RENEWABLE ENERGY TRAINING PROGRAM
MODULE 7 | BIOENERGY
Life-cycle Analysis of Woody Biomass Energy

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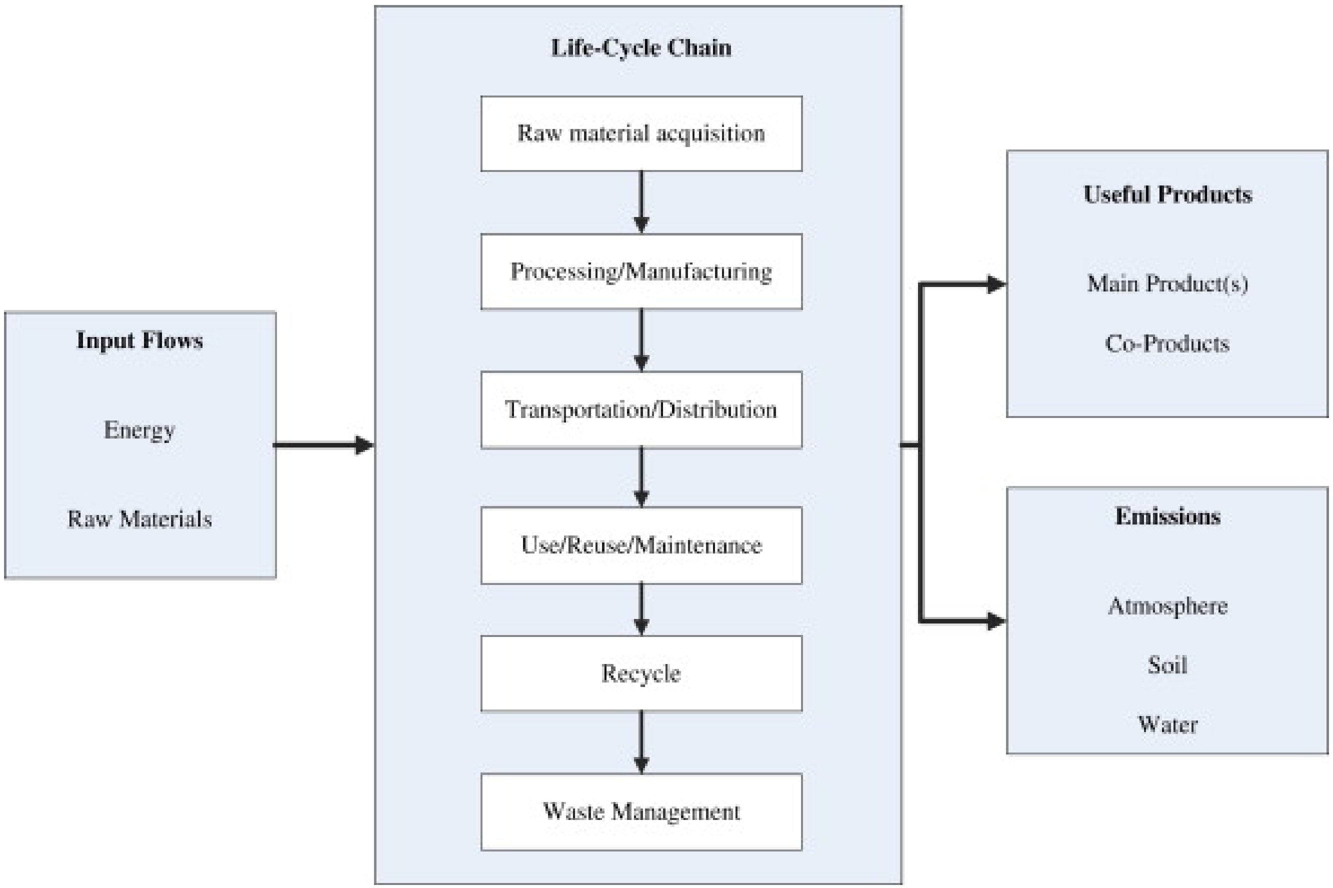
18 June 2014

Overview

- What is LCA?
- How is it done?
- Key concepts
- Examples
  - LCAs for bioenergy
  - Charcoal in Brazil

What is LCA?



1. Goal and scope definition
2. Life cycle inventory
3. Impact assessment
4. Interpretation

LCA methodologies

1. Goal and scope definition:

   defines the <u>system boundary</u> and <u>functional unit</u> and level of detail required for input data.

An example from my research:

- **Goal:** compare <u>environmental impacts</u> of producing charcoal using hot-tail kilns, as is current practice, and using container kilns with pyrolysis gases utilized for cogeneration

What happens when you add cogeneration to a traditional charcoal production system?

- **Boundary:** nursery to plantation-gate (prior land use not included)

- **Functional Unit:** 1 ton of carbon in charcoal

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Review

Innovation in charcoal production: A comparative life-cycle assessment of two kiln technologies in Brazil

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ABSTRACT
This paper presents a comparative analysis of environmental impacts in Brazil's industrial charcoal industry resulting from a shift from hot-tail kilns, which are the most common kiln used by the industry, to metal container kilns. Hot-tail kilns vent pyrolysis emissions directly to the atmosphere, but container kilns allow for easy capture of pyrolysis gases, which may be used as co-products, adding value to charcoal production and reducing environmental impacts through the displacement of other products and/or processes. This analysis uses hot-tail kilns as a reference scenario and considers four alternative scenarios using container kilns in which pyrolysis gases are utilized in different ways. We find that the container kilns improve environmental performance relative to hot-tail kilns across a range of indicators including greenhouse gas (GHG) emissions, water demand, energy-return-on-investment (EROI). Ozone depletion potential (ODP), photochemical oxidation (PCO), acidification, and eutrophication. GHG reductions range from 28% to 119% (10–43 ktons of CO_2e per year) depending on the utilization of specific co-products. Water consumption declines by 25% consistently across all scenarios, and EROI improves by 24–157%. ODP also improves between 30% and 300%. However, container kilns do not show improvements in other impact categories: PCO increases by 20–58% while the potential for both acidification and eutrophication increase 20 to 40 fold. These increases in environmental impacts arise primarily from NO_x and non-methane hydrocarbon emissions, which increase when charcoal production is coupled to cogeneration using pyrolysis gases and/or woodwaste. These additional emissions could be avoided with existing control technologies.

Contents

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LCA methodologies

2. Life cycle inventory

Cataloging material flows along all stages of production:

- All input/output (I/O) data to define the system
- Sources of data include:
  - direct observation
  - life cycle inventory (LCI) databases
  - previous/similar analyses

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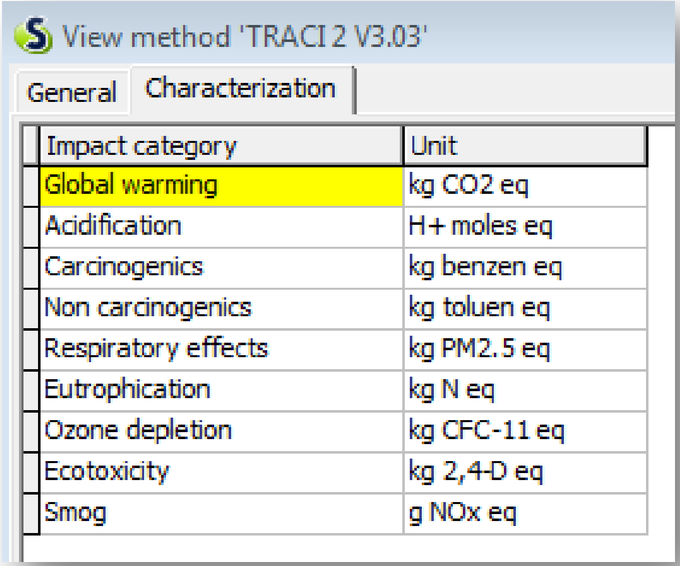
Life cycle materials and processes	Units [a]	Per hectare		Per Functional Unit (FU)	
Nursery stage					
Water	liters	10667	10667	75.6	57.4
Electricity	kWh	5.24	5.24	0.037	0.028
KCl	kg-K_2O	2.6	2.6	0.019	0.014
Mono-ammonium phosphate (as N)	kg-N	0.004	0.004	3.0E-05	2.3E-05
Mono-ammonium phosphate (as P_2O_5)	kg-P_2O_5	0.021	0.021	1.5E-04	1.1E-04
$CaNO_3$	kg-N	0.61	0.61	4.3E-03	3.3E-03
Blend of NPK fertilizers (as N) [b]	kg-N	0.062	0.062	4.4E-04	3.4E-04
" (as P_2O_5)	kg-P_2O_5	0.31	0.31	2.2E-03	1.7E-03
" (as K_2O)	kg-K_2O	0.062	0.062	4.4E-04	3.4E-04
$(NH_4)_2SO_4$	kg-N	0.13	0.13	9.2E-04	7.0E-04
$MgSO_4$	kg	4.2	4.2	0.030	0.022
Sowing and management stage					
Water for irrigation	liters	15,000	15,000	106	81
Water transpired by trees	liters	262,800,000	262,800,000	1.9E6	1.4E6
Fuel (diesel)	liters	348	348	2.5	1.9
Glyphosate (applied for new seedlings)	liters	10	10	0.07	0.05
Blend of NPK fertilizers (as N) [c]	kg-N	0.19	0.19	0.001	0.001
" (as P_2O_5)	kg-P_2O_5	0.39	0.39	0.003	0.002
" (as K_2O)	kg-K_2O	0.17	0.17	0.001	0.001
50% KCl (plus micronutrients)	kg-K_2O	310	310	2.2	1.7
Tractor	p	0.00057	0.00057	0.0000041	0.0000031
Harvesting and transport of feedstock					
Fuel (diesel)	liters	1695	1695	12.0	9.1
Feller/buncher	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Skidder	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Cutter/delimber	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Loader	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Kiln infrastructure					
Bricks	tons	0.67	--	0.0047	--
Mortar	tons	2.14	--	0.015	--
Steel	tons	--	0.17	--	0.001
Pyrolysis and cogeneration <u>inputs</u>					
Fuel (diesel)	liters	1846	1420	13.1	7.6
Lorry - 16t	p	0.0060	0.0060	0.000042	0.000032
Water (for cooling in cogen units)[d]	m^3	NA	NA	0	0/1.6/3.7/6.7
Electricity demand [c]	kWh	NA	NA	0	52/52/64/97
Pyrolysis and cogeneration <u>outputs</u>					
Charcoal output	tons	192	240	1.4	1.3
Charcoal-carbon output	tons	142	187	1.0	1.0
Electricity to grid [c]	kWh	NA	NA	0	0/274/613/1122
Tar [c]	kg			0	0/220/0/0

