *319* (5867), 1238-1240.

Energy balance



- All feedstocks are net energy positive.
- Yard waste has the highest net energy.
- Agrochemical production and drying consume largest proportion of energy.
- Biomass and biochar transport (15 km) consume < 3%.
- "Other" category includes biochar transport, plant dismantling, avoided fertilizer production, farm equipment, and biochar application.

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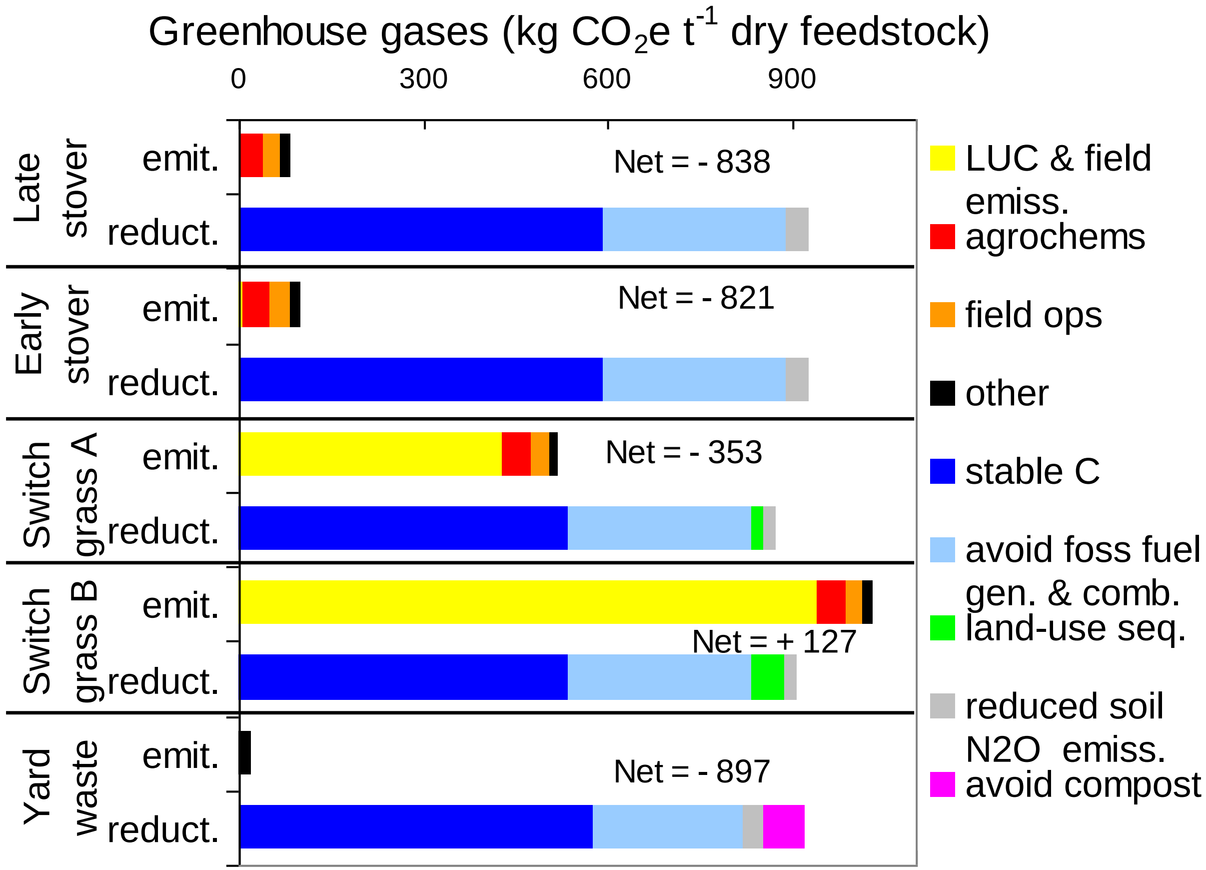
GHG emissions balance



- Stover and yard waste have net (-) emissions (greater than -800 kg CO_2e).
- However, switchgrass A has -353 kg CO_2e of emissions reductions, while B actually has net emissions of +127 kg CO_2e.
- "Other" category includes biomass transport, biochar transport, chipping, plant construction and dismantling, farm equipment, biochar application and avoided fertilizer production.

