RENEWABLE ENERGY TRAINING PROGRAM
Session 7 | BIOENERGY
Solid Biomass for Power Generation

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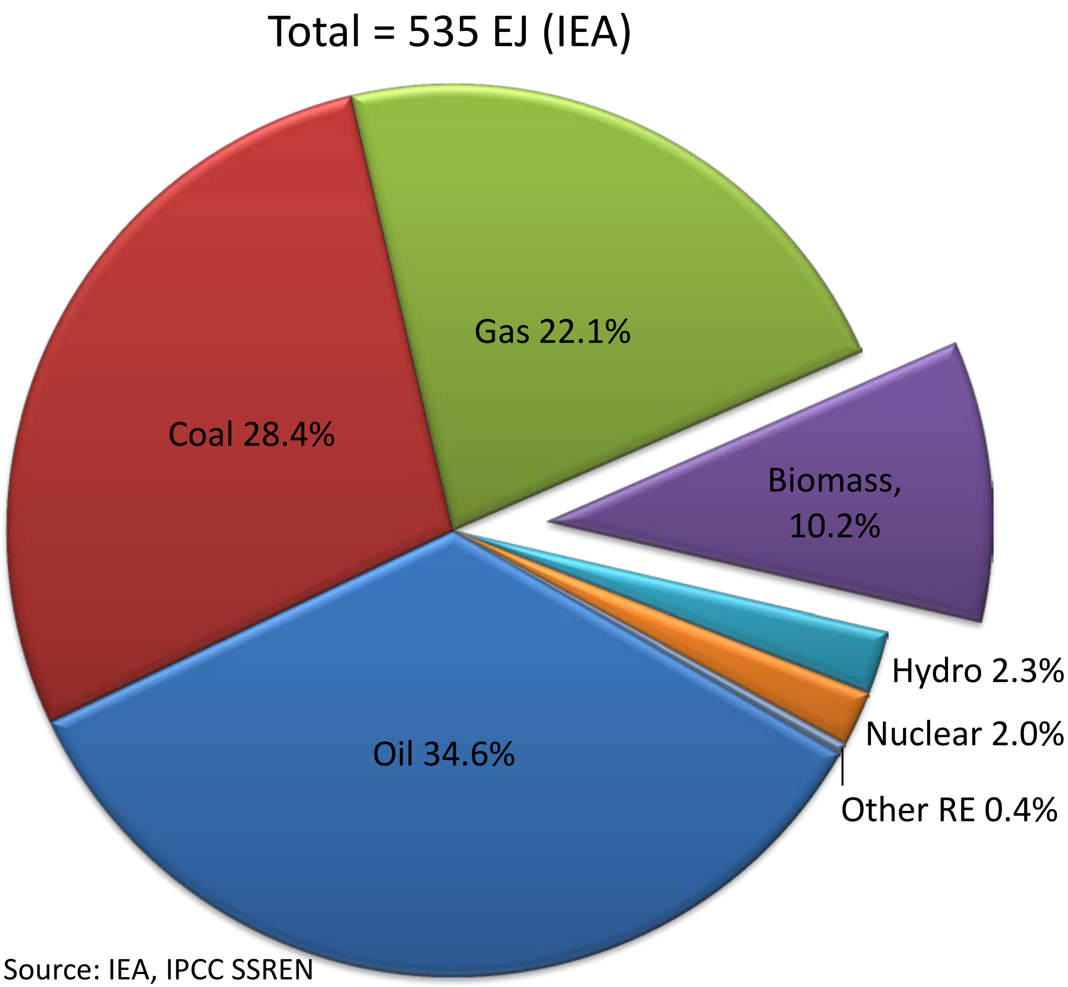
18 June 2014

Overview

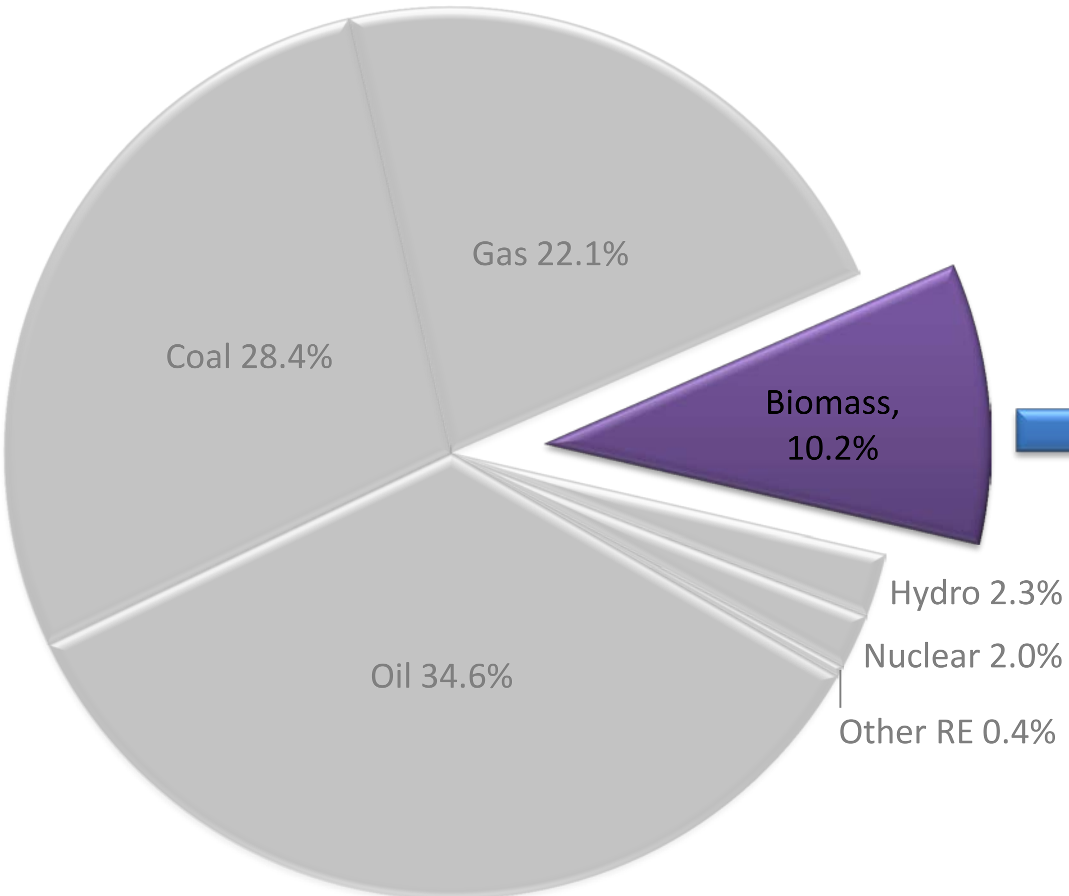
- Introduction
- Current status of solid biomass
- Technologies
- Brazil as an example

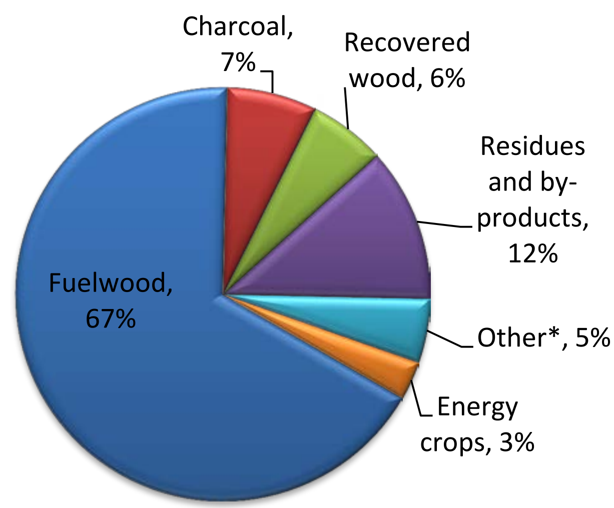
TPES (2009)



Source: IEA, IPCC SSREN

Supply of Bioenergy (2009)

