Carbon Footprint and Economic Analysis to Determine the Minimum Carbon Price Required for the Utilization of Residual Forest Materials in Greenhouse Gas Mitigation

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Sustainability?

- How do we supply societies needs without harming the environment or future generations' ability to meet their needs?
  - **People – Planet - Profit**

- We have many options to meet our demands.

- How to choose the "best" option?

- Life cycle assessment (LCA) helps to inform our choices.

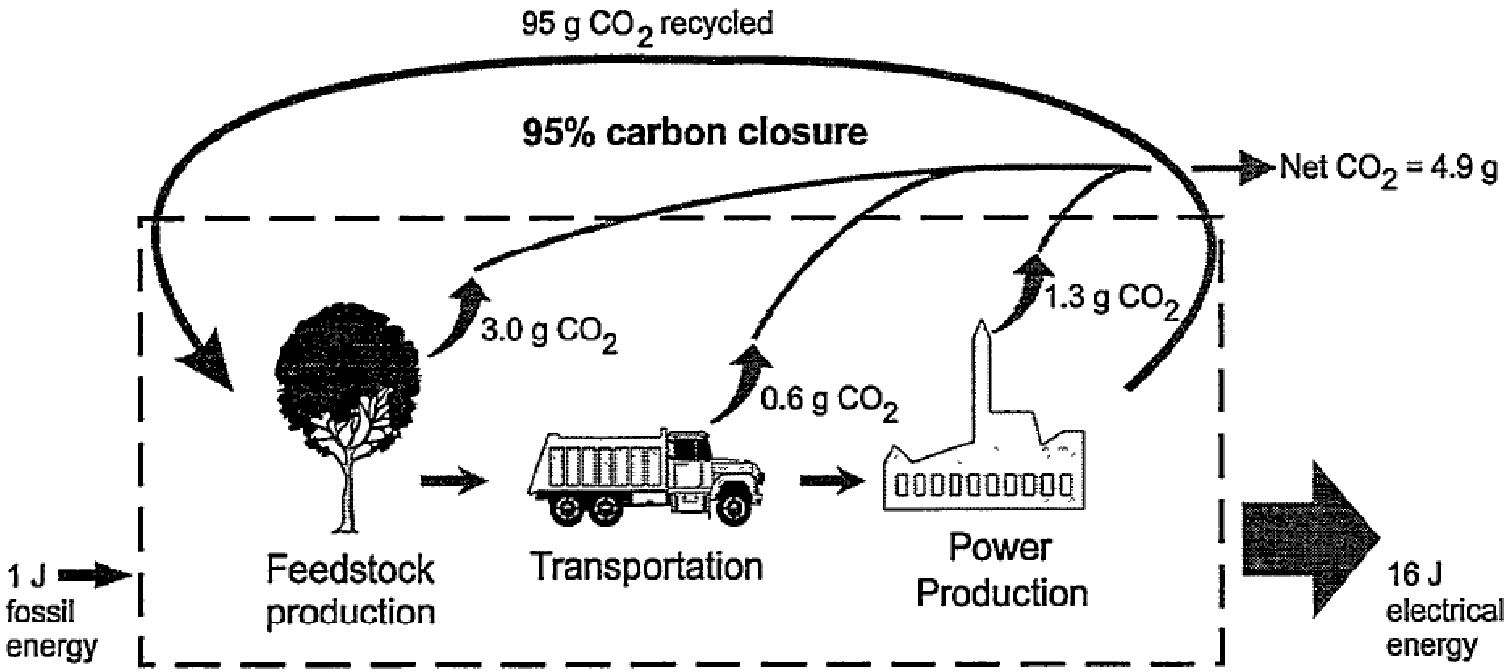
- LCA has objective and subjective parts!!!

Forest Residuals:

- When harvesting wood the residual amount not suitable for timber logs or pulp logs can be substantial
- This material includes branches, thinnings, tops…..
- For hardwood, around 40% residuals
- For softwoods, around 15% residuals

- Are there alternatives to leaving these residuals on the ground?
- How can they best be utilized?