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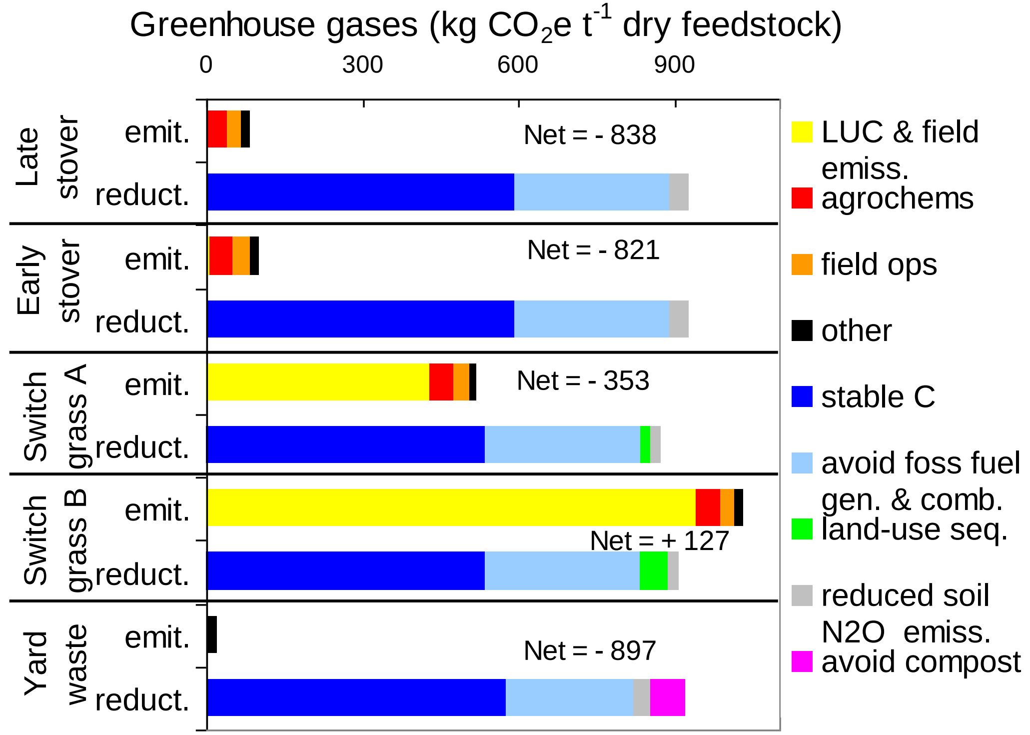