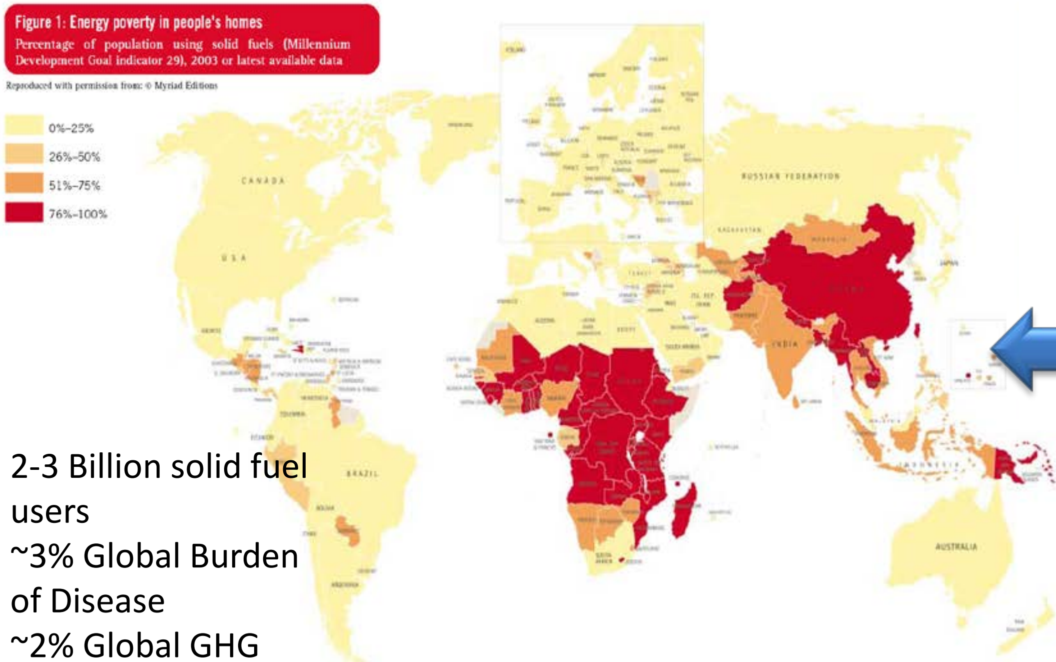




* Includes MSW, LFG, forest residues, and black liquor

Source: IPCC SSREN
IEA stats

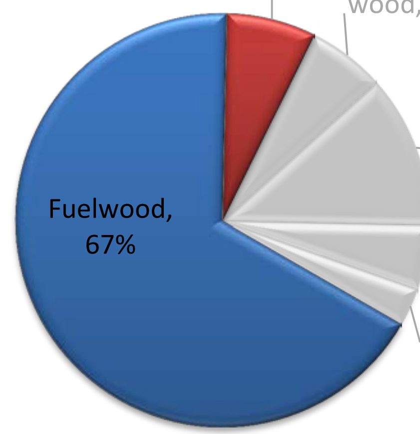
Traditional fuels



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

WHO 2006

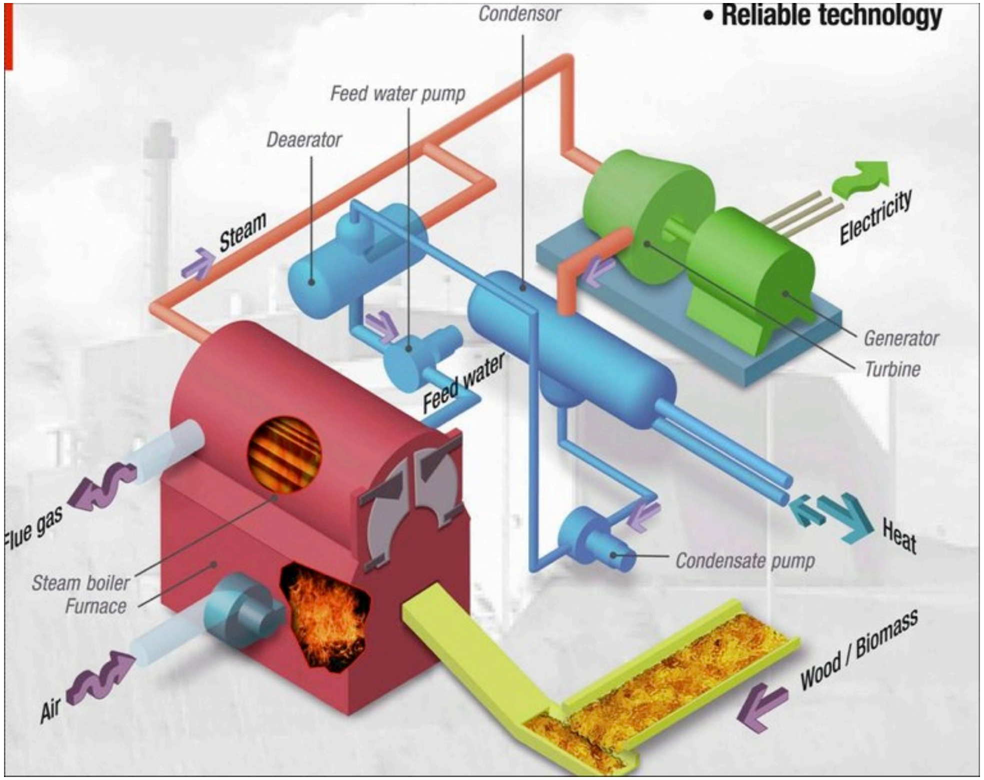
Contribution of “traditional biofuels” 38 EJ



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

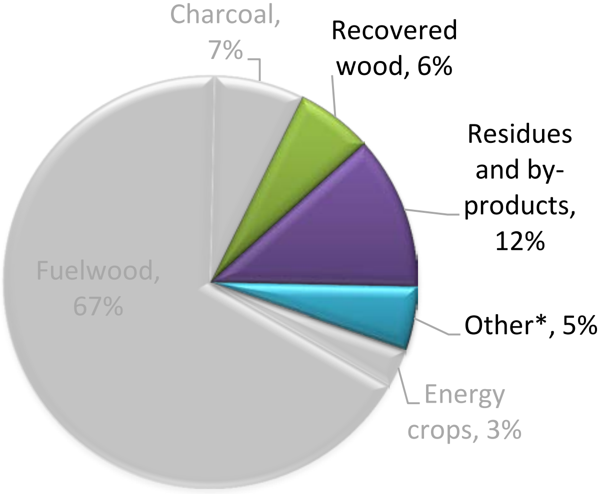
Source: IPCC SSREN
IEA stats

Heat and power applications



Cogeneration – common use of biomass waste and residues

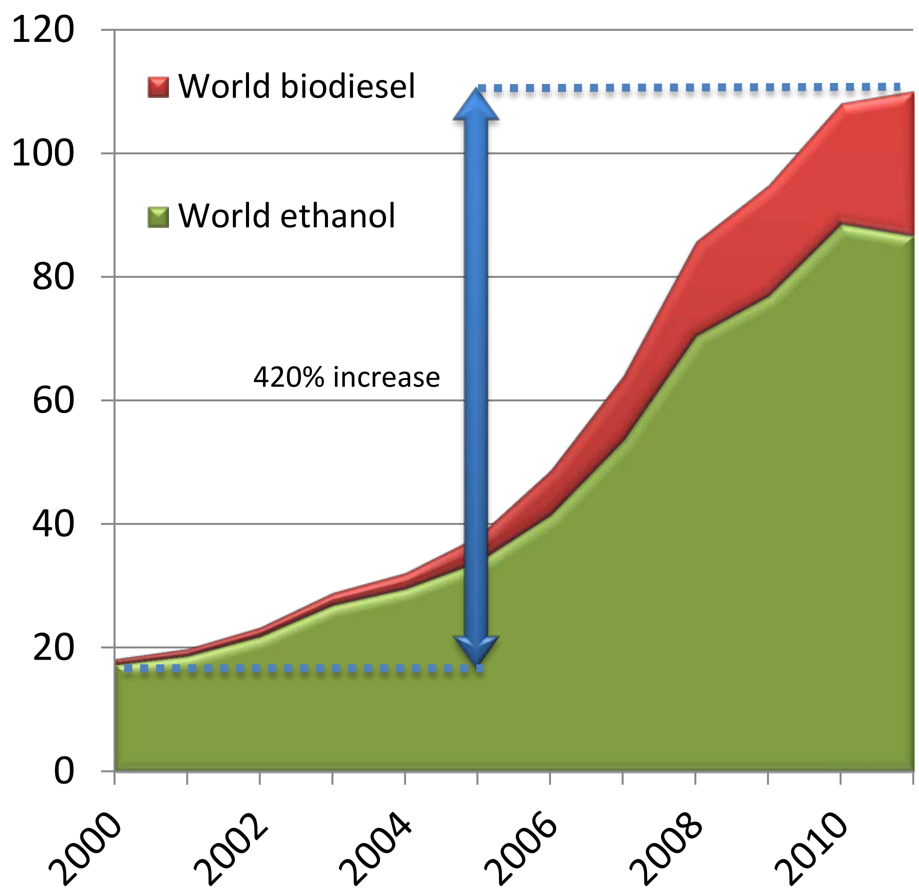
Contribution of biomass to heat and power
12 EJ (IEA)



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

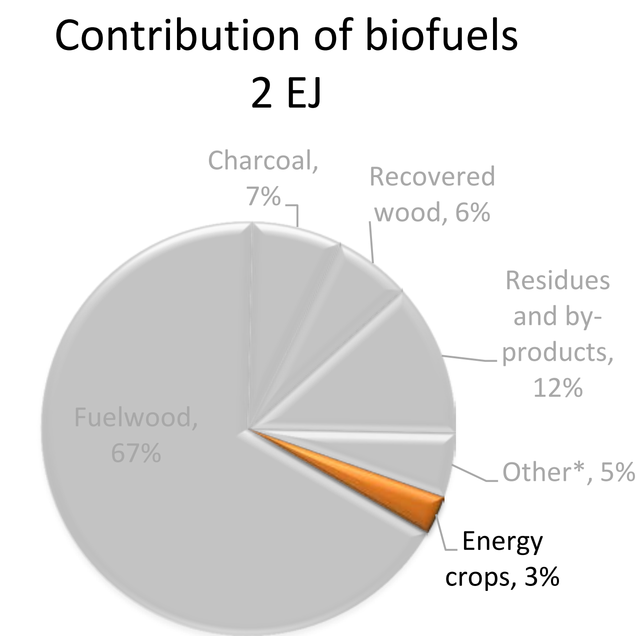
Source: IPCC SSREN
IEA stats

Biofuels



- Rapeseed (canola)
- Soy
- Oil palm
- WVO
- Other oilseeds

- Maize
- Sugarcane
- Other starches and sugars



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

Source: IPCC SSREN
IEA stats

EIA, 2013

Biomass for electricity (2012)

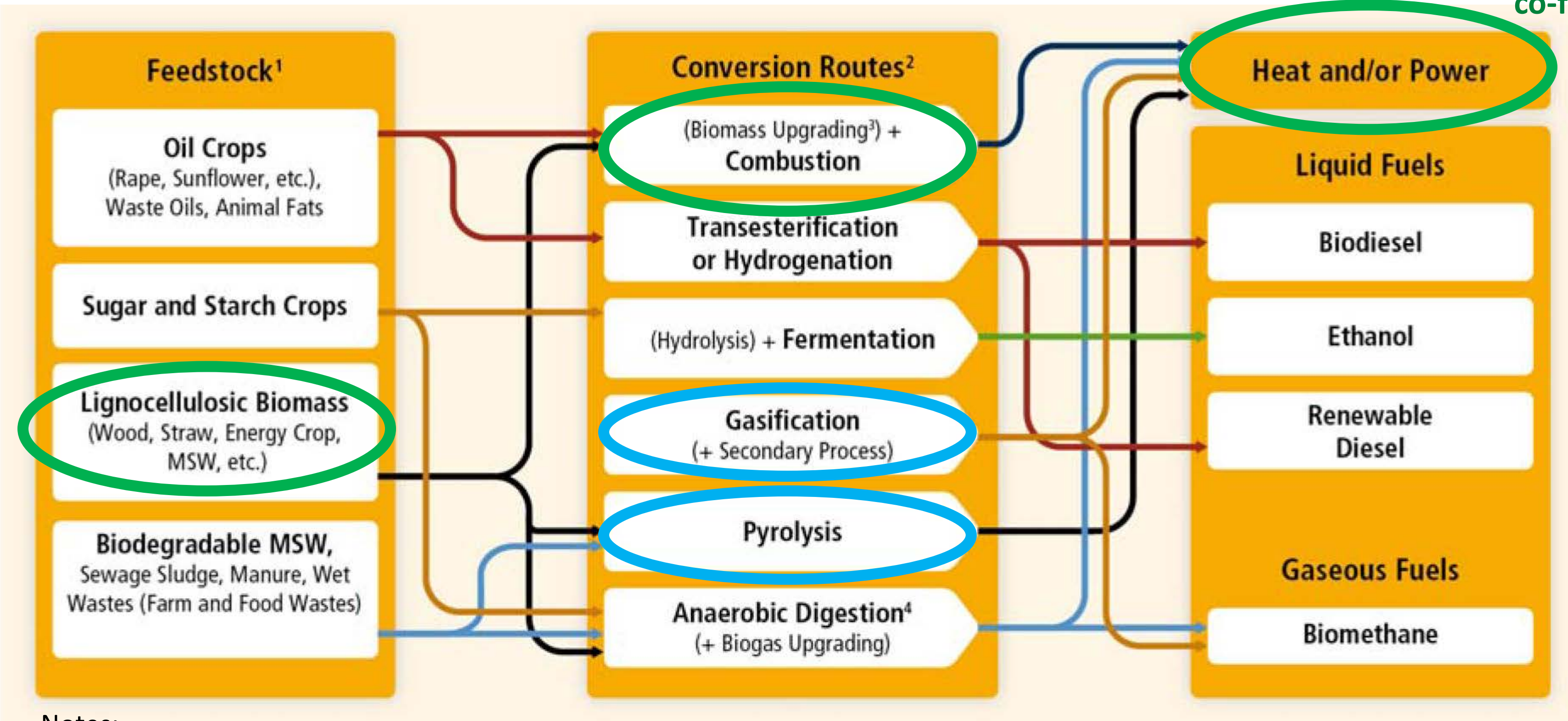
Technology	World Total	EU-27	BRICS	China	United States	Germany	Spain	Italy	India
	(GW)								
Bio-power	83	31	24	8	15	7.6	1	3.8	4
Geothermal power	11.7	0.9	0.1	~0	3.4	~0	0	0.9	0
Ocean (tidal) power	0.5	0.2	~0	~0	~0	0	~0	0	0
Solar PV	100	69	8.2	7.0	7.2	32	5.1	16.4	1.2
Concentrating solar thermal power (CSP)	2.5	2	~0	~0	0.5	~0	2	~0	~0
Wind power	283	106	96	75	60	31	23	8.1	18.4
Total renewable power capacity (not including hydropower)	**480**	**210**	**128**	**90**	**86**	**71**	**31**	**29**	**24**