LCA methodologies

3. Impact assessment:

   Converts raw input/output data into meaningful measurements

   - May be assessed as raw data, intermediate, or final impact
   - Example: climate impacts
     - Raw data: tons of CO_2, CH_4, and N_2O
     - Intermediate impact: aggregate global warming pot'l (GWP)
     - Final impact: temperature increase or physical/economic damages



Impact category	Unit
Global warming	kg CO2 eq
Acidification	H+ moles eq
Carcinogenics	kg benzen eq
Non carcinogenics	kg toluen eq
Respiratory effects	kg PM2.5 eq
Eutrophication	kg N eq
Ozone depletion	kg CFC-11 eq
Ecotoxicity	kg 2,4-D eq
Smog	g NOx eq

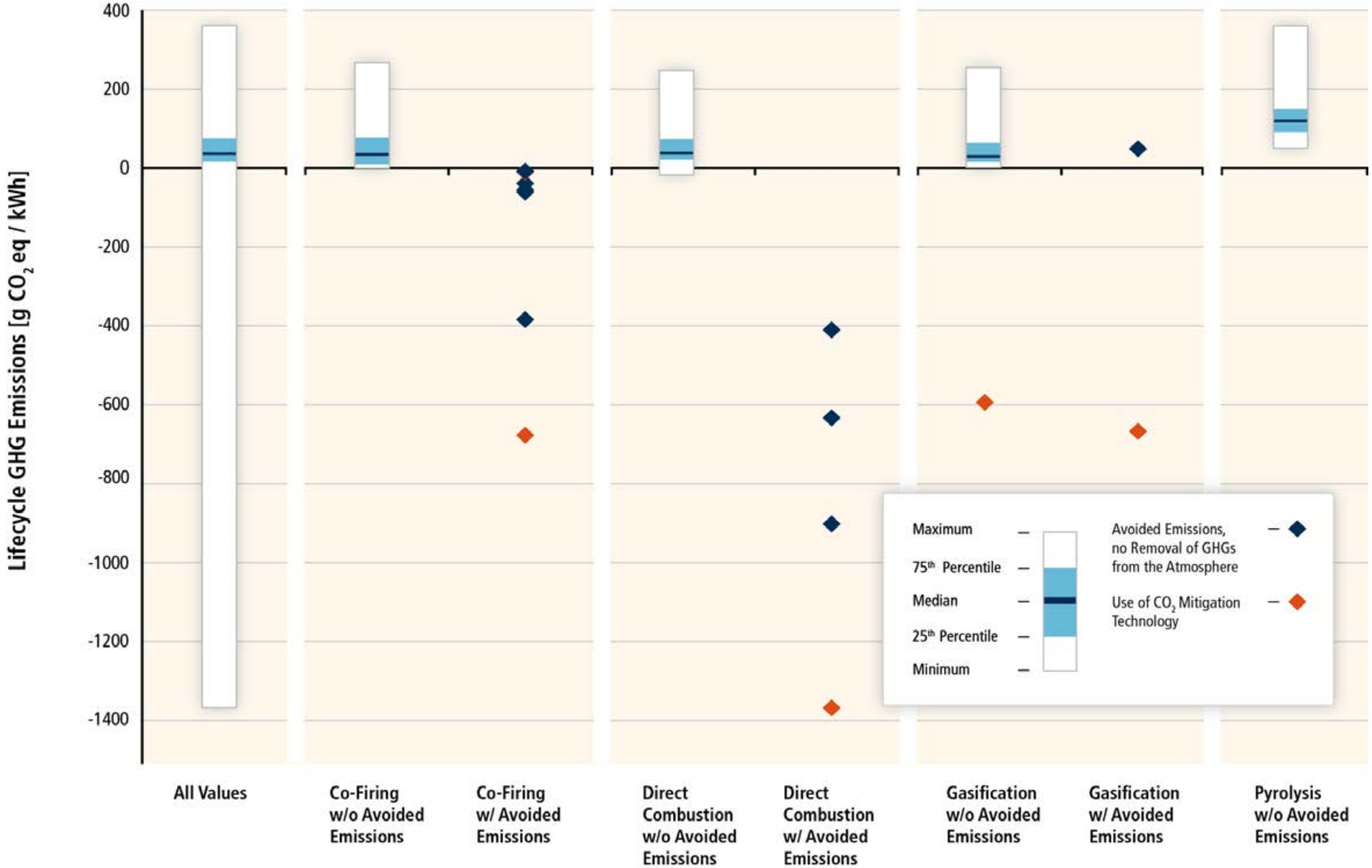
LCA methodologies

4. Interpretation: an assessment of the outcomes of the inventory analysis and impact assessment, including sensitivities.

LCA methodologies

- Additional considerations:
  - Treatment of co-products
    - Most bioenergy systems multiple products
    - How do we allocate impacts?
  - Temporality (past, current and future impacts)
    - Attributional and Consequential LCA
  - Land Use Change (LUC)

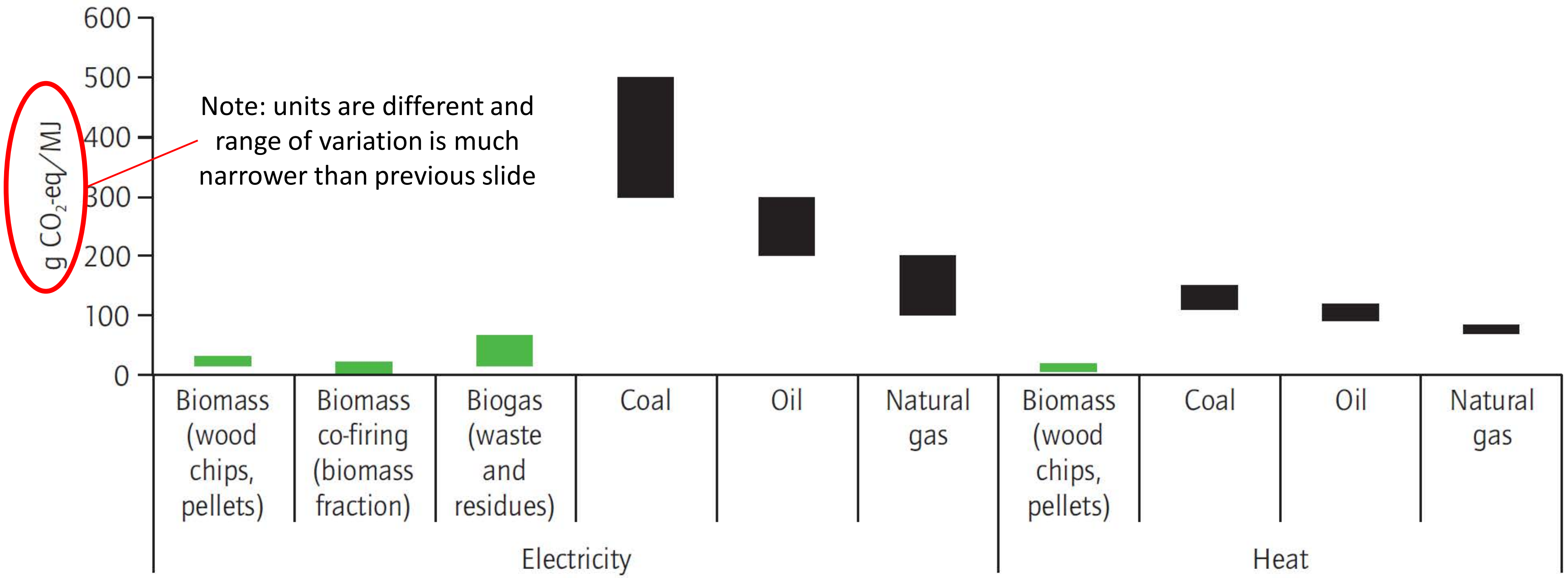
Bioenergy LCAs– strong focus on GHGs



Estimates:	228	54	7	102	4	45	2	14
References:	53	19	4	26	3	20	1	3

Life-cycle GHG emissions of biopower technologies per unit of electricity generation, including supply chain emissions (land use-related net changes in carbon stocks and land management impacts are excluded). Co-firing is shown for the biomass portion only (without GHG emissions and electricity output associated with coal). From IPCC SRREN – Ch. 2.

