RENEWABLE ENERGY TRAINING PROGRAM
MODULE 8 | BIOENERGY
Solid Biomass for Power Generation

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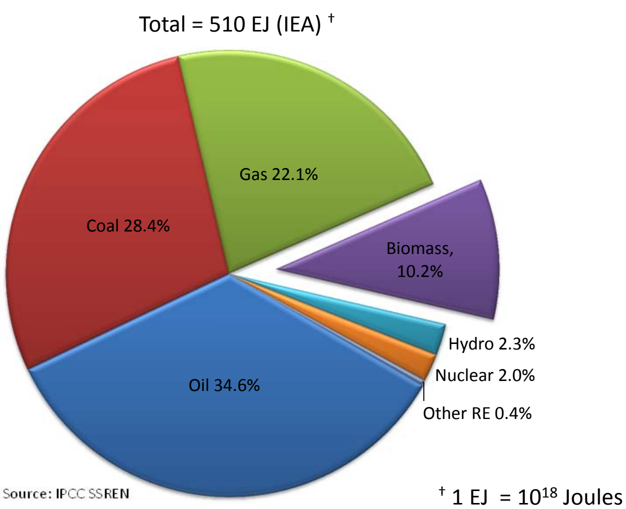
Overview

- Introduction
- Current status of solid biomass
- Technologies
- Brazil as an example

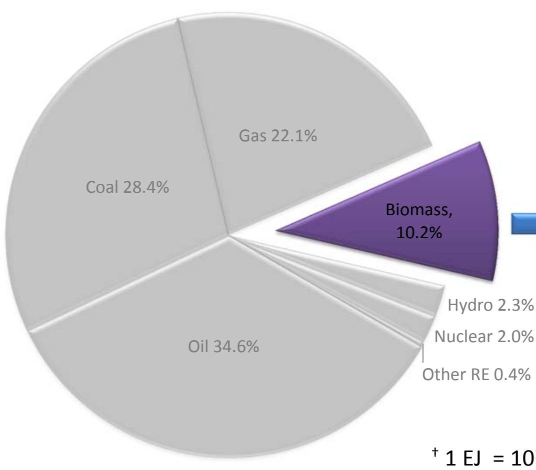
Total Primary Energy Supply (TPES) in 2008

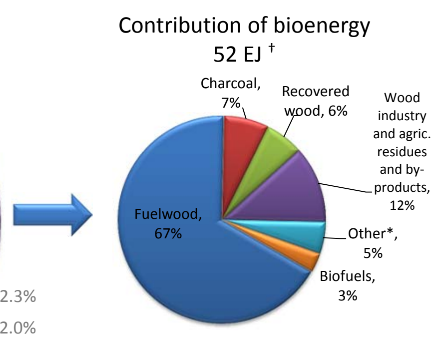


Source: IPCC SSREN

† 1 EJ = 10^{18} Joules

Supply of Bioenergy (2008/9)



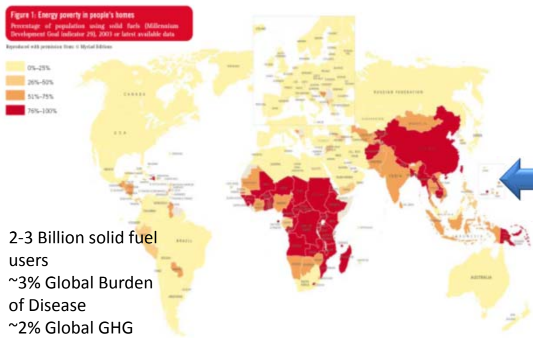


* Includes MSW, LFG, forest residues, and black liquor

† 1 EJ = 10^{18} Joules

Source: IPCC SSREN
IEA stats

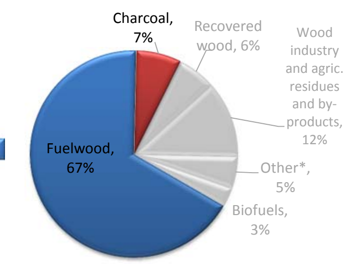
1. Traditional fuels



- 2-3 Billion solid fuel users
- ~3% Global Burden of Disease
- ~2% Global GHG emissions