REN21 2013 Global Status Report

Bioenergy conversion pathways

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

Includes "co-firing"



Notes:

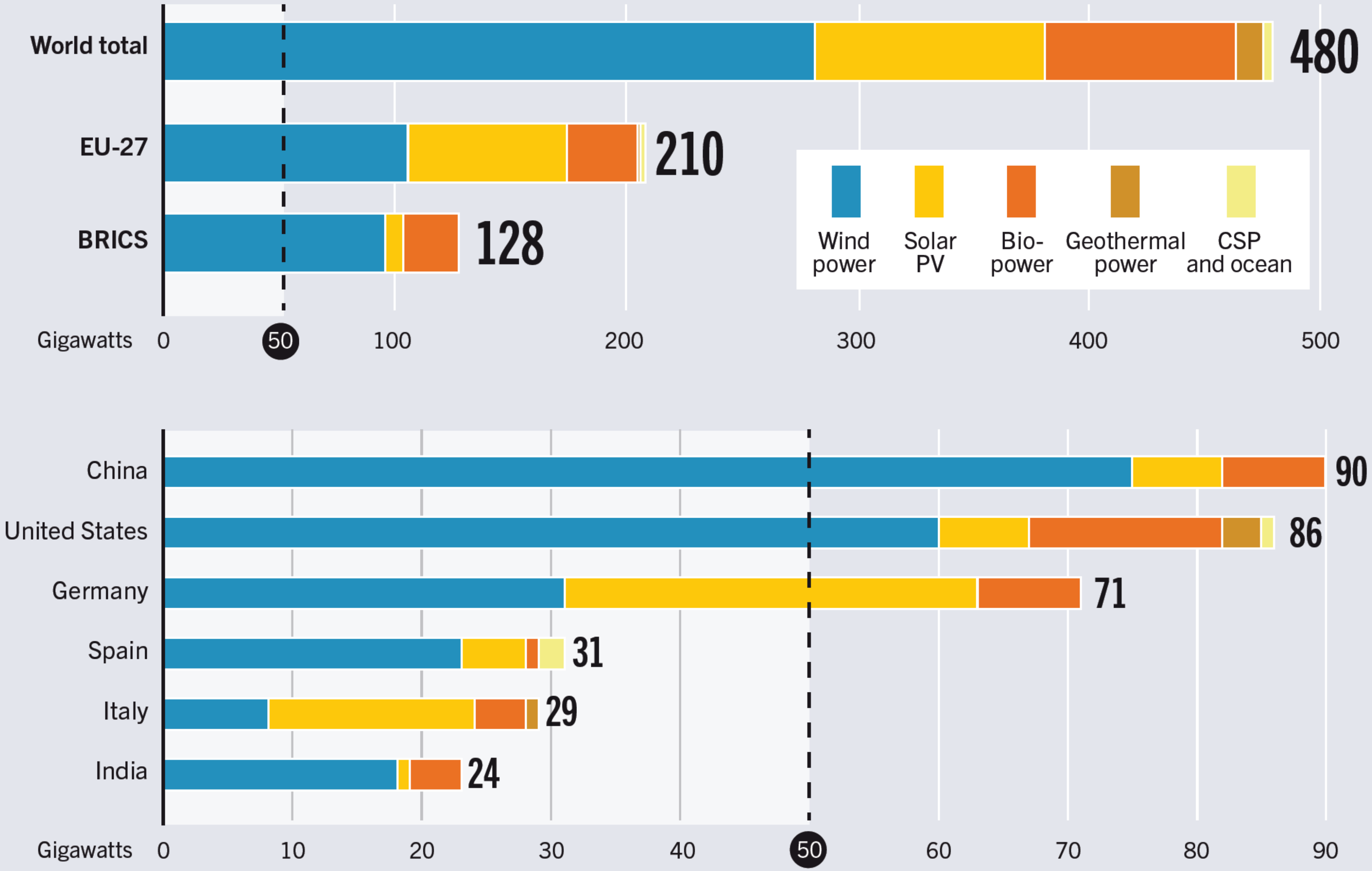
[1]Parts of each feedstock (e.g. crop residues) could be used in other routes.

[2]Each route also gives coproducts.

[3]Biomass upgrading includes any one of the densification processes (pelletization, pyrolysis, etc.).

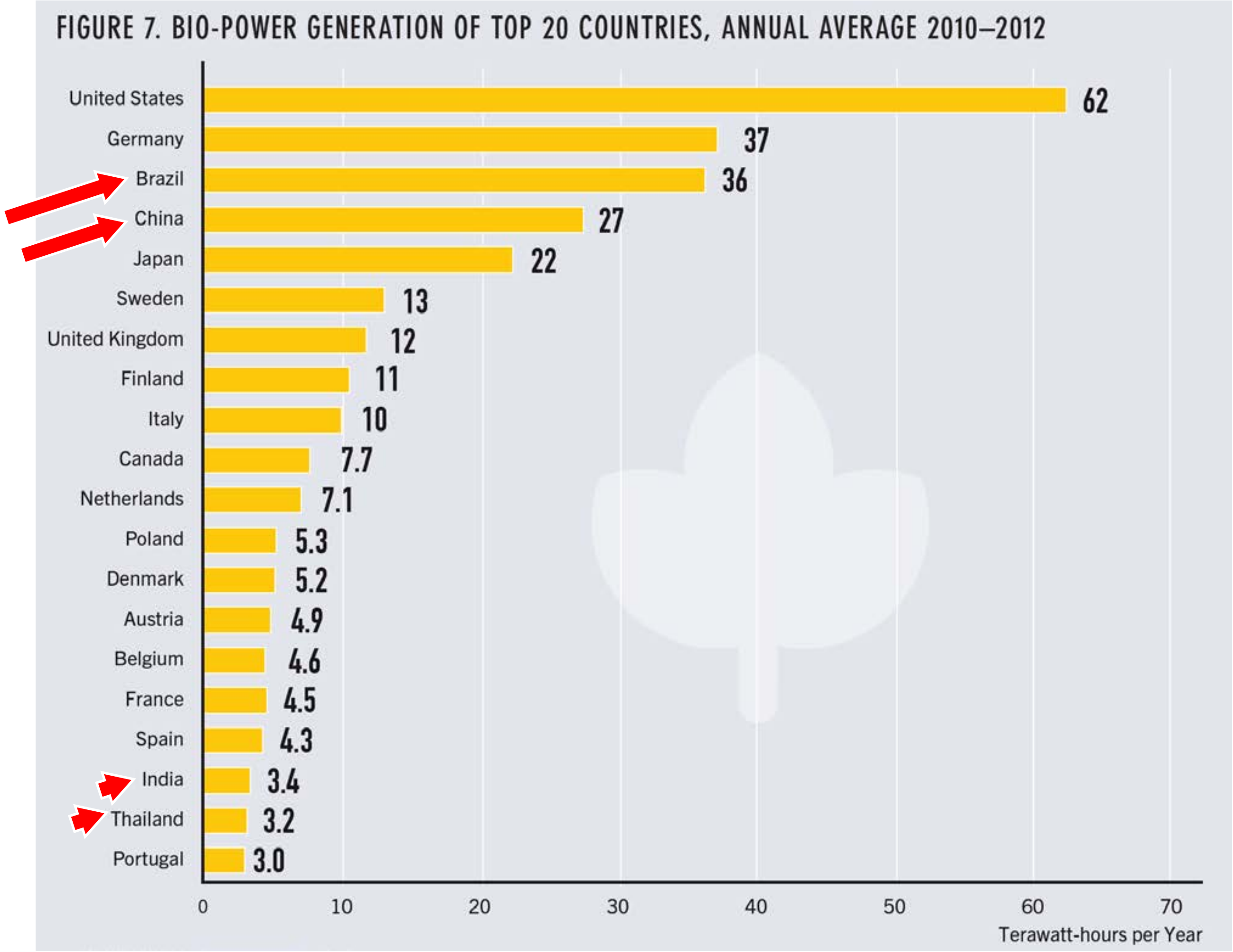
[4]Anaerobic digestion processes release methane and CO_2 and removal of CO_2 provides essentially methane, the main component of natural gas; the upgraded gas is called biomethane.