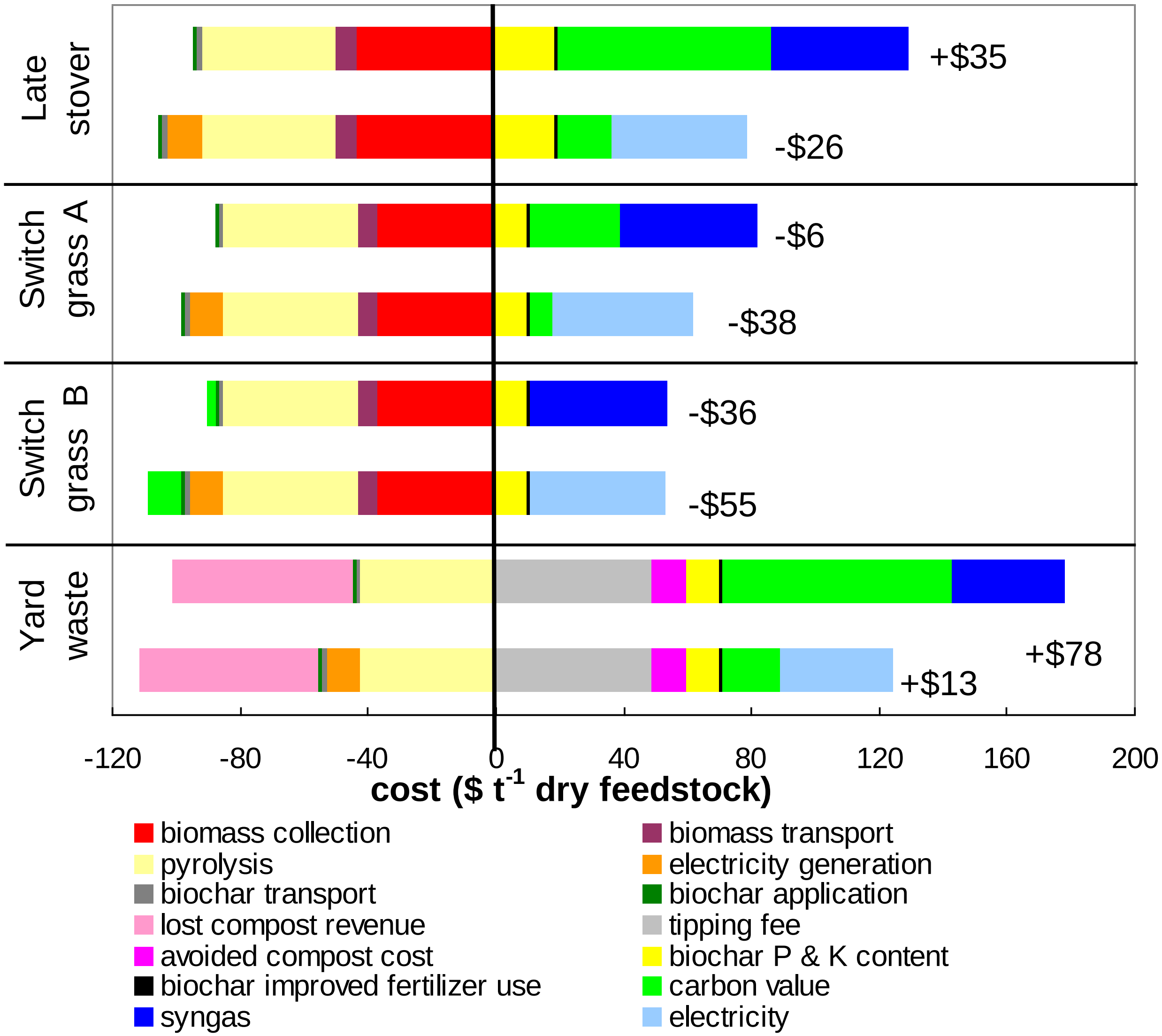
GHG emissions (cont.)