…in comparison to fossil options

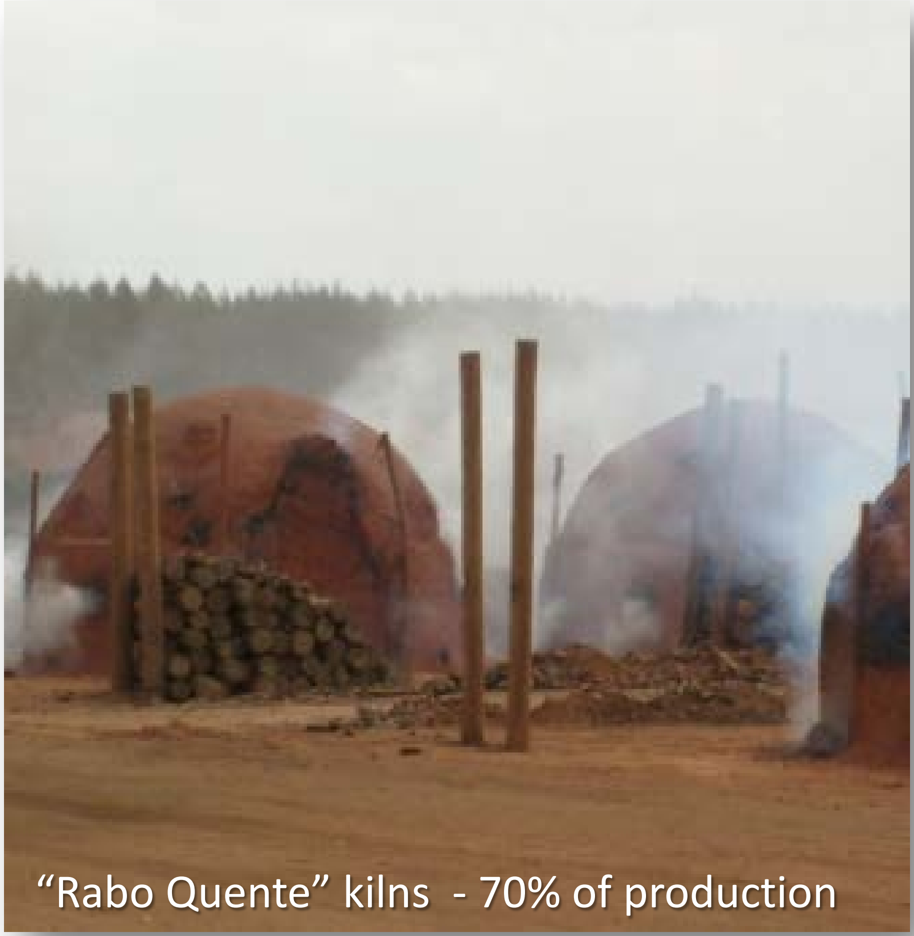


Note: Based on current state of technologies. Ranges reflect variations in performance as reported in literature. Possible emissions from land-use change are not included here.

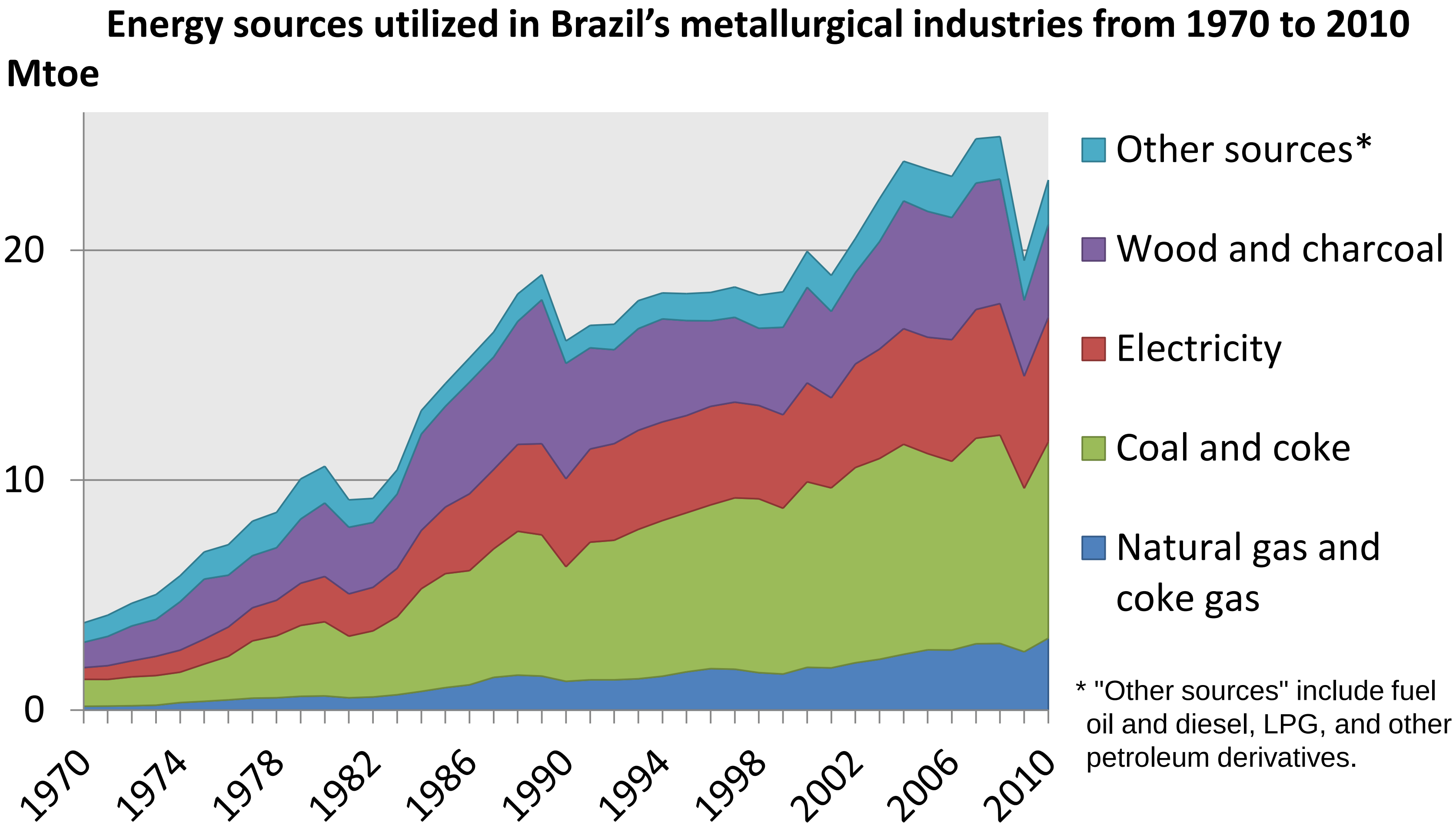
Source: Based on Cherubini *et al.*, 2009; IPCC, 2011.

Example – Innovation in Brazilian Charcoal Production

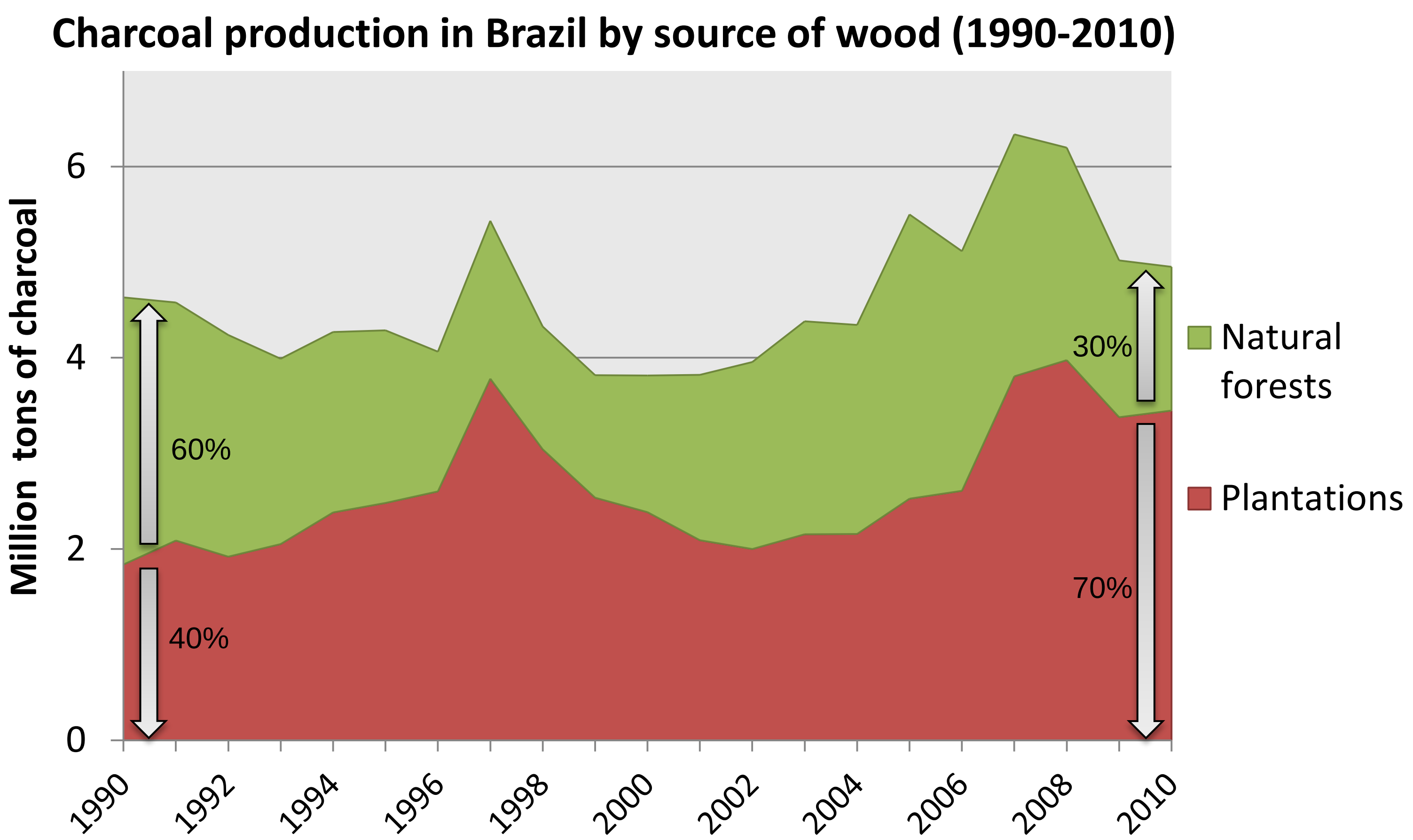
- Brazil is the world's largest charcoal user
- > 80% used by the metallurgical industries
  - source of carbon and energy