Biomass Gasification for Electricity: 16 units of energy produced/1 unit of fossil fuel input



Life Cycle Assessment of a Biomass Gasification Combined-Cycle System, Margaret K. Mann, Pamela L. Spath, NREL, 1997

Goal:

- Goal: Determine among several alternative utilization scenarios, for a ton of residual biomass which scenario:
  - Has the smallest carbon footprint?
  - Has the lowest cost?
  - Has the lowest cost per ton of carbon dioxide saved?

  - **What is the minimum price of carbon to break even with leaving the residuals on the ground?**

Methodology:

Carbon Footprint: Impact Assessment Method

- **Partial life cycle analysis**
- **A picture of the overall greenhouse gas (GHG) impact (not just CO2) of a product over its lifecycle (cradle-to-grave).**
- **Reports the net amount of GHG's for a defined process, in units of kgCO2(equiv)/basis**

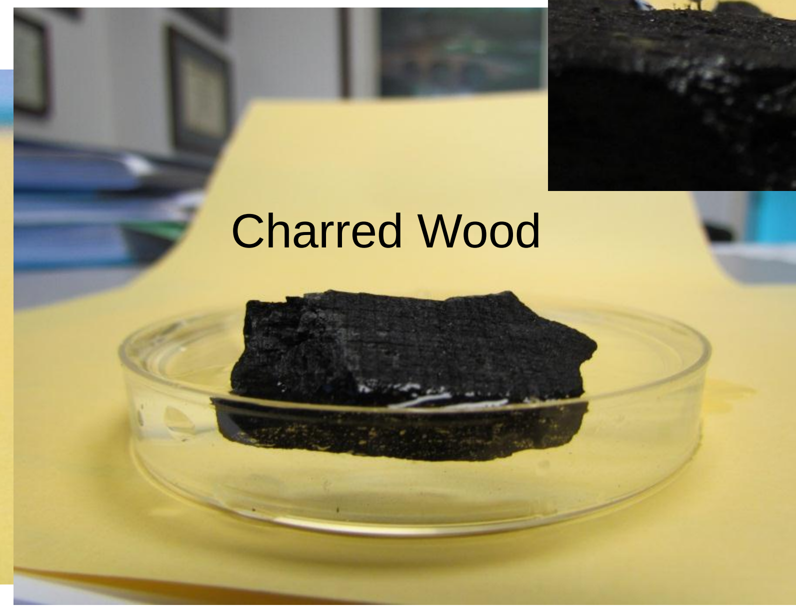
Revision Year	CO_2 equivalents for CH_4	CO_2 equivalents for N_2O
1996	21	310
2001	23	296
2006	25	298

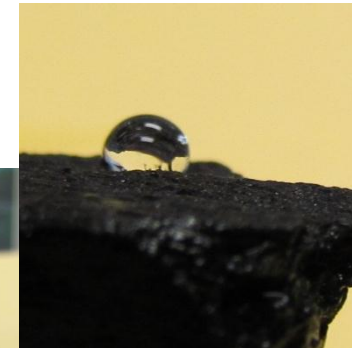
INTERGOVERNMENTAL PANEL ON climate change

Forest Residuals:

Pretreatments

Pretreatments:





Advantages: dry, hydrophobic, low density, brittle, energy dense

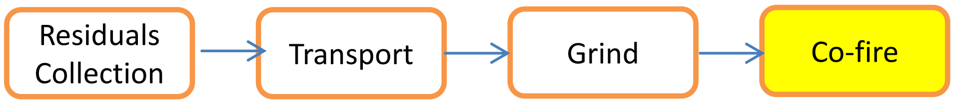
Pretreatments

Process	Treatment	Moisture % (wet basis)	Solids Loss	% Carbon in product (dry basis)	Heating value, MMBTU/ton
Green wood		50	0	50	7.4
Field-dried	Under tarp for 3 months	20	0	50	14
Torrefaction	Heated to 250-300 C w/o oxygen	0	1/3	53	22
Char	Heated to 450-660 Cw/o oxygen	0	2/3	90	27

Coal is 24 mmBTU/ton

Description of Systems:

- Leaving biomass on ground
- Co-firing green biomass with coal



- Co-firing field dried biomass with coal

- Co-firing torrefied biomass with coal

- Co-firing charred biomass with coal

- Applying char to agricultural lands

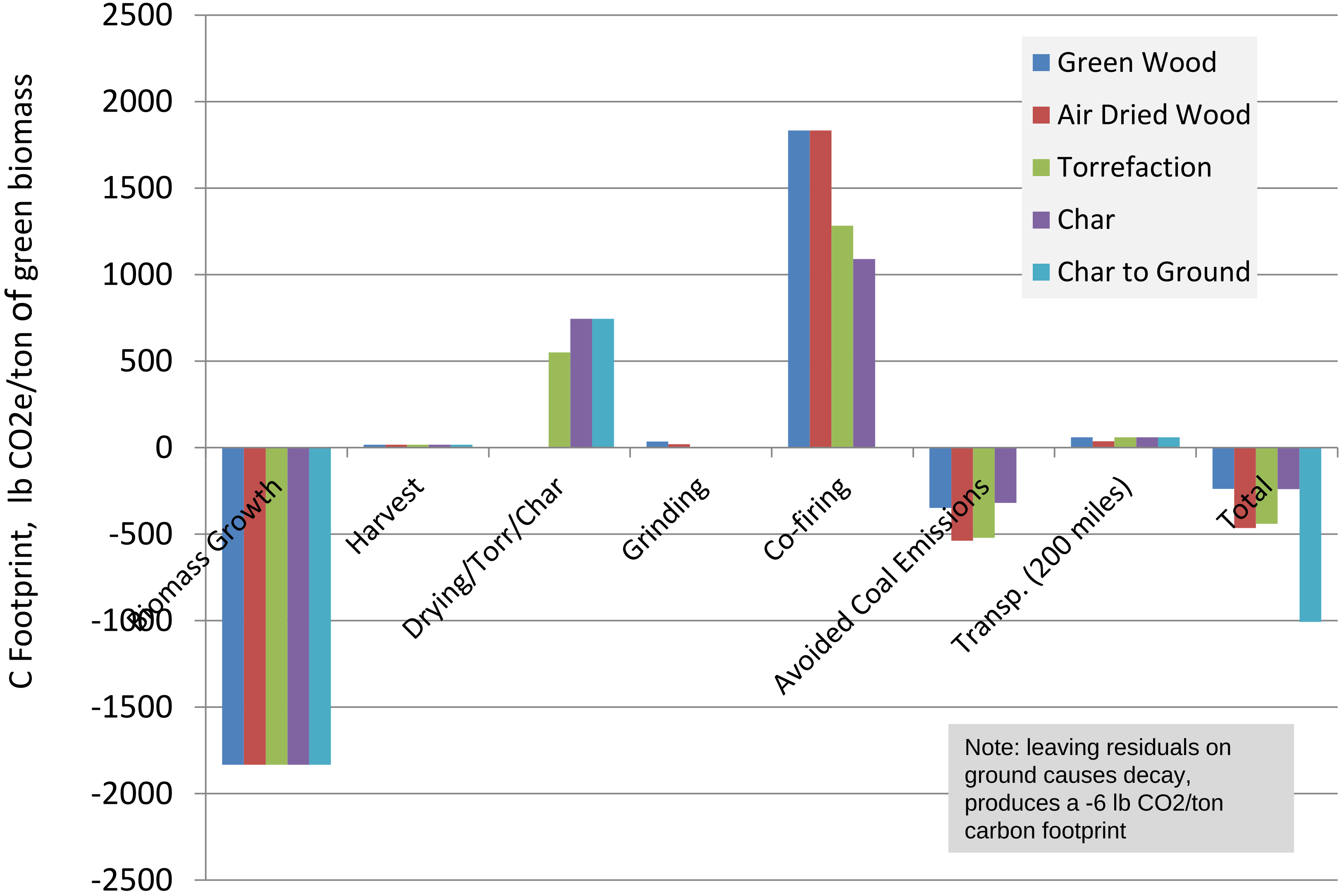
Results:

Carbon Footprints

	Residuals Left on Ground	Green Wood Co-fire	Field Dry Wood Co-fire	Torrefied Wood Co-fire	Char Co-fire	Char to Soil
Biomass Growth	-1833	-1833	-1833	-1833	-1833	-1833
Feller/Buncher		2.3	2.3	2.3	2.3	2.3
Skidder		6.6	6.6	6.6	6.6	6.6
Chipper		6.9	6.9	6.9	6.9	6.9
Torrefaction/Char Emissions		0	0	550	744	744
Size Reduction		34.5	19.9	5.2	2.2	2.2
Avoided Emissions		-349	-538	-521	-320	
Emissions from Combustion		1833	1833	1283	1089	
Decay Emissions	1827					
Carbon Emissions in Soil Application						2.2
Carbon Sequestered in Ground						-1089
Carbon Footprint (no transport)	**-6**	**-298**	**-502**	**-500**	**-301**	**-1068**

Units: lbs CO_2e/ton green wood

Carbon Footprint of Various Systems



Global Warming Potential: Biomass Gasification for Power

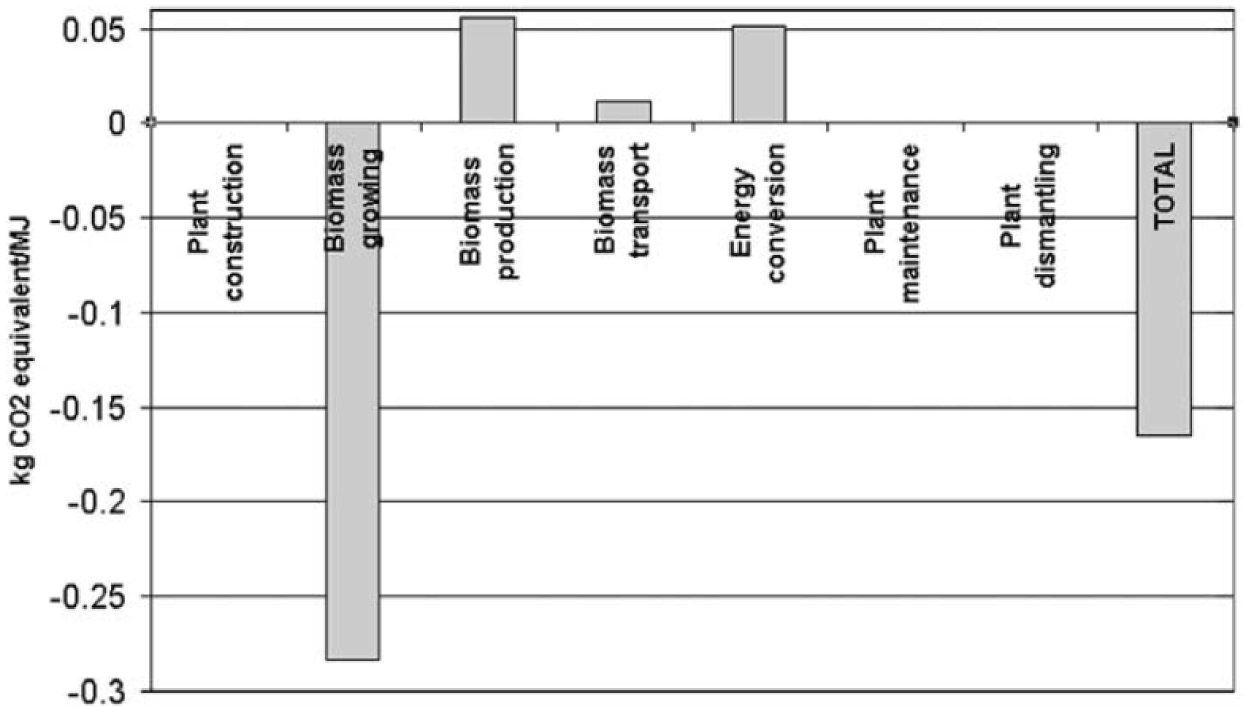
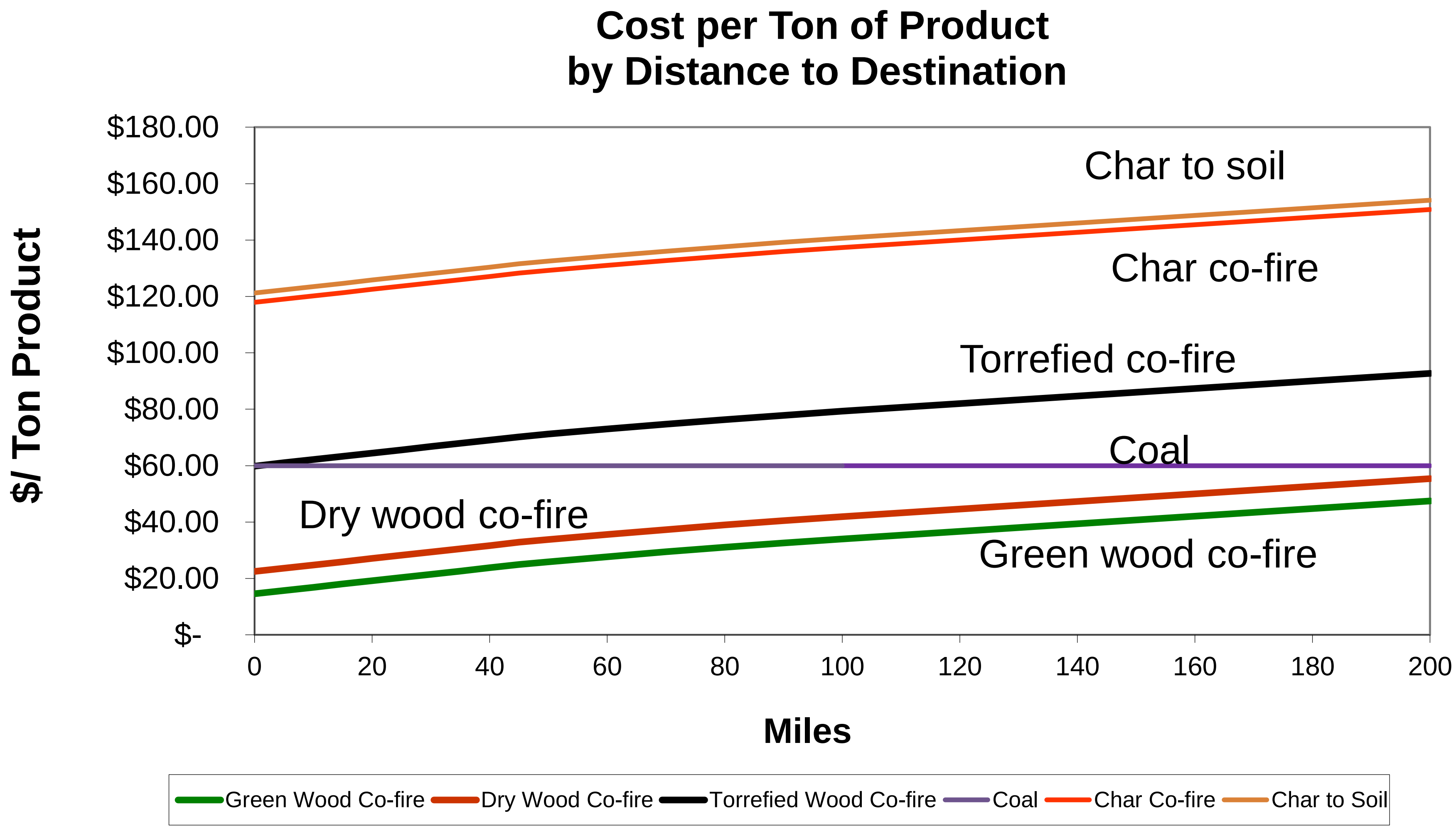


Fig. 5. Greenhouse effect indicator.