FIGURE 4. RENEWABLE POWER CAPACITIES* IN WORLD, EU-27, BRICS, AND TOP SIX COUNTRIES, 2012



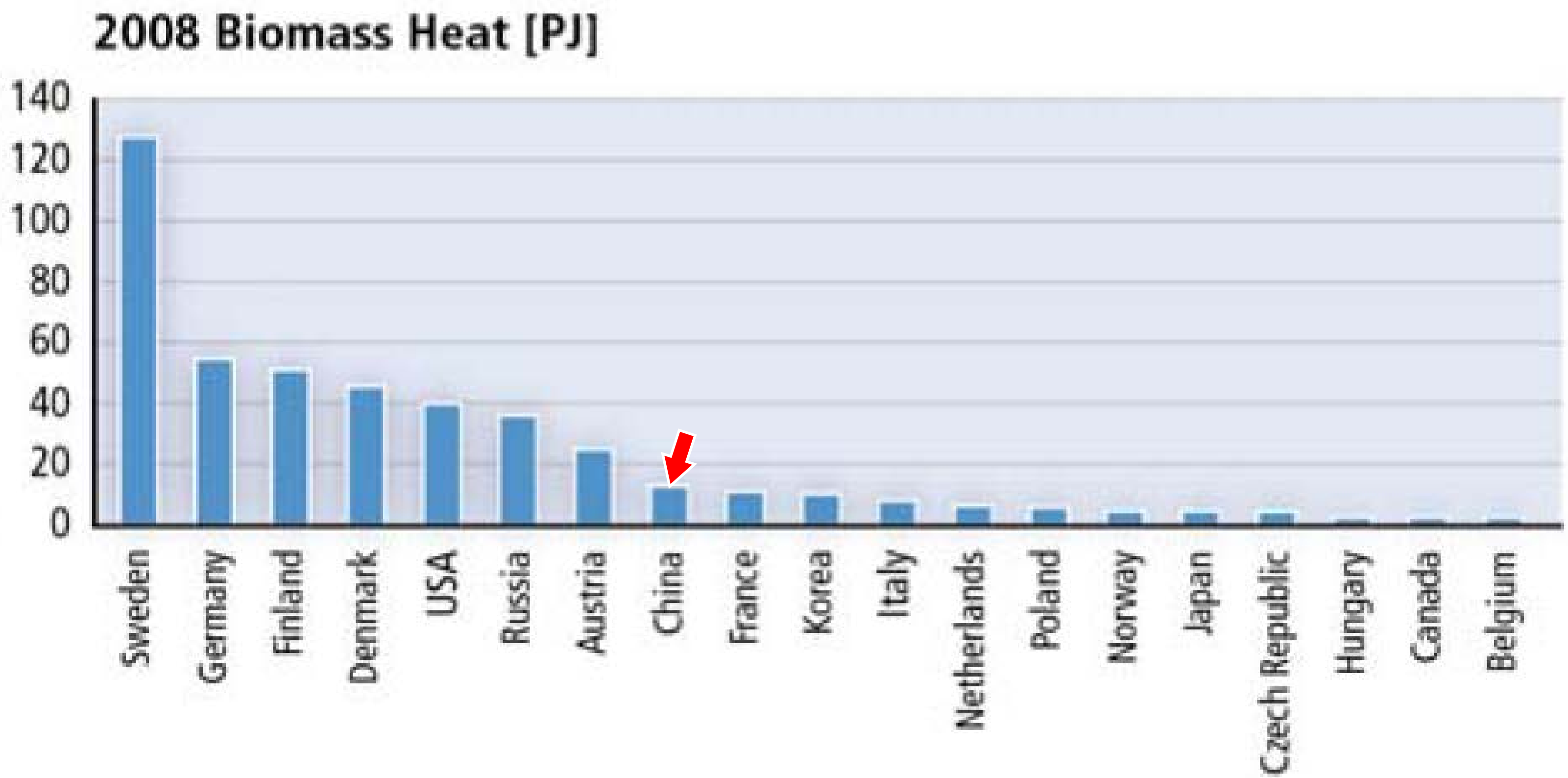
*not including hydropower

Top producers in 2008: biomass electricity



REN21, 2013

Top producers in 2008: biomass heating



IPCC SSREN

Costs

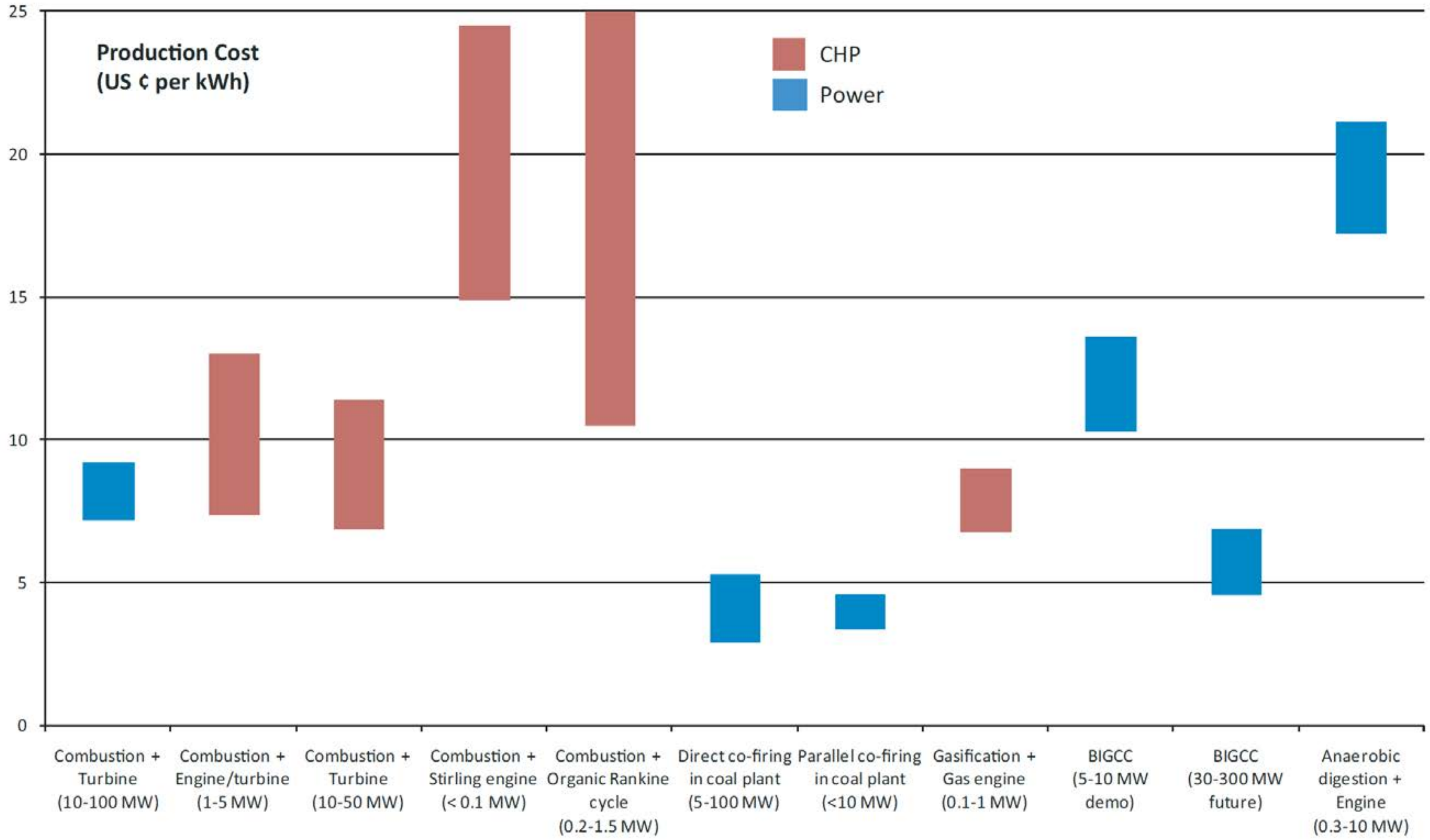


Figure 11.16 | Projected production costs for biomass to power and to CHP. Anaerobic digestion can also be operated in CHP mode; production cost will reduce by 60–80% (depending on technology and plant size) if "free" biomass feedstock is used, such as MSW, manure, or wastewater. Source: based on Bauen et al., 2009.

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

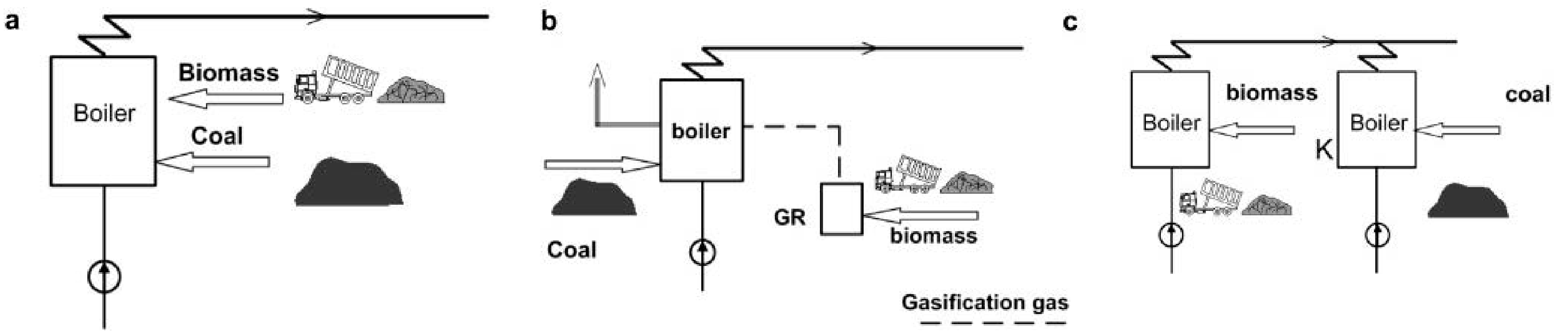
  Rankine (steam) cycle

  $\eta \approx$ 18-33% (< comparably-sized fossil plants)