Brazilian Charcoal Production

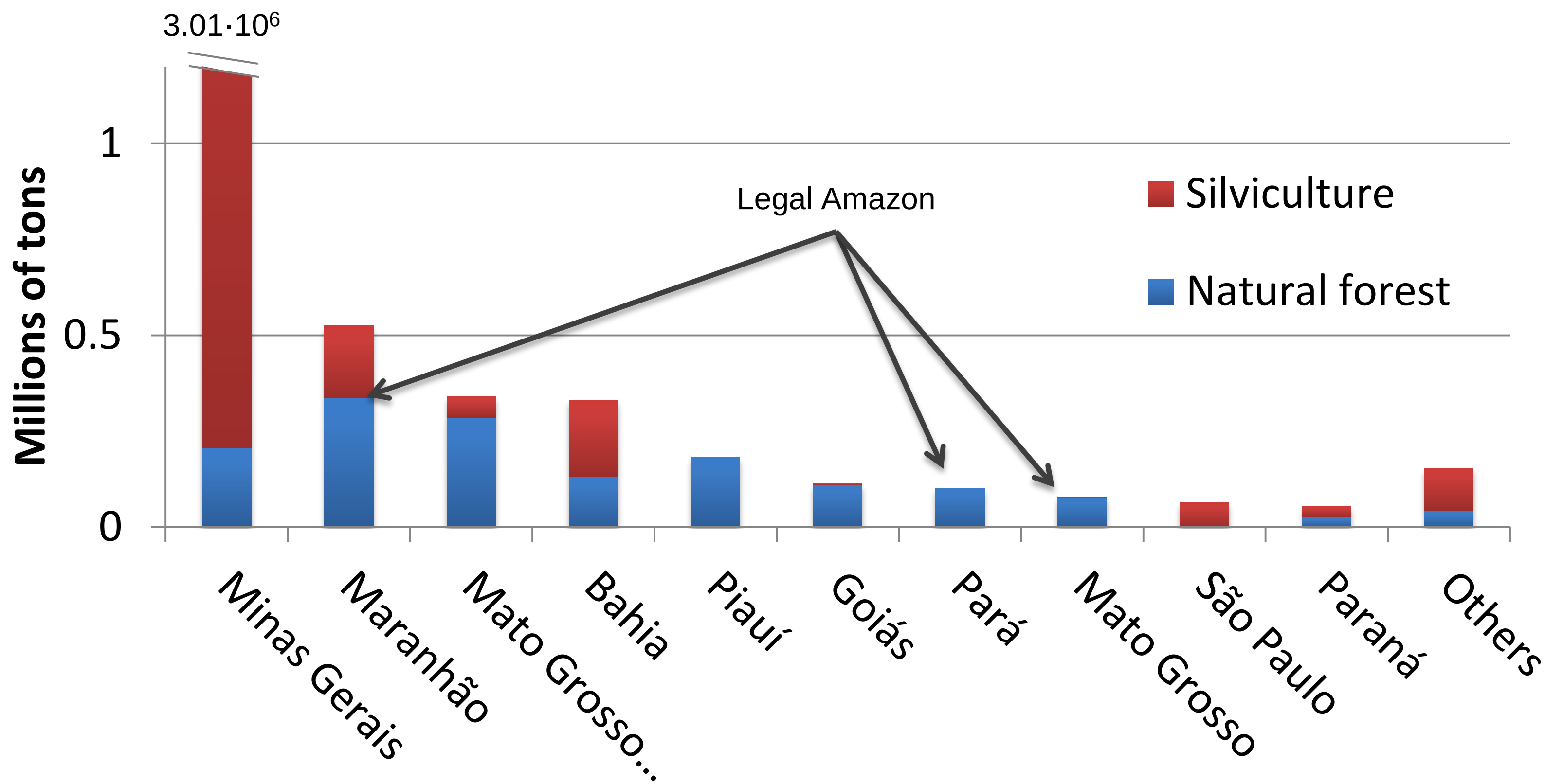


The majority of feedstock originates from plantations, but…



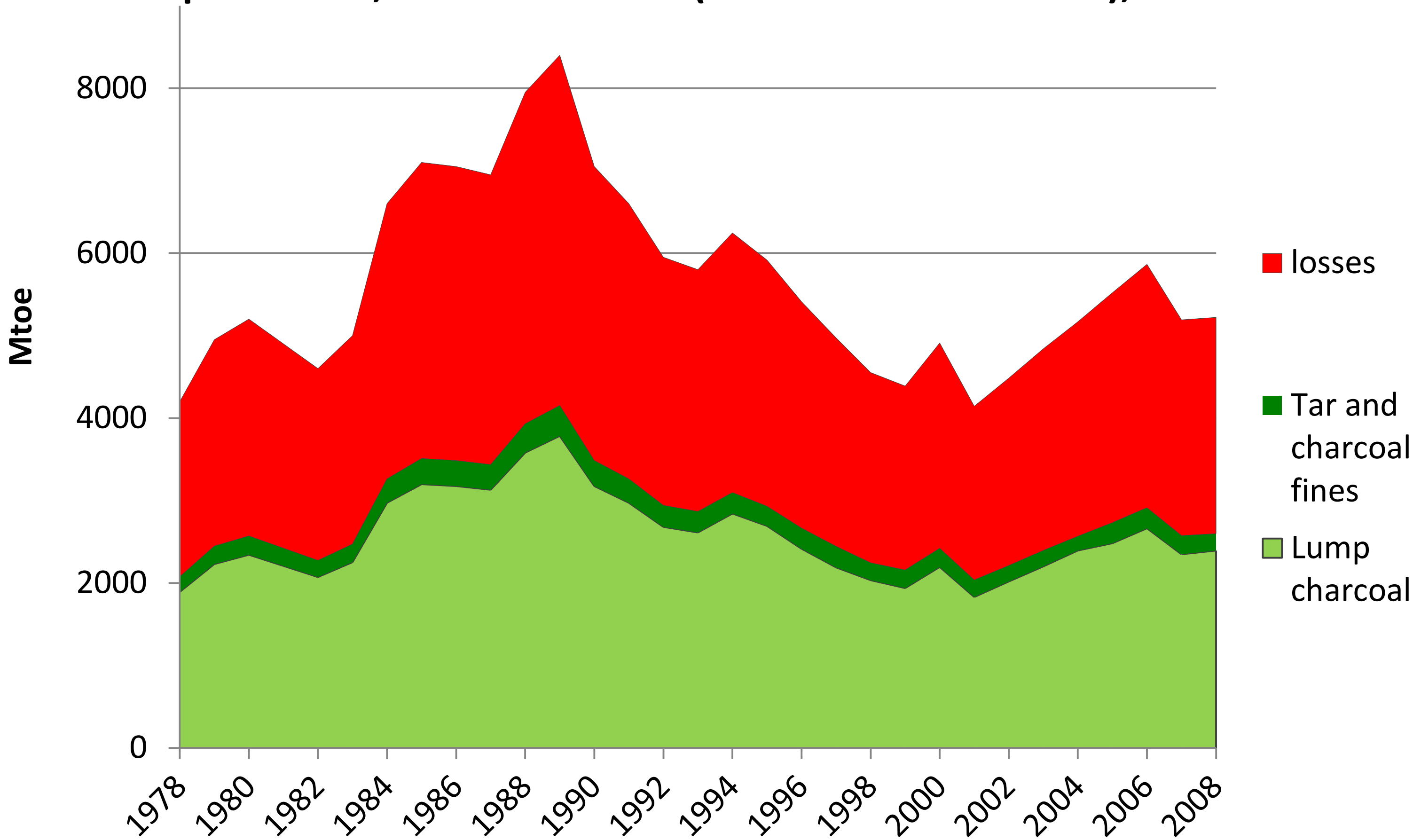
Source: [IBGE, 2012]