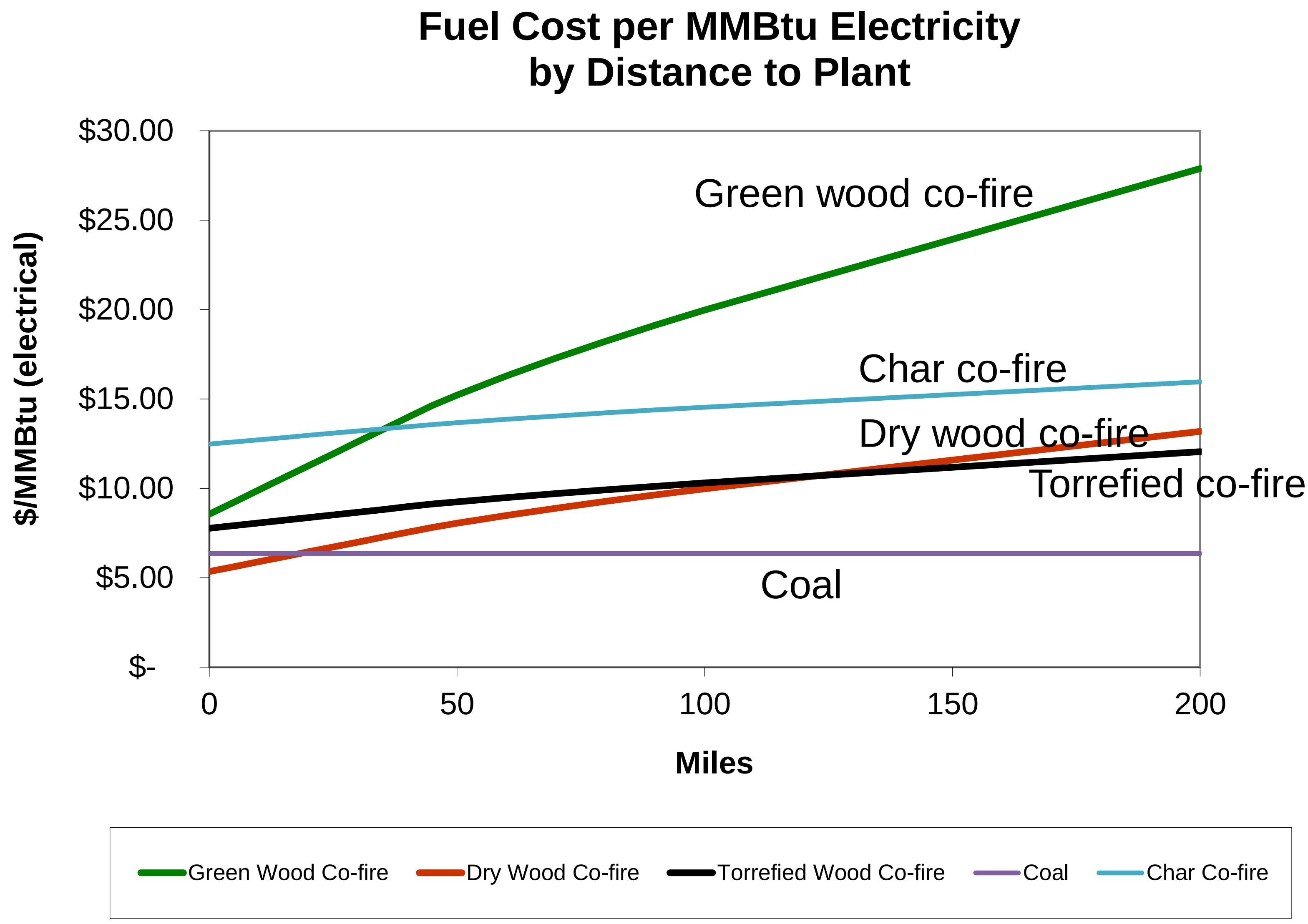
Life cycle assessment (LCA) of an integrated biomass gasification combined cycle (IBGCC) with CO2 removal. Matteo Carpentieri *, Andrea Corti, Lidia Lombardi, Energy Conversion and Management 46 (2005) 1790–1808

Manufacturing Costs:

Source of Cost	Cost Per Green Ton	Comments
Feller-Buncher	$2.36	
Skidder	$0.74	
Chipper	$6.03	
Total Harvest	$9.12	
Overhead and Profit	30%	
Total Harvesting Cost	$11.86	
transportation cost/(ton*mile)	$0.23	
torrefaction cost/GW feed ton	$23.00	Bergman 05, p. 55
char cost/GW feed ton	$45.00	Roberts et al, 2010, S20
Applied to Soil Cost, $/ton	$3.30	Roberts etal, 2010, SI18
Stored on Roadside, $/ton	$1.00	
Coal $/ton	$60	
Electricity Price	0.0000139	$/kJ
Grinding Energy		Bergman, 2005
Green Wood	195	kJe/kg
Air Dry Wood (20% MC)	180	kJe/kg
Torrefied Wood	90	kJe/kg
Char (coal, Govin 2009)	75	kJe/kg