- Biomass and biochar transport (15 km) each contribute < 3%.
- The stable C sequestered in the biochar contributes the largest percentage (~ 60%) of emission reductions.
- Avoided natural gas also accounts for a significant portion of reductions (~30%).
- Reduced soil N_2O emissions upon biochar application to the soil contributes only 2-4% of the total emission reductions.

Economic analysis

- High revenue scenario
  - $80 t^{-1} CO_2e
  - Syngas product
- Low revenue scenario
  - $20 t^{-1} CO_2e
  - Electricity product



- The high revenue of late stover (+$35 t^{-1} stover).
- Late stover breakeven price is $38 t^{-1} CO_2e.
- Neither switchgrass A nor B is profitable.
- Yard waste biochar is economically profitable even with no C price.
- Highest revenues for waste stream feedstocks with a cost associated with current management.

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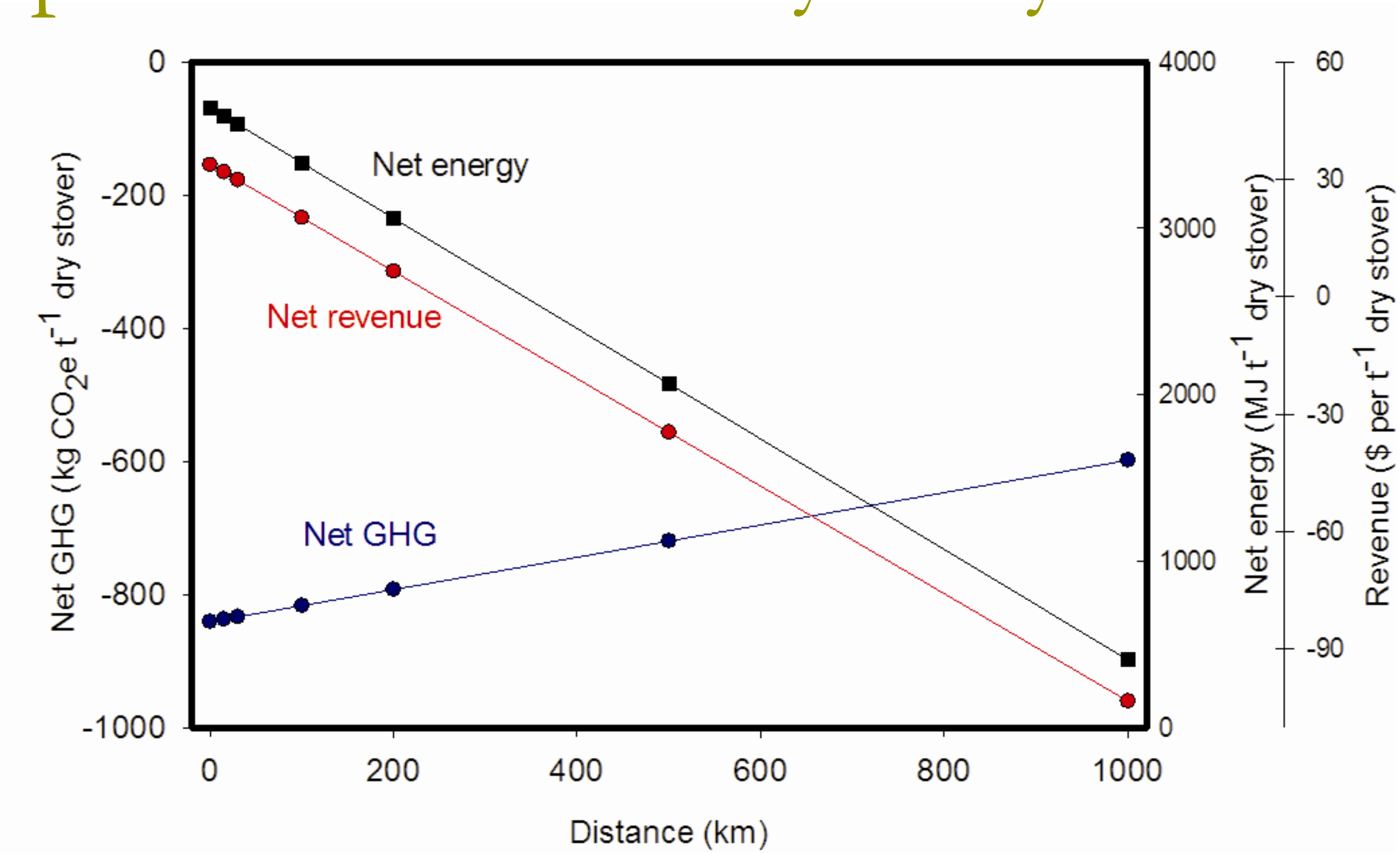
Transportation sensitivity analysis



- The net revenue is most sensitive to the transport distance, where costs increase by \$0.80 t^{-1} for every 10 km.
- The net GHG emissions are less sensitive to distance than the net energy.
- Transporting the feedstock and biochar each 200 km, the net CO_2 emission reductions decrease by only 5% of the baseline (15 km).
- Biochar systems are most economically viable as distributed systems with low transportation requirements.

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Conclusions

- Careful feedstock selection is required to avoid unintended consequences such as net GHG emissions or consuming more energy than is generated.
- Waste biomass streams have the most potential to be economically viable while still being net energy positive and reducing GHG emissions (over 800 kg CO_2e per tonne feedstock).
- Valuing greenhouse gas offsets at a minimum of \$38 t^{-1} CO_2e and further development of pyrolysis-biochar systems will encourage sustainable strategies for renewable energy generation and climate change mitigation.

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Thank you!

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