Charcoal production by state in 2010 (IBGE, 2012)



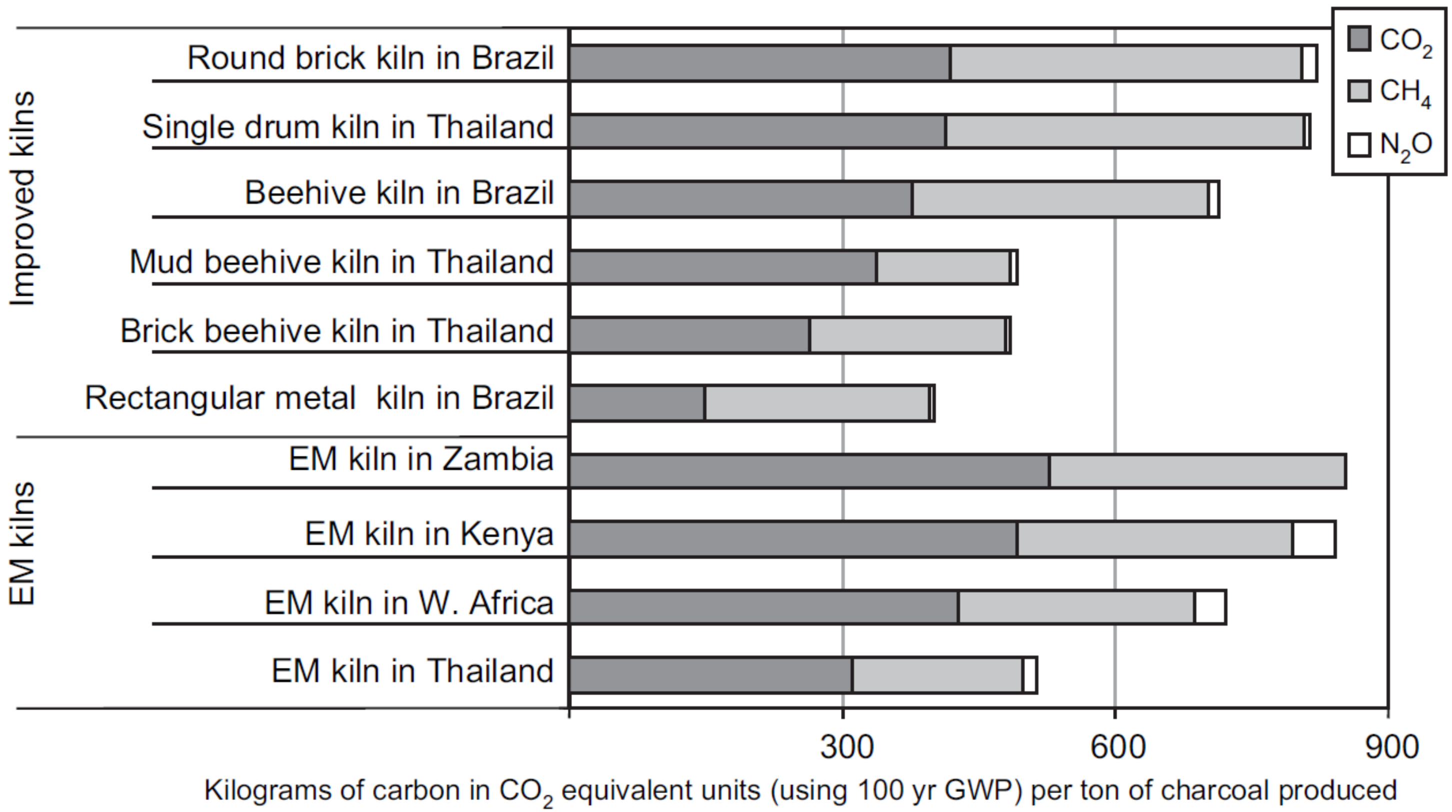
There are also large energy losses…

Energy flows in charcoal production in Minas Gerais, Brazil (1978 to 2008) as lump charcoal, other materials (charcoal fines and tar), and losses



Miranda et al. 2012

…and emissions

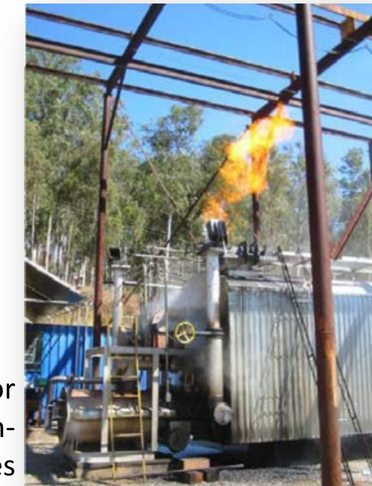


Emissions measured in traditional earthmound (EM) kilns and a variety of improved kilns reported in the literature showing emissions of each GHG weighted by its 100-year global warming potential (Bailis 2009)

Alternative technologies


DK biochar reactor with Stirling Engine

DPC charcoal reactor flaring non-condensable gases




CML charcoal plant


RIMA pilot plant with container kilns

Rima’s concept (Vilela, 2010)

Ciclo Contínuo

Carbonização

(12 horas)

Resfriamento

(12 horas)

Descarregamento (1 hora)