Cost per Ton of Product
by Distance to Destination
$/ Ton Product
$180.00
$160.00
$140.00
$120.00
$100.00
$80.00
$60.00
$40.00
$20.00
$-
0
20
40
60
80
100
120
140
160
180
200
Miles
Char to soil
Char co-fire
Torrefied co-fire
Coal
Dry wood co-fire
Green wood co-fire
Green Wood Co-fire
Dry Wood Co-fire
Torrefied Wood Co-fire
Coal
Char Co-fire
Char to Soil



Fuel Cost per MMBtu Electricity
by Distance to Plant
$/MMBtu (electrical)
$30.00
$25.00
$20.00
$15.00
$10.00
$5.00
$-
0
50
100
150
200
Miles
Green wood co-fire
Char co-fire
Dry wood co-fire
Torrefied co-fire
Coal
Green Wood Co-fire
Dry Wood Co-fire
Torrefied Wood Co-fire
Coal
Char Co-fire

Carbon Prices:

Carbon pricing: placing a price on carbon through either subsidies, a carbon tax, or an emissions trading ("cap-and-trade") system.

Associating an approximate cost to damage such as increasing extreme weather, carbon pricing may be used as an incentive to cut carbon emissions.

"Carbon Price". Global Greenhouse Warming.com. Retrieved 2010-09-01.

Source: www.pointcarbon.com.
One Euro equals about $1.5.

Calculation of Minimum Carbon Prices:

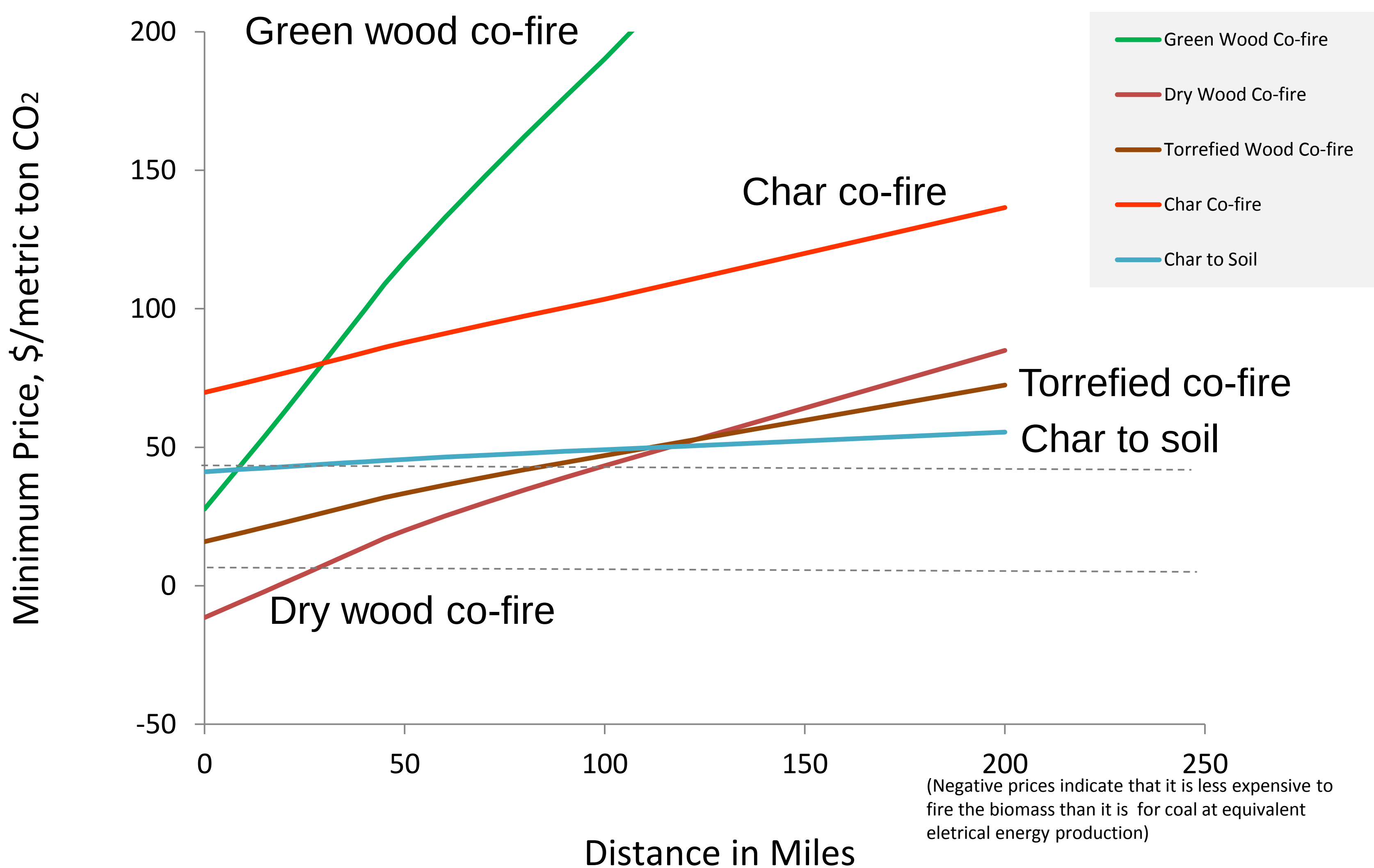
$$Minimum\ Carbon\ price\ \left(\frac{\$}{\text{ton CO2}}\right) = \left(\frac{\$Cost\ Biomass - \$Cost\ Coal}{MMBTUe}\right)\left(\frac{MMBTUe\ by\ Biomass}{Ton\ CO2\ saved}\right)$$