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

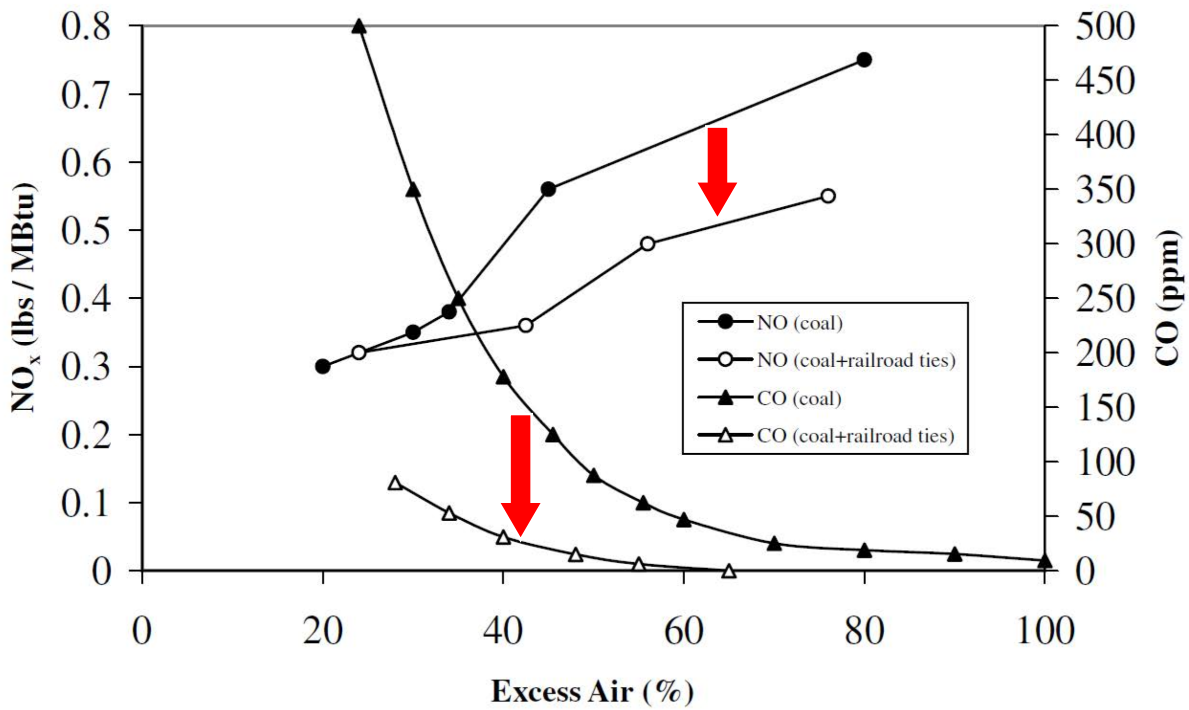
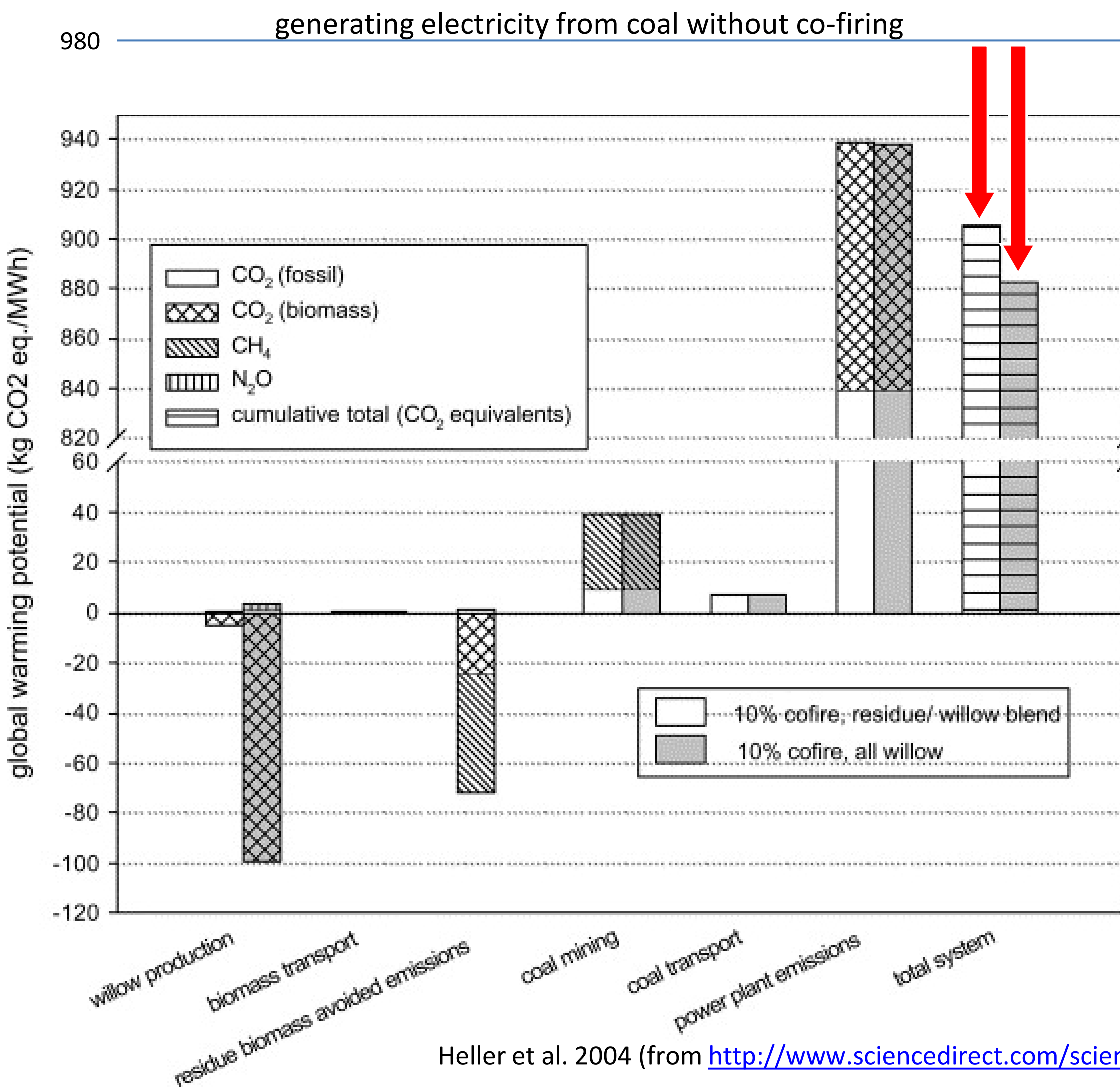


Fig. 21. Effects of co-firing 20% (mass basis) railroad ties with coal on NO_x and CO emissions [76].

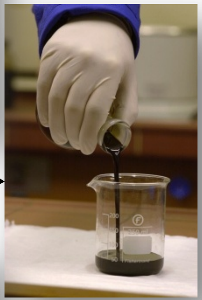
Co-firing – pollution reduction



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

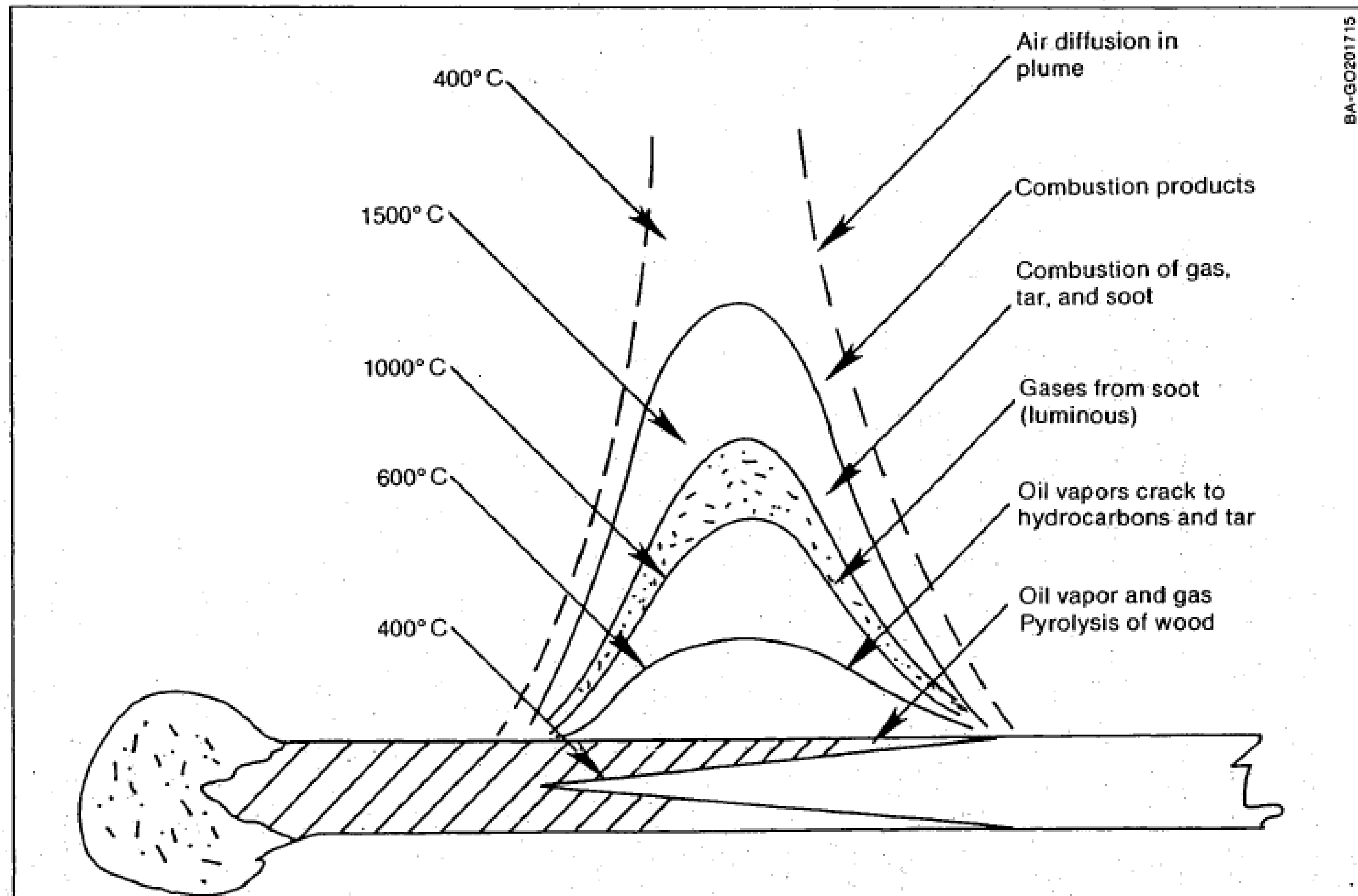
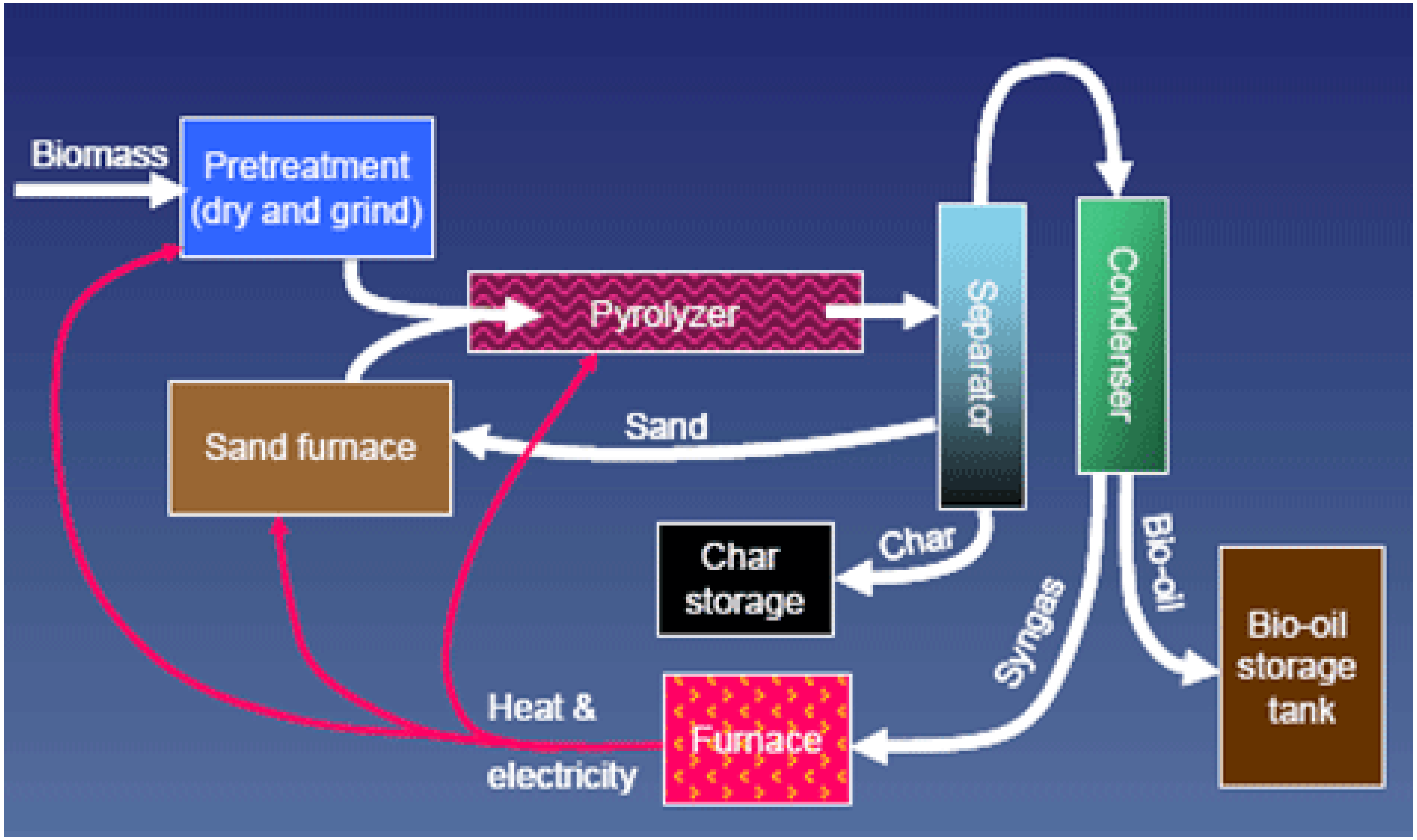