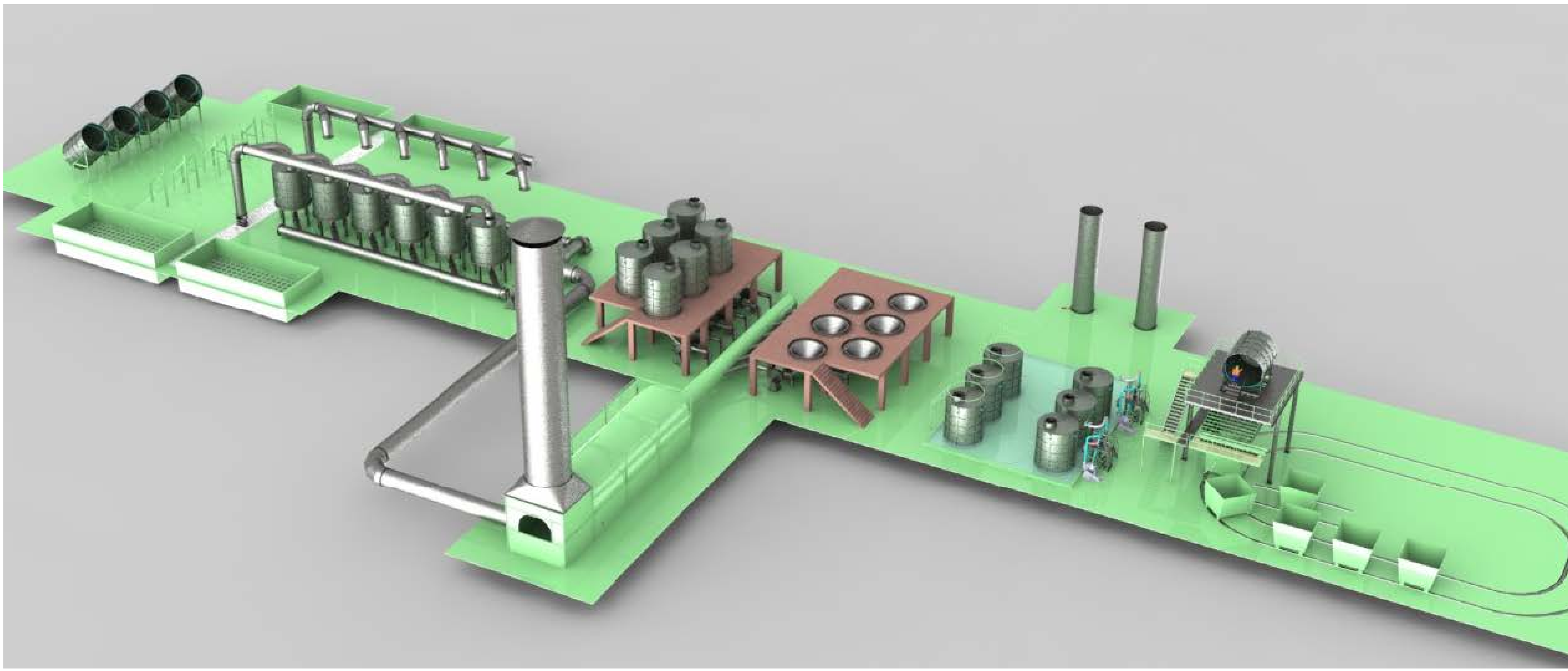
Carregamento

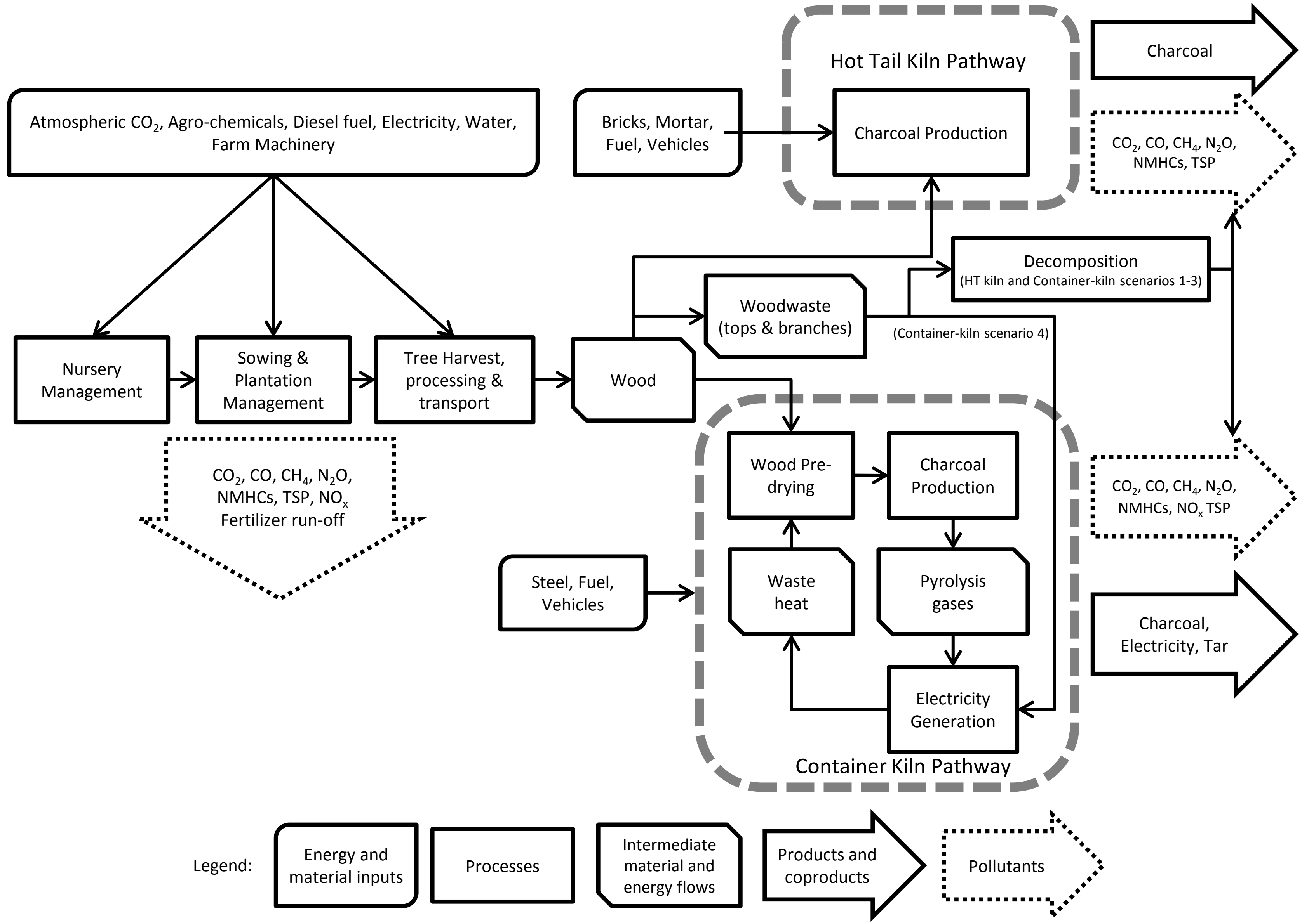
(3 horas)

Secagem

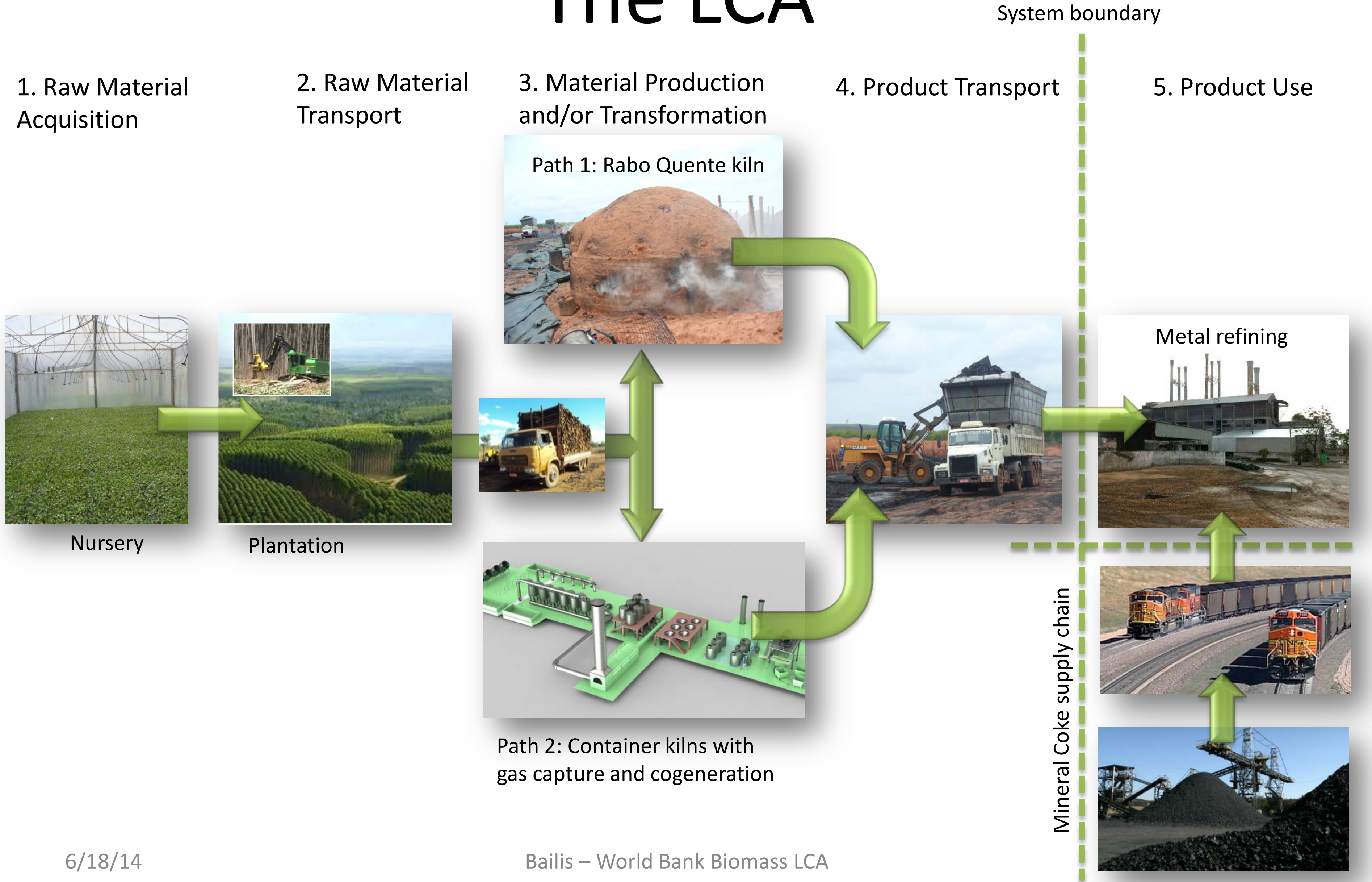
(6 horas)

Rima’s concept (Vilela, 2010)