(Added cost to utilize biomass) (Amt of CO2 saved using biomass)

$$Minimum\ Carbon\ price\ \left(\frac{\$}{\text{ton CO2}}\right) = \left(\frac{\$Cost\ to\ Apply\ Char\ to\ land}{ton\ biomass\ consumed}\right)\left(\frac{ton\ biomass\ consumed}{Ton\ CO2\ saved}\right)$$

(Added cost to utilize biomass) (Amt of CO2 saved using biomass)

Minimum Carbon Price Required to Promote Biomass System



(Negative prices indicate that it is less expensive to fire the biomass than it is for coal at equivalent eletrical energy production)

Dashed lines: historical high (45) and price 7/2011 (15) of CO2 as reported by http://www.nytimes.com /2009/01/21/business/worldbusiness

Summary

- Char to ground has the lowest carbon footprint
- Life Stagest that Dominate the carbon footprint:
  - Biomass growth
  - preprocessing (torrefaction and charring)
  - co-firing
- Transportation distance not important for carbon footprint
- Transportation distance very important for costs
- Field Dried or torrefied wood, under the model assumptions, have the most potential for commercial viability in a carbon market
  - Require travel distances of less than 100 miles

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Minimum Carbon Price Required to Promote Biomass Systems: Carbon Footprints

Material Balances of 1 Ton green wood					
	Units	Green Wood	20% MC Air Dry Wood	Torrefied Wood	Charred Wood
Total Material		1	0.625	0.33	0.165
Total Material Loss	mass/mass	0	0.375	0.67	0.835
Solids		0.5	0.5	0.33	0.165
Solids Loss	mass/mass	0	0	0.34	0.67
Water		0.5	0.125	0	0
Water Loss	mass/mass	0	0.75	1	1
Carbon		0.25	0.25	0.175	0.1485
Carbon Loss	mass/mass	0	0	0.3	0.406
% Carbon (dry basis)		50	50	53	90

MMBTU/ton	
Green Wood	7.4
Air Dry Wood (20% MC)	14
Torrefied Wood	22
Coal	24
Charred Wood	27
Efficiency Thermal to Electricity	
Green Wood	23%
Air Dry Wood (20% MC)	30%
Torrefied Wood	35%
Coal	35%
Charred Wood	35%

Note: leaving residuals on ground causes decay, produces a -6 lb CO_2/ton carbon footprint