WHO 2006

Contribution of “traditional biofuels”
38 EJ †



* Includes MSW, LFG, forest residues, and black liquor

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Source: IPCC SSREN
IEA stats

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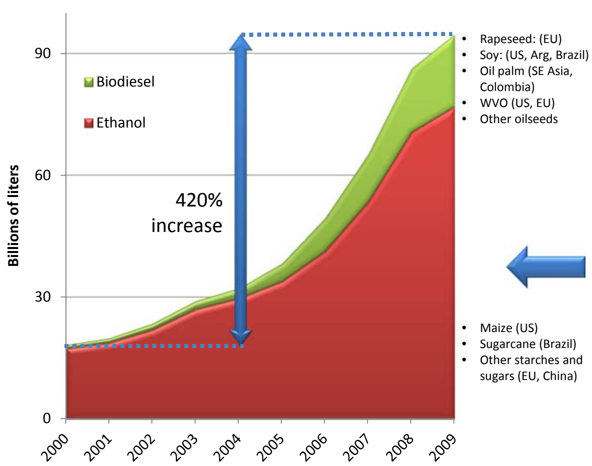
2. Biofuels

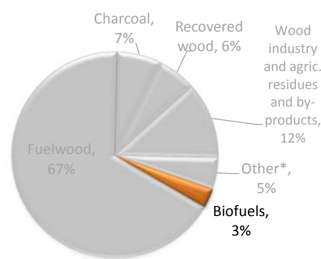


- Rapeseed: (EU)
- Soy: (US, Arg, Brazil)
- Oil palm (SE Asia, Colombia)
- WVO (US, EU)
- Other oilseeds

- Maize (US)
- Sugarcane (Brazil)
- Other starches and sugars (EU, China)

Bailis, German, van Gelder, in review

Contribution of biofuels
2 EJ †



* Includes MSW, LFG, forest residues, and black liquor

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Source: IPCC SSREN
IEA stats

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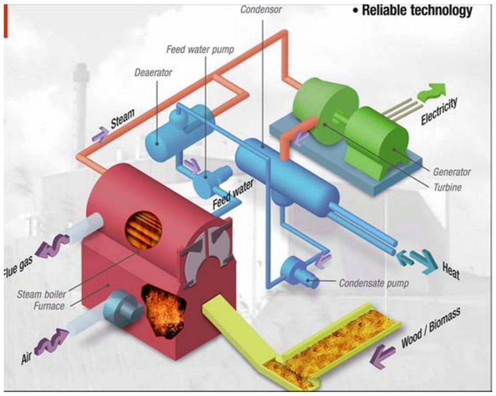
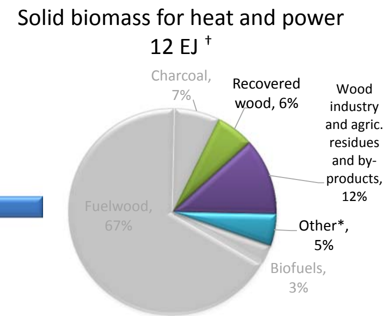
3. Solid fuels for heat and power



Cogeneration – common use of solid biomass



* Includes MSW, LFG, forest residues, and black liquor

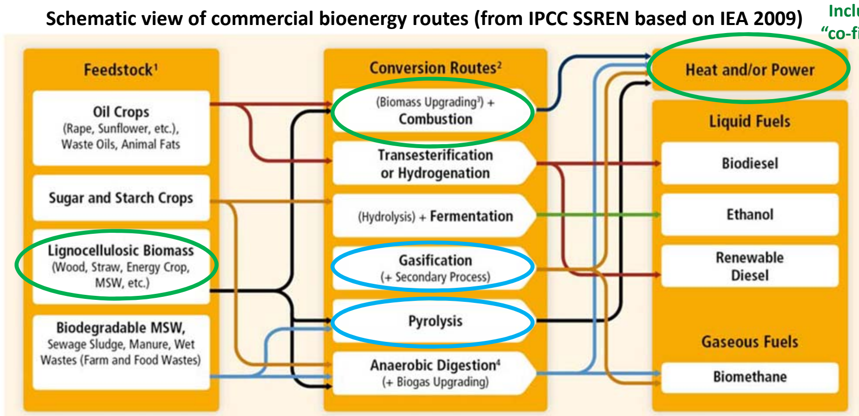
† 1 EJ = 10^{18} Joules

Source: IPCC SSREN
IEA stats

Bioenergy conversion pathways

Schematic view of commercial bioenergy routes (from IPCC SSREN based on IEA 2009)

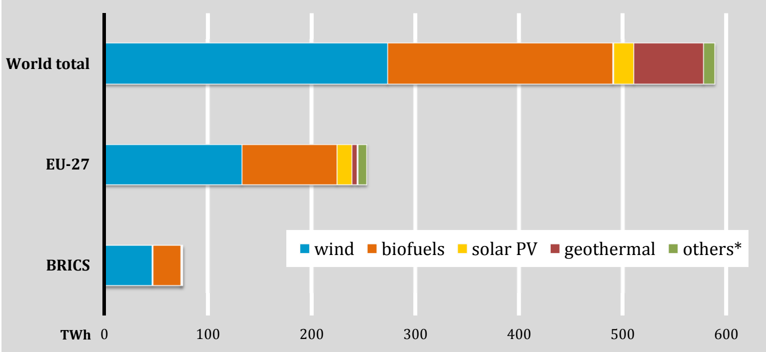
Includes "co-firing"



Notes:
[1]Parts of each feedstock (e.g. crop residues) could be used in other routes.
[2]Each route also gives coproducts.
[3]Biomass upgrading includes any one of the densification processes (pelletization, pyrolysis, etc.).
[4]Anaerobic digestion processes release methane and CO_2 and removal of CO_2 provides essentially methane, the main component of natural gas; the upgraded gas is called biomethane.

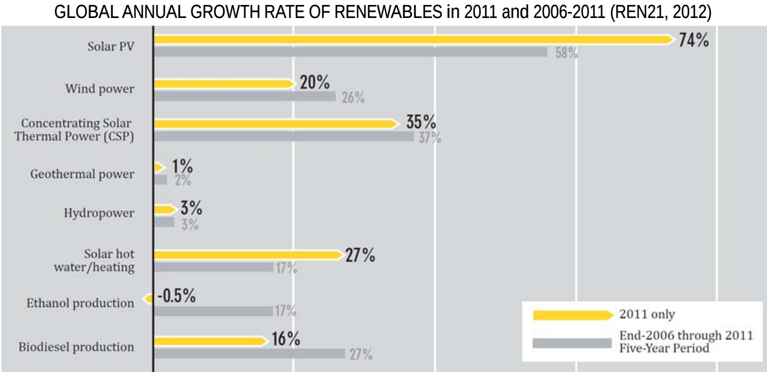
Current status

RENEWABLE POWER DELIVERED TO GRID IN 2009: WORLD, EU27, BRICS (IEA, 2012)

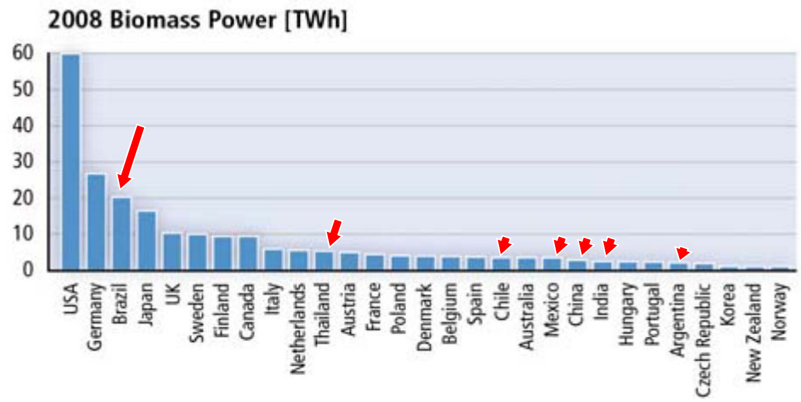


Current status

GLOBAL ANNUAL GROWTH RATE OF RENEWABLES in 2011 and 2006-2011 (REN21, 2012)

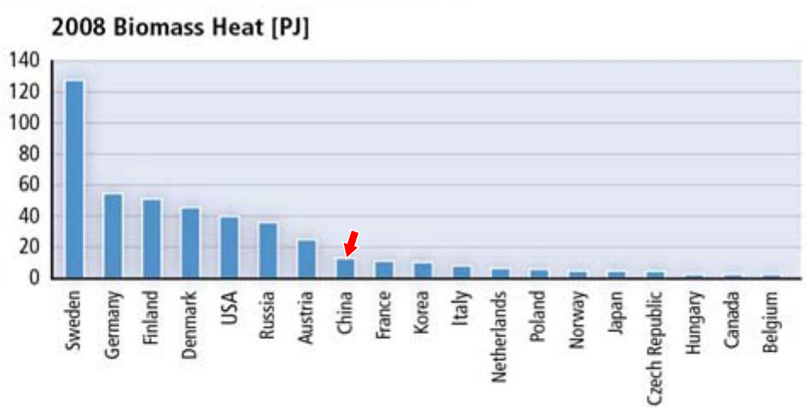


Top producers in 2008: biomass electricity



IPCC SSREN

Top producers in 2008: biomass heating



IPCC SSREN

Technologies for Heat and Power from Solid Biomass

- Combustion
- Pyrolysis
- Gasification

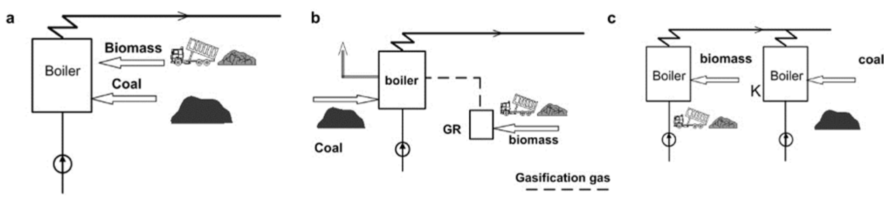
Combustion

- Most popular route for both heat and power
  - Wide range of fuels (logs, chips, pellets, MSW, **bagasse**…)
- Heat - typically 1-10 MW
  - Common for industries and district heating
- Power - typically 10-50 MW
  - Rankine (steam) cycle
  - $\eta \approx$ 18-33% (< comparably-sized fossil plants)

(Heat and Power together: CHP)

Co-firing

- “Easy” way to integrate biomass in heat or power production
- Utilize higher efficiencies in large plants (100-1000 MW)
- 5-10% mix readily achievable w/direct combustion
- > 100 commercial facilities worldwide (IEA database)



Biomass co-firing technologies. a) Direct co-firing. b) Indirect co-firing. c) Parallel co-firing from Al-Mansour and Zuwala (2010)
http://dx.doi.org/10.1016/j.biombioe.2010.01.004

Co-firing – pollution reduction

M. Sami et al. / Progress in Energy and Combustion Science 27 (2001) 171–214

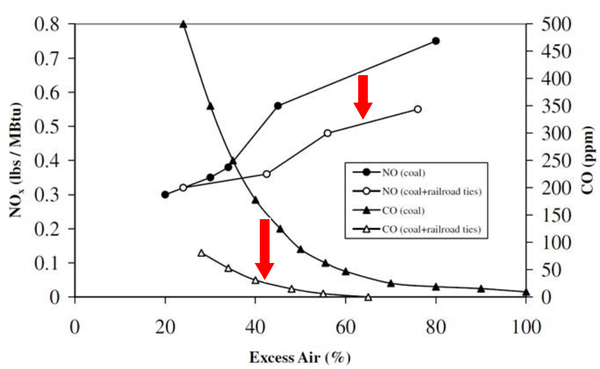
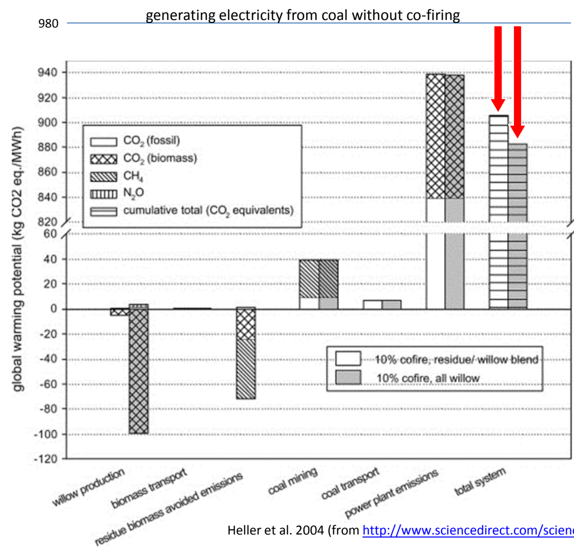


Fig. 21. Effects of co-firing 20% (mass basis) railroad ties with coal on NO_x and CO emissions [76].

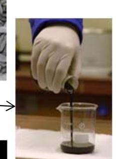
Co-firing – pollution reduction



Heller et al. 2004 (from http://www.sciencedirect.com/science/article/pii/S0960148103003914)

Pyrolysis

- Thermal decomposition of biomass occurring in the absence of oxygen that produces:
  - a **solid** (char/charcoal)
  - a **liquid** (pyrolysis oil or bio-oil)
  - **gases** (CO_2, CO, H_2, CH_4, HCs…)



- Always the first step in combustion and gasification processes

(followed by total/partial oxidation of primary products)

Pyrolysis

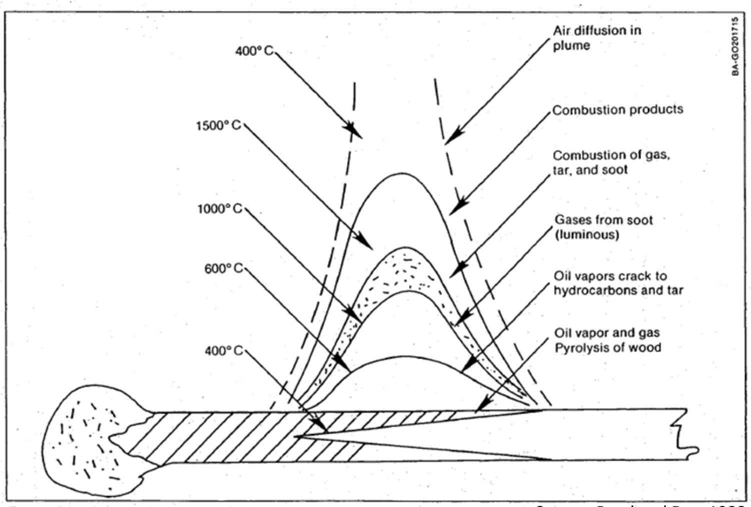
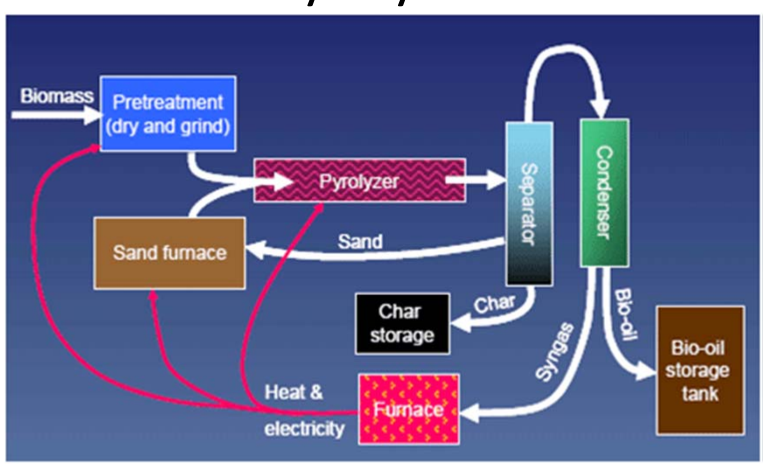


Fig. 4-2. Pyrolysis, gasification, and combustion in the flaming match

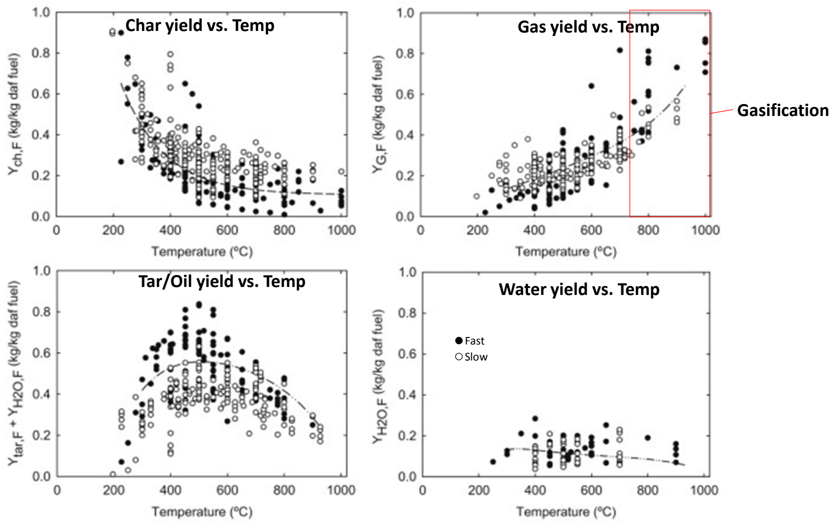
Source: Reed and Das, 1988

Pyrolysis



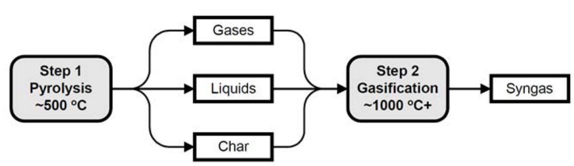
http://www.ars.usda.gov

Pyrolysis



Gasification

- Partial thermal oxidation of biomass



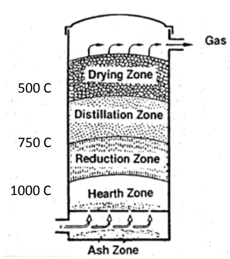
  - Results in a combustible mixture of gases
    - "syn gas" or "producer gas"
    - Mainly CO and H_2
    - 5 - 20 MJ/Nm^3 (10-45% HV or nat. gas)
      - Air-based systems are lower (N_2 dilutes the mix)
      - Steam or oxy-based systems are higher

Gasification

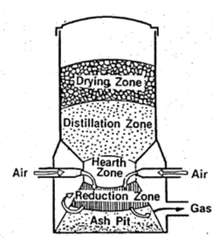
Primary devolatilization				
Biomass	→	Primary tar (CH_xO_y) CO, CO_2, CH_4, C_2H_4, H_2O Carbon		*[eq.1]*
Tar cracking and reforming				
Primary tar	→	Secondary tar CO, CO_2, CH_4, C_2H_4, H_2		*[eq.2]*
Homogenous gas-phase-reactions			ΔH	
Secondary tars	→	C, CO, H_2		*[eq.3]*
$H_2 + 0{,}5\ O_2$	→	H_2O	-242 kJ/mol	*[eq.4]*
$CO + 0{,}5\ O_2$	→	CO_2	-283 kJ/mol	*[eq.5]*
$CH_4 + 0{,}5\ O_2$	→	$CO + 2\ H_2$	-110 kJ/mol	*[eq.6]*
$CH_4 + CO_2$	→	$2\ CO + 2\ H_2$	+247 kJ/mol	*[eq.7]*
$CH_4 + H_2O$	→	$CO + 3\ H_2$	+206 kJ/mol	*[eq.8]*
$CO + H_2O$	→	$CO_2 + H_2$	-40,9 kJ/mol	*[eq.9]*
Heterogenous reactions				
$C + O_2$	→	CO_2	-393,5 kJ/mol	*[eq.10]*
$C + 0{,}5\ O_2$	→	CO	-123,1 kJ/mol	*[eq.11]*
$C + CO_2$	→	$2\ CO$	+159,9 kJ/mol	*[eq.12]*
$C + H_2O$	→	$CO + H_2$	+118,5 kJ/mol	*[eq.13]*
$C + 2\ H_2$	→	CH_4	-87,5 kJ/mol	*[eq.14]*

Gasification

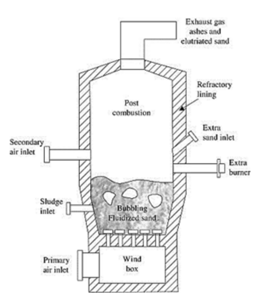
Updraft



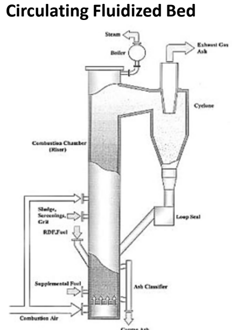
Downdraft



Bubbling Fluidized Bed



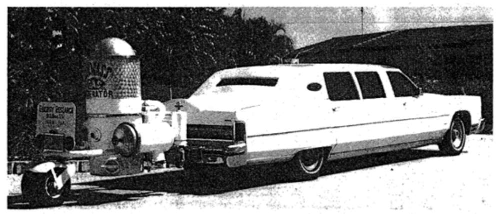
Circulating Fluidized Bed



Gasifier Type	Flow Direction Fuel	Flow Direction Oxidant	Support	Heat Source
Updraft Fixed Bed	Down	Up	Grate	Combustion of Char
Downdraft Fixed Bed	Down	Down	Grate	Partial Combustion of Volatiles
Bubbling Fluidized Bed	Up	Up	None	Partial Combustion of Volatiles and Char
Circulating Fluidized Bed	Up	Up	None	Partial Combustion of Volatiles and Char

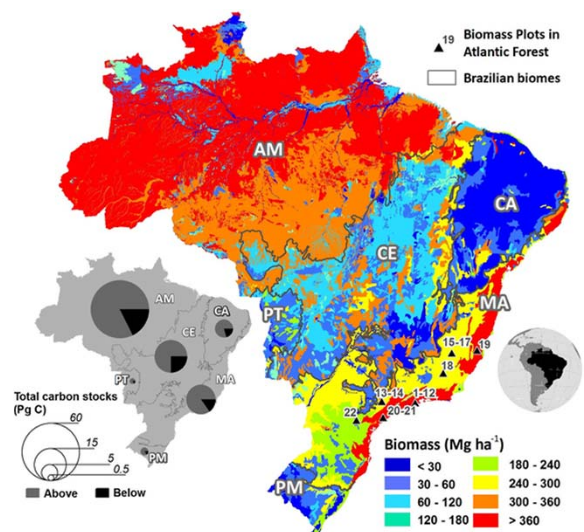
http://seca.doe.gov/technologies/coalpower/gasification/pubs/pdf/BMassGasFinal.pdf

1940s



1970s

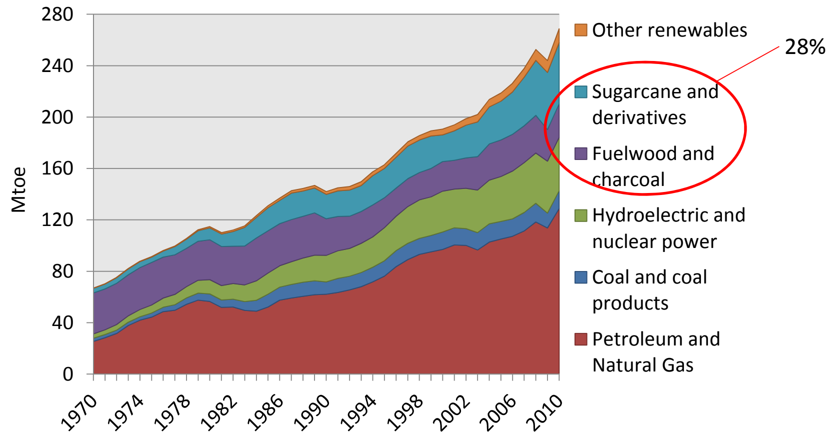
2000s



EXAMPLE - BRAZIL

Brazil – Primary Energy

Brazilian Domestic Energy Supply from 1970-2010 (EPE, 2011)