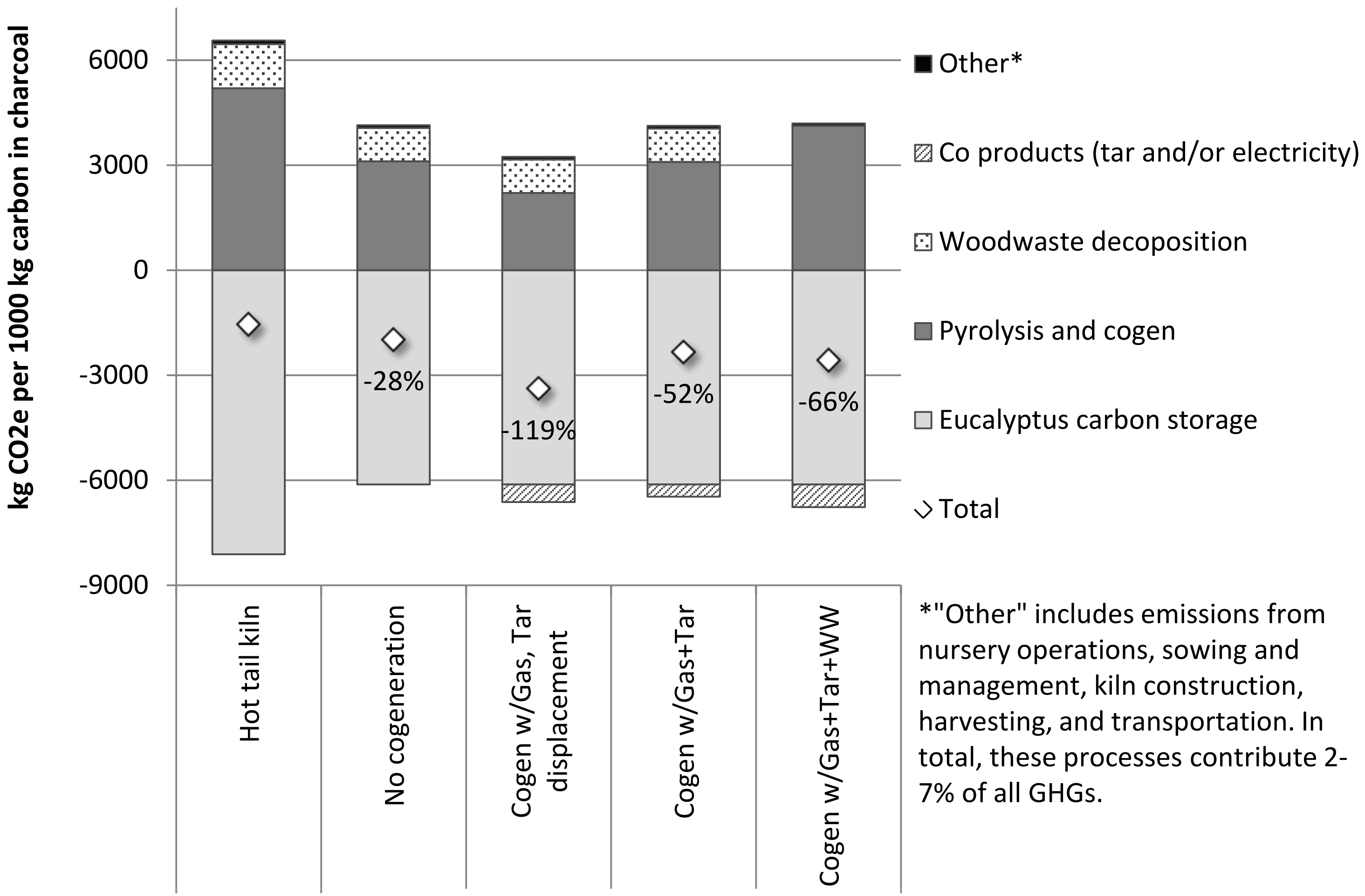



Hot Tail Kiln Pathway
Charcoal Production
Charcoal
CO_2, CO, CH_4, N_2O, NMHCs, TSP
Atmospheric CO_2, Agro-chemicals, Diesel fuel, Electricity, Water, Farm Machinery
Bricks, Mortar, Fuel, Vehicles
Decomposition
(HT kiln and Container-kiln scenarios 1-3)
Woodwaste (tops & branches)
(Container-kiln scenario 4)
Nursery Management
Sowing & Plantation Management
Tree Harvest, processing & transport
Wood
CO_2, CO, CH_4, N_2O, NMHCs, TSP, NO_x Fertilizer run-off
Wood Pre-drying
Charcoal Production
CO_2, CO, CH_4, N_2O, NMHCs, NO_x TSP
Steel, Fuel, Vehicles
Waste heat
Pyrolysis gases
Charcoal, Electricity, Tar
Electricity Generation
Container Kiln Pathway
Legend:
Energy and material inputs
Processes
Intermediate material and energy flows
Products and coproducts
Pollutants

The LCA

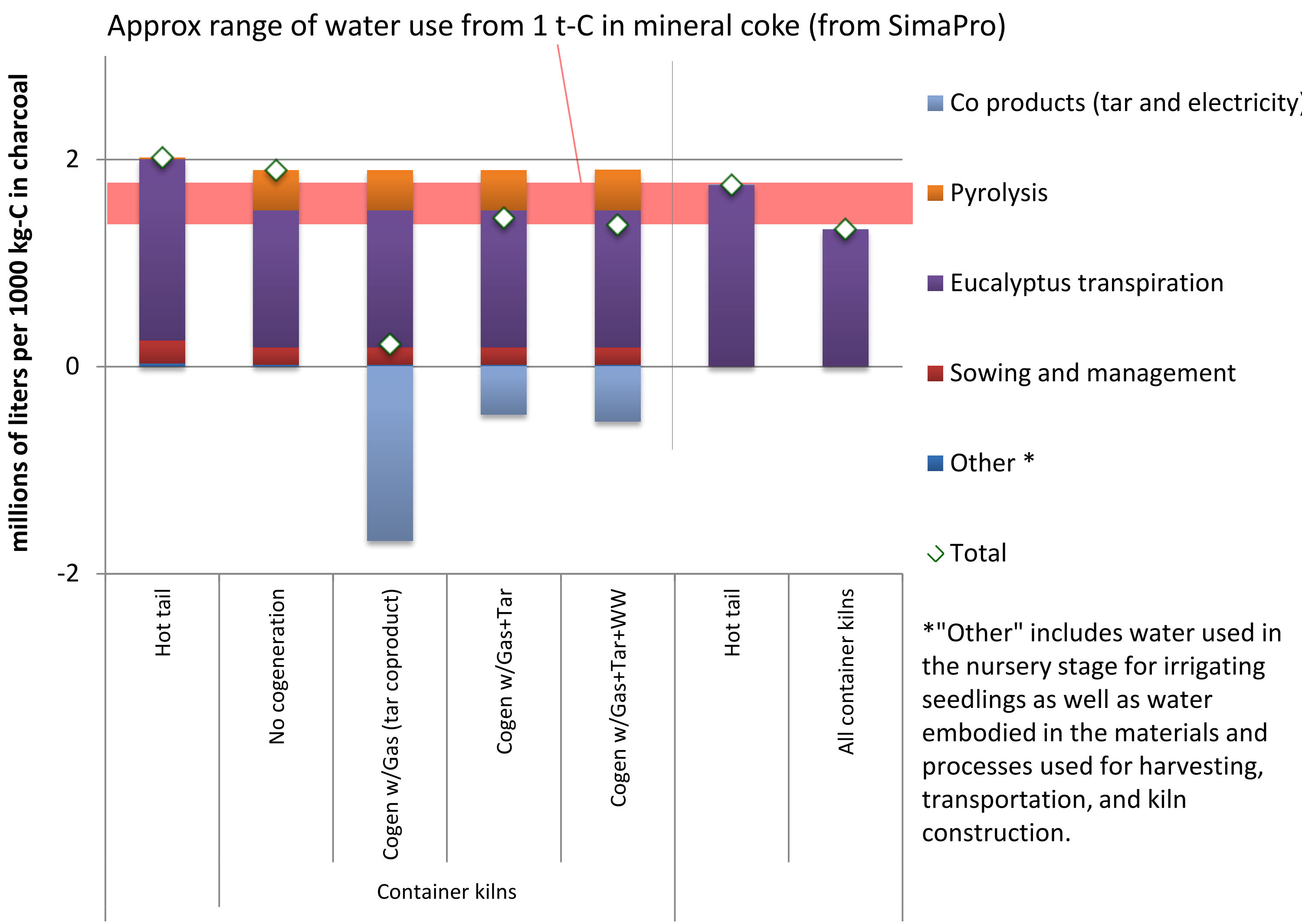

System boundary
1. Raw Material Acquisition
2. Raw Material Transport
3. Material Production and/or Transformation
4. Product Transport
5. Product Use
Path 1: Rabo Quente kiln
Nursery
Plantation
Metal refining
Path 2: Container kilns with gas capture and cogeneration
Mineral Coke supply chain

Results - GHGs



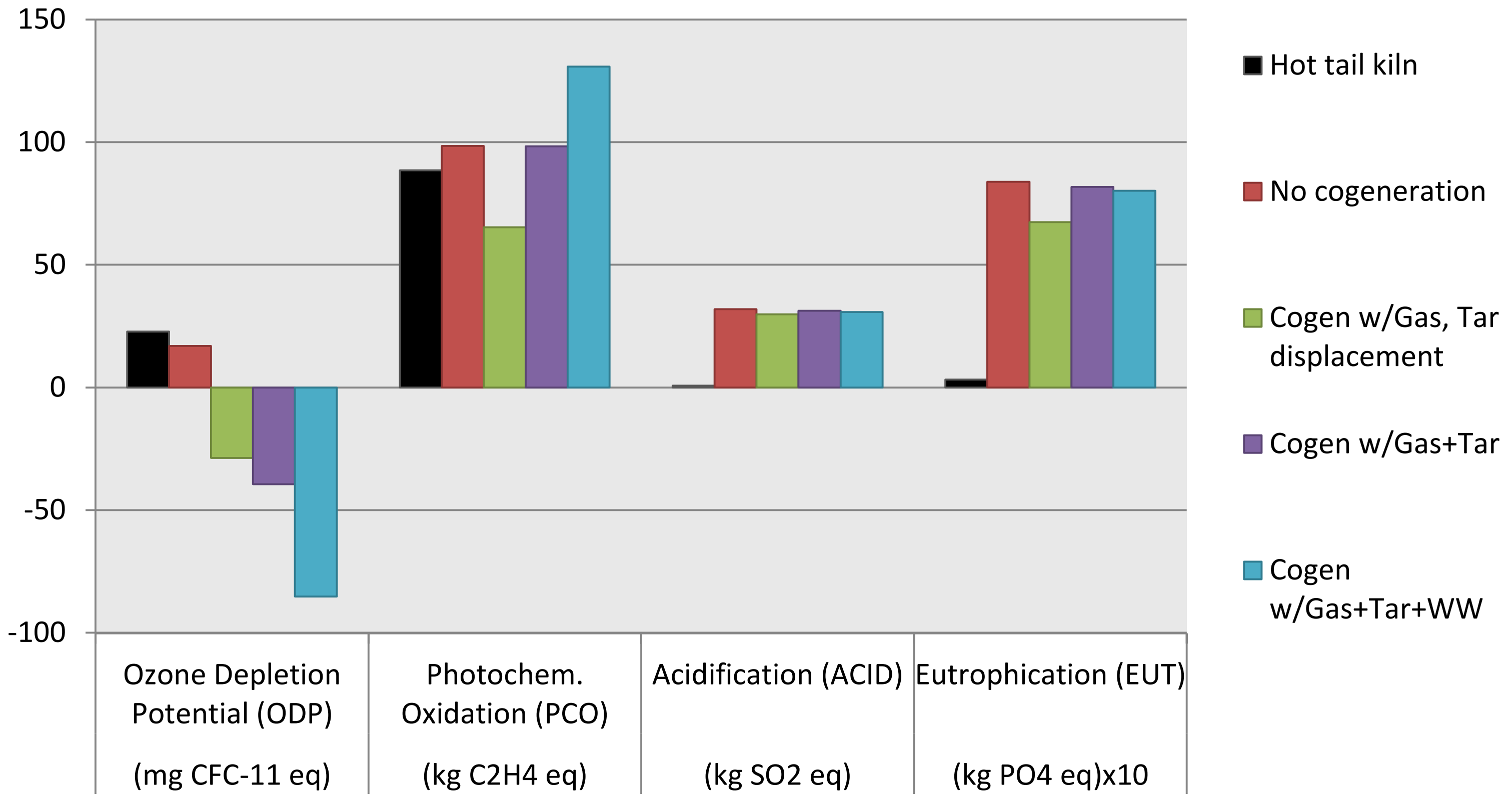
*"Other" includes emissions from nursery operations, sowing and management, kiln construction, harvesting, and transportation. In total, these processes contribute 2-7% of all GHGs.