Fig. 4-2. Pyrolysis, gasification, and combustion in the flaming match

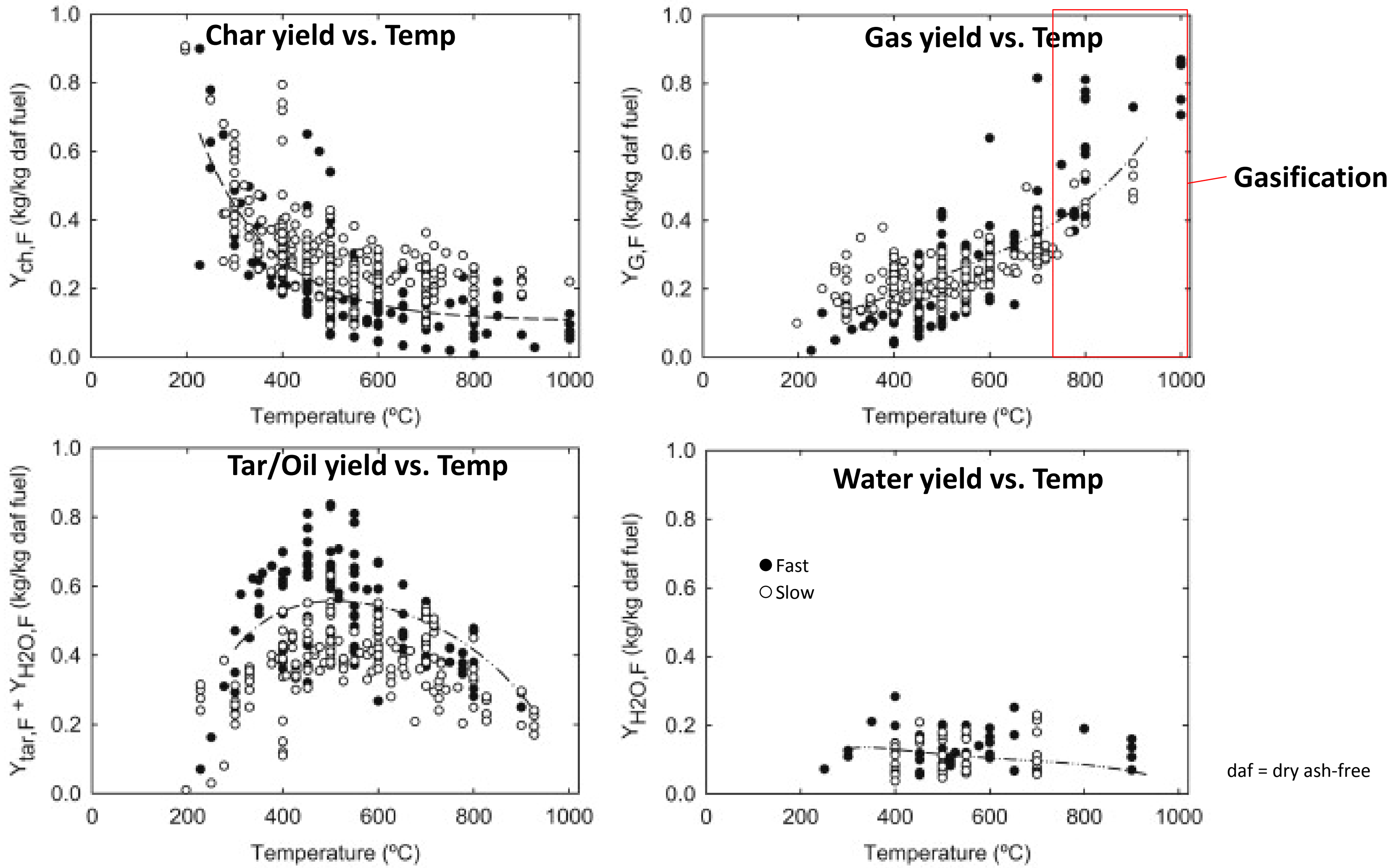
Source: Reed and Das, 1988

Pyrolysis



http://www.ars.usda.gov

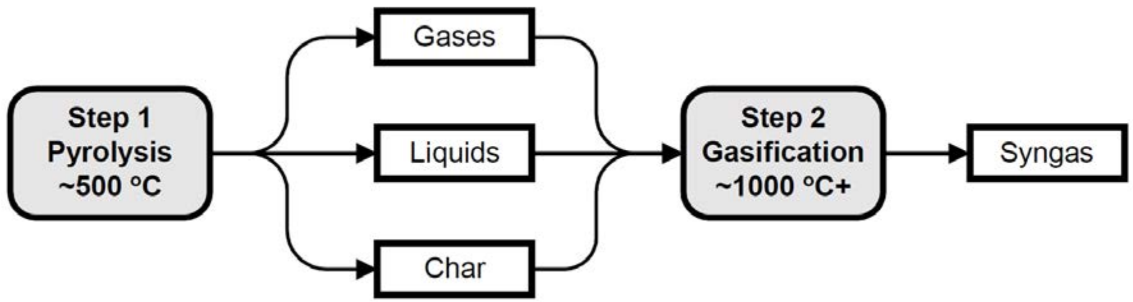
Pyrolysis



daf = dry ash-free

Gasification

- Partial thermal oxidation of biomass



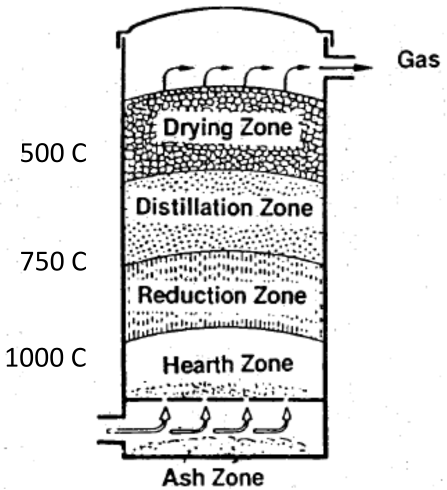
  - Results in a combustible mixture of gases
    - "syn gas" or "producer gas"
    - Mainly CO and H_2
    - 5 - 20 MJ/Nm^3 (10-45% HV or nat. gas)
      - Air-based systems are lower (N_2 in the air dilutes the mix)
      - Steam or oxy-based systems are higher

Gasification

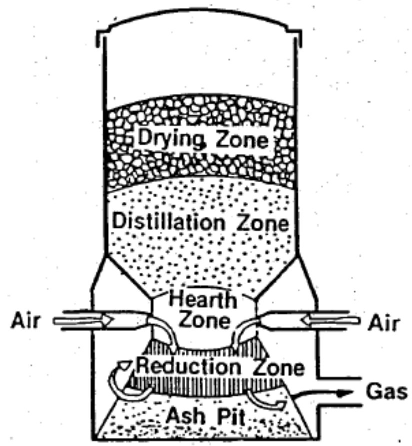
Primary devolatilization				
Biomass	→	Primary tar (CH_xO_y) CO, CO_2, CH_4, C_2H_4, H_2O Carbon		*[eq.1]*
Tar cracking and reforming				
Primary tar	→	Secondary tar CO, CO_2, CH_4, C_2H_4, H_2		*[eq.2]*
Homogenous gas-phase-reactions			ΔH	
Secondary tars	→	C, CO, H_2		*[eq.3]*
$H_2 + 0{,}5\ O_2$	→	H_2O	-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

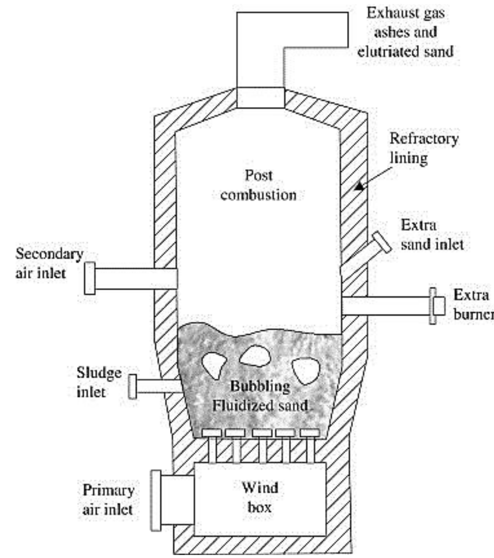
Updraft



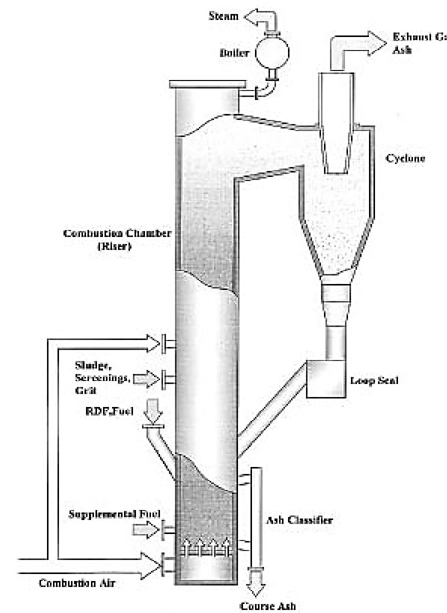
Downdraft



Bubbling Fluidized Bed



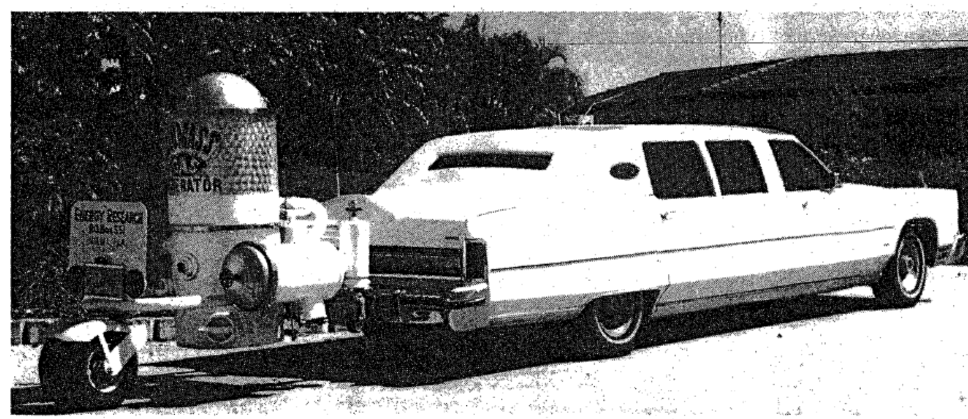
Circulating Fluidized Bed



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

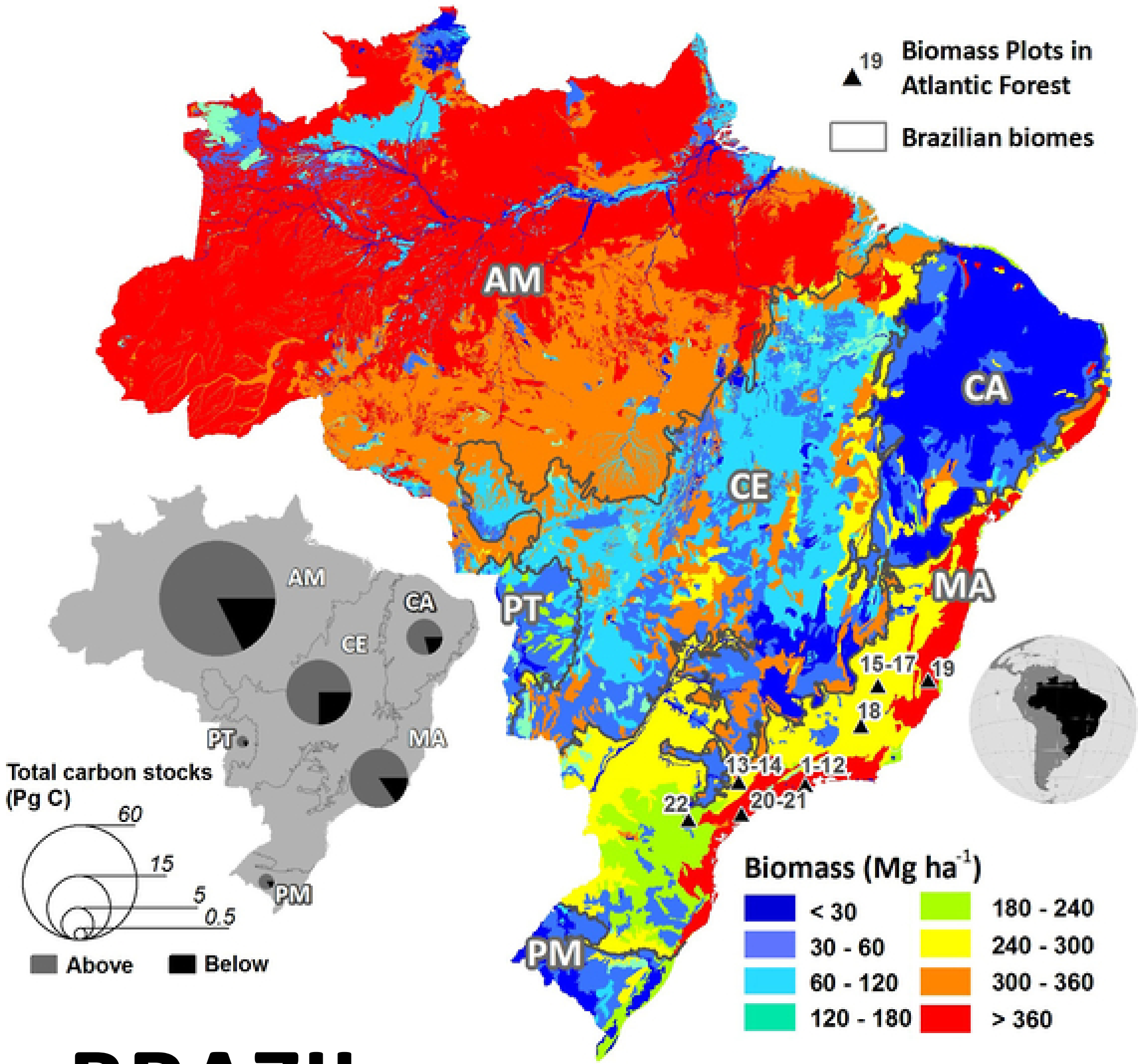
http://seca.doe.gov/technologies/coalpower/gasification/pubs/pdf/BMassGasFinal.pdf

1940s



1970s

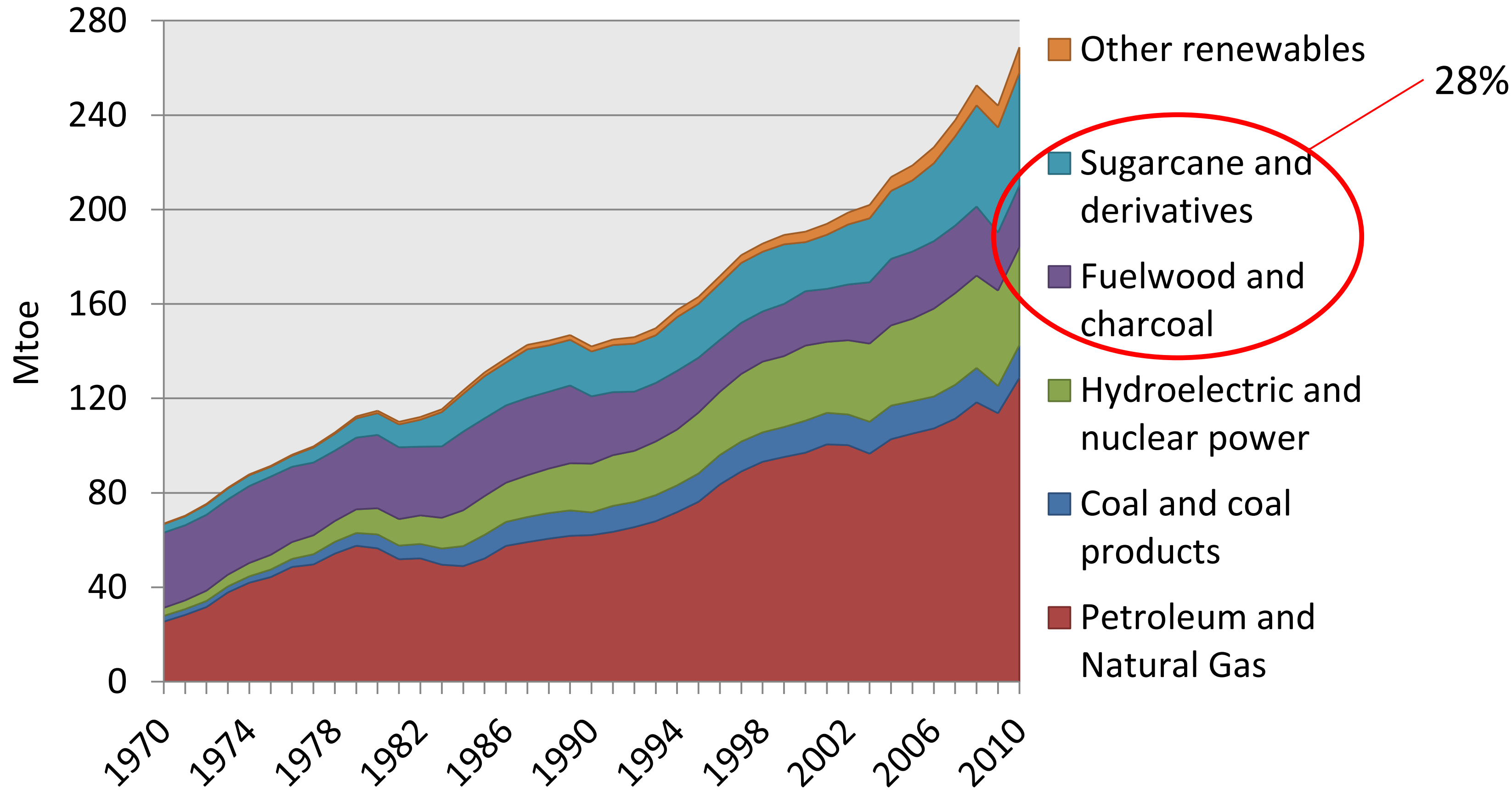
2000s



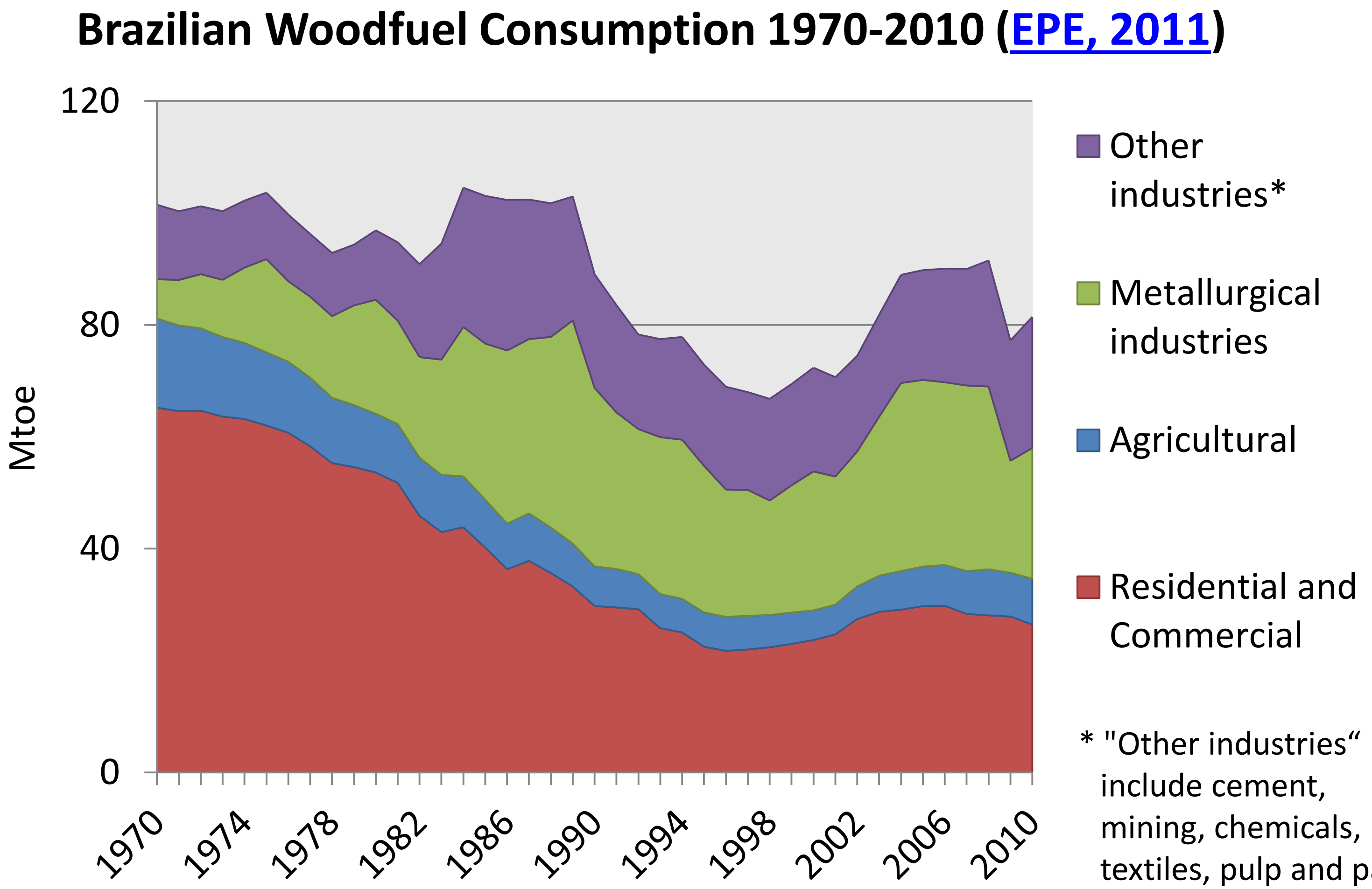
EXAMPLE - BRAZIL

Brazil – Primary Energy

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

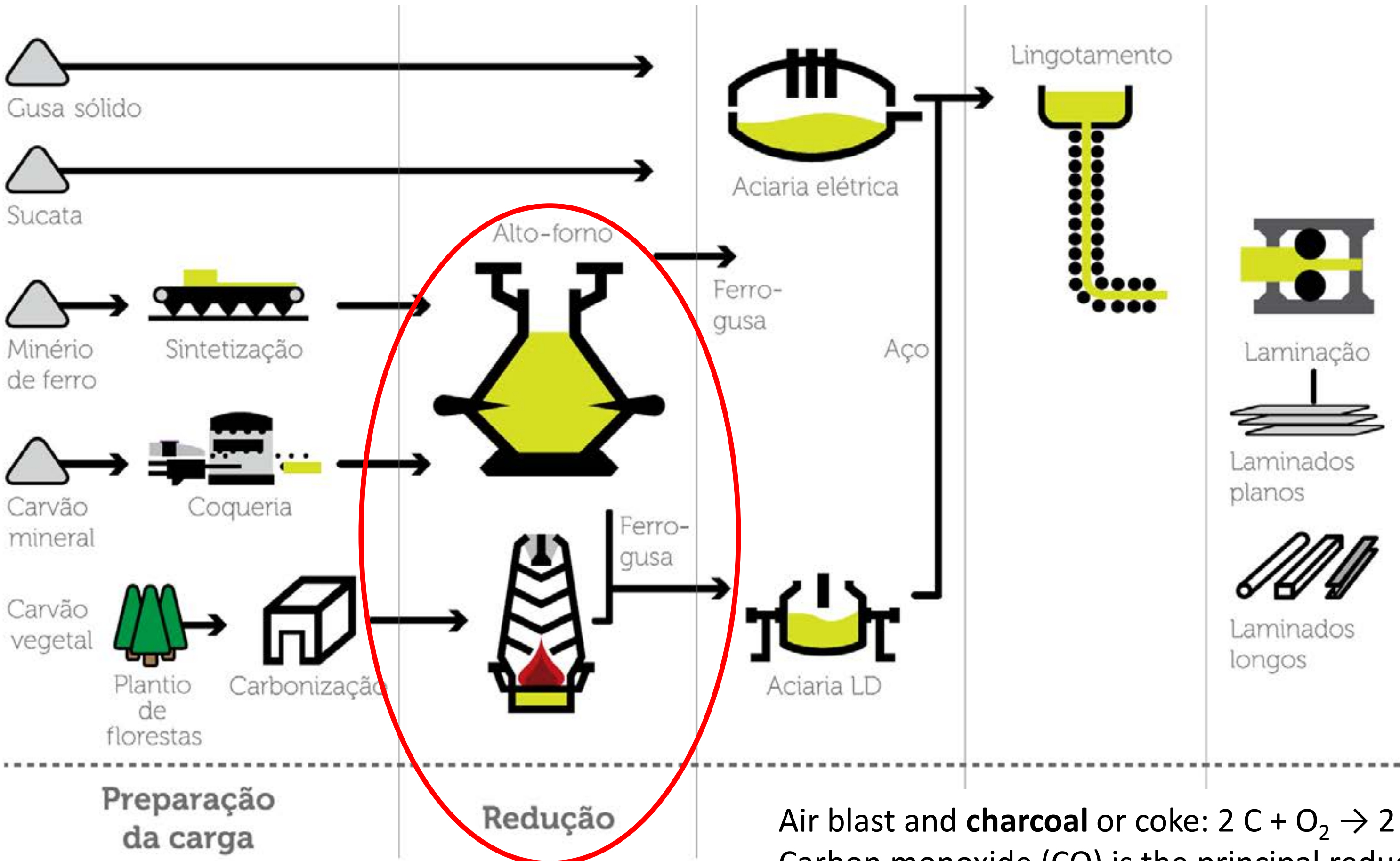


Brazil – woodfuel consumption



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

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.

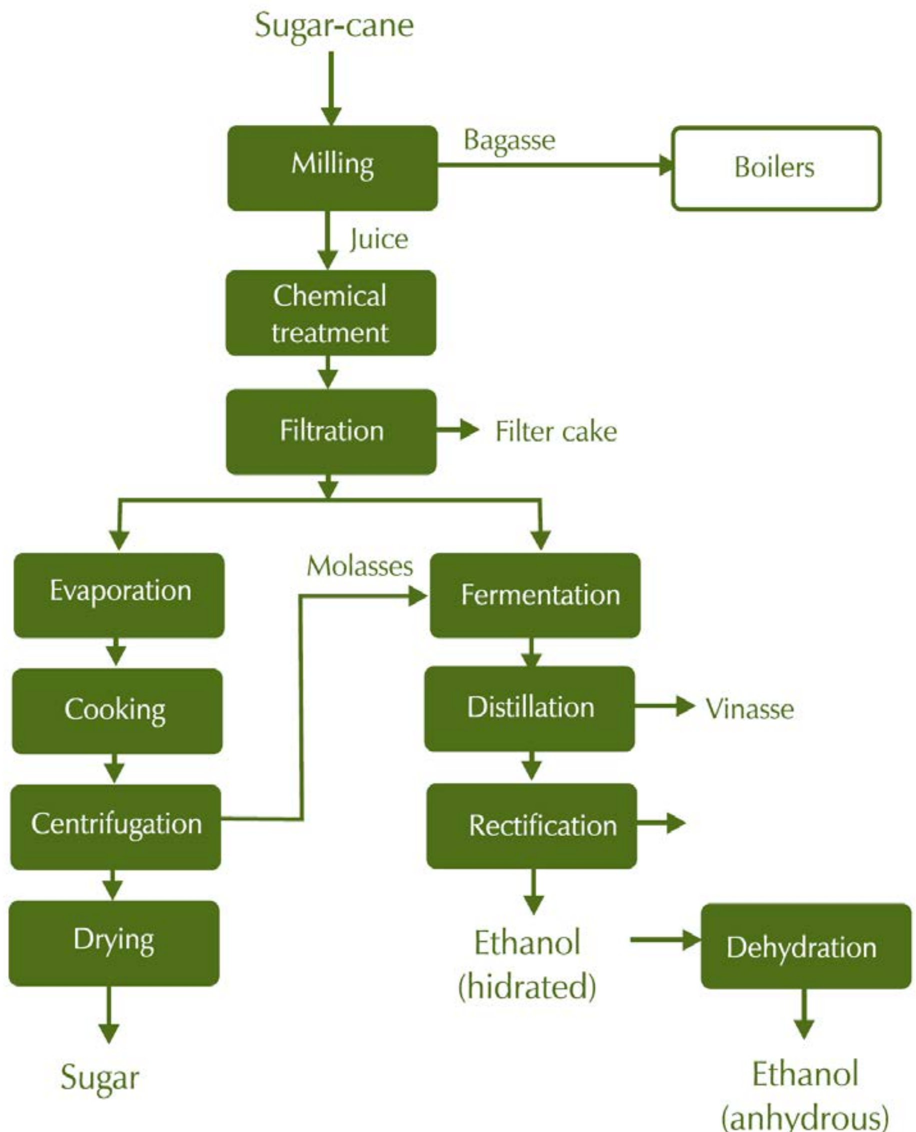
Stage One: $3\ Fe_2O_3 + CO \rightarrow 2\ Fe_3O_4 + CO_2$

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

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

Use of solid biomass

Brazil - Sugarcane



BNDES, 2008

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

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

Solid biomass in the CDM

Method	Title	Projects	PoAs
ACM3	Emission reduction through partial substitution of fossil fuels with alternative fuels in cement manufacture	44	
ACM6	Grid-connected electricity from biomass residues (includes AM4 & AM15)	353	2
ACM18	Electricity generation from biomass residues (co-fired) in power-only plants	81	2
ACM20	Co-firing of biomass residues for heat generation and/or electricity generation in grid connected power plants		
AM7	Analysis of the