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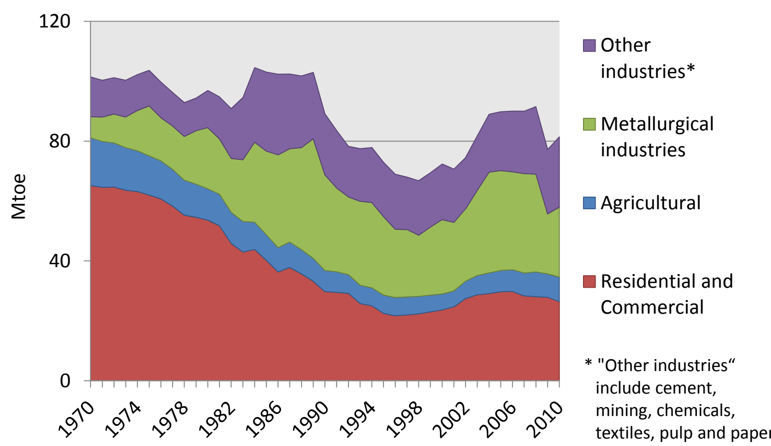
Brazil – woodfuel consumption

Brazilian Woodfuel Consumption 1970-2010 (EPE, 2011)



* "Other industries" include cement, mining, chemicals, textiles, pulp and paper and ceramics.

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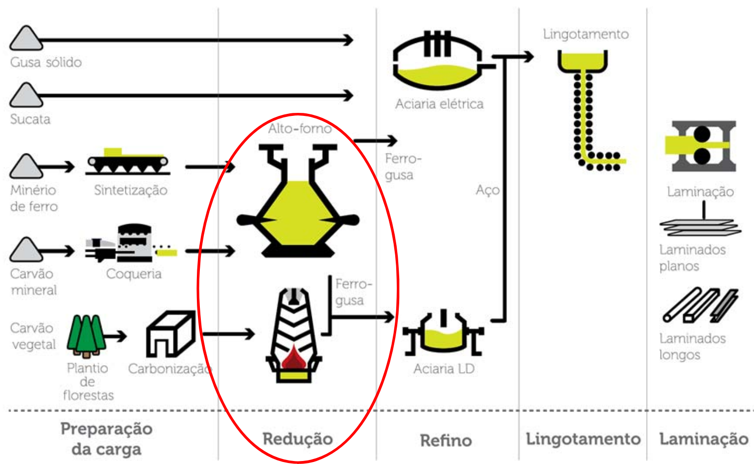
Brazil – biomass and the metallugical industry



Air blast and **charcoal** or coke: $2\,C + O_2 \rightarrow 2\,CO$

Carbon monoxide (CO) is the principal reduction agent.

Stage One: $3\,Fe_2O_3 + CO \rightarrow 2\,Fe_3O_4 + CO_2$

Stage Two: $Fe_3O_4 + CO \rightarrow 3\,FeO + CO_2$

Stage Three: $FeO + CO \rightarrow Fe + CO_2$

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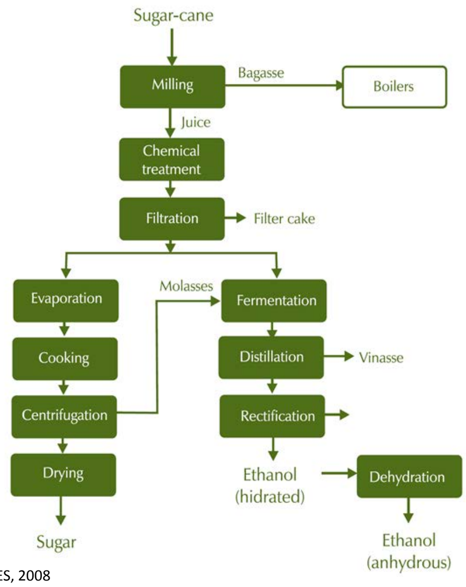
Use of solid biomass

Brazil - Sugarcane



Energy balance of sugarcane ethanol production in Brazil (MJ/ton-cane)

Component	2005/2006	2020 Scenario
Cane production & transport	210	238
Bioethanol Production	24	24
Fossil Input (total)	234	262
Bioethanol	1,926	2,060
Bagasse surplus	176	0
Electricity surplus	83	972
Total renewable output	2,185	3,032
Energy production ÷ consumption		
Bioethanol + bagasse	9	8
Bioethanol + bagasse + electricity	9.3	12

BNDES, 2008

Gasification…

"The pilot plants are hard to build and even harder to operate. Failure cases abound. However, we still found the risk to be worth taking because Brazil's potential to increase sugarcane production is so great…

Instituto de Pesquisas Tecnológicas President Fernando Landgraf