Results – water use

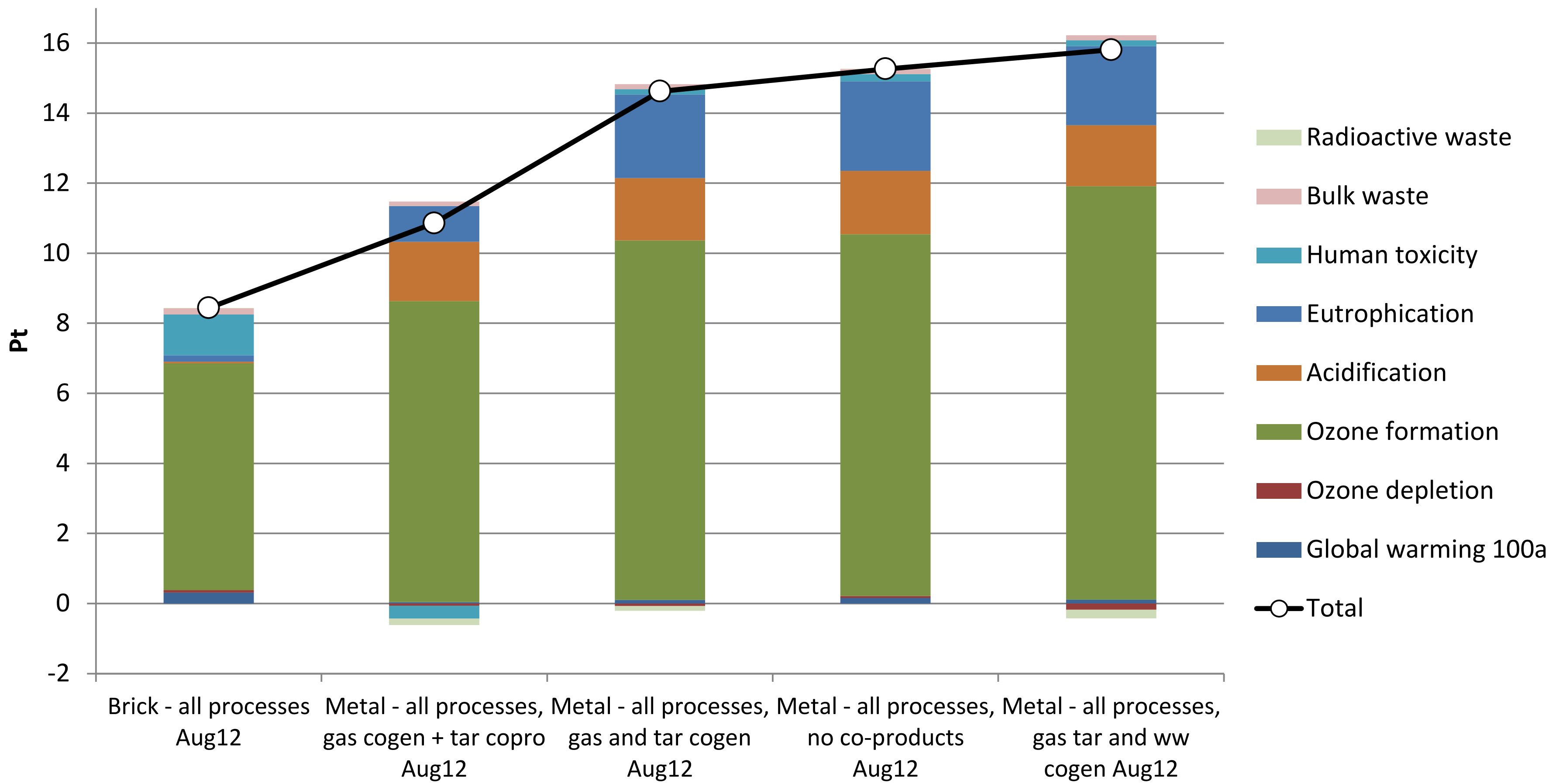


*"Other" includes water used in the nursery stage for irrigating seedlings as well as water embodied in the materials and processes used for harvesting, transportation, and kiln construction.

Results – other impacts



Aggregating results???



Comparing product stages;
Method: EDIP 2003 V1.03 / Default / Single score

Concluding thoughts

- LCA is a powerful tool to compare technological options
  - But proceed with caution!
- More than just GHGs
  - When we introduce multiple impacts, comparing and/or aggregating is risky
  - Only meaningful if local context is taken into consideration

EXTRA SLIDES

LCA metho

2. Life cycle inventory

<u>all stages of production</u>:

1) Raw Material Acquisition
2) Raw Material Transport
3) Material Production
4) Product Transport
5) Product Use
6) Product disposal/recycling

Life cycle materials and processes	Units [a]	Per hectare	
Main assumptions		hot-tail	Container
Seedlings produced per month	no.	605,000	605,000
Area	ha	1	1
Planting density	no./ha	1,050	1,050
No. of seedling plantings	no.	2	2
Seedlings planted	no.	2100	2100
Nursery stage			
Water	liters	10667	10667
Electricity	kWh	5.24	5.24
KCl	kg-K_2O	2.6	2.6
Mono-ammonium phosphate (as N)	kg-N	0.004	0.004
Mono-ammonium phosphate (as P_2O_5)	kg-P_2O_5	0.021	0.021
$CaNO_3$	kg-N	0.61	0.61
Blend of NPK fertilizers (as N) [b]	kg-N	0.062	0.062
" (as P_2O_5)	kg-P_2O_5	0.31	0.31
" (as K_2O)	kg-K_2O	0.062	0.062
$(NH_4)_2SO_4$	kg-N	0.13	0.13
$MgSO_4$	kg	4.2	4.2
Sowing and management stage			
Water for irrigation	liters	15,000	15,000
Water transpired by trees	liters	262,800,000	262,800,000
Fuel (diesel)	liters	348	348
Glyphosate (applied for new seedlings)	liters	10	10
Blend of NPK fertilizers (as N) [c]	kg-N	0.19	0.19
" (as P_2O_5)	kg-P_2O_5	0.39	0.39
" (as K_2O)	kg-K_2O	0.17	0.17
50% KCl (plus micronutrients)	kg-K_2O	310	310
Tractor	p	0.00057	0.00057
Harvesting and transport of feedstock			
Fuel (diesel)	liters	1695	1695
Feller/buncher	p	3.3E-04	3.3E-04
Skidder	p	3.3E-04	3.3E-04
Cutter/delimber	p	3.3E-04	3.3E-04
Loader	p	3.3E-04	3.3E-04
Kiln infrastructure			
Bricks	tons	0.67	--
Mortar	tons	2.14	--
Steel	tons	--	0.17
Pyrolysis and cogeneration <u>inputs</u>			
Fuel (diesel)	liters	1846	1420
Lorry - 16t	p	0.0060	0.0060
Water (for cooling in c			NA
Electricity demand [d]			NA
Pyrolysis and cogeneratio			
Charcoal output			240
Charcoal-carbon outp			187
Electricity to grid [d]			0/114/51/206
Tar [d]			0/220/0/0

[a] p = individual pieces;
[b] NPK fertilizer at the nursery stage include 300 kg of 6-30-6 and 250 kg of slow-release 15-9-12 per 605,000 seedlings. Values here reflect density of 1,050 seedlings per ha and 2 planting cycles.
[c] NPK fertilizer in the plantation include 3-27-8 applied at establishment at 350 kg/ha and 12-14-0 applied 2-6 months after establishment at 1000 kg/ha. Both are applied for each harvest cycle.
[d] Varies with scenario: data are given for Scenario 1/Scenario 2/Scenario 3/Scenario 4 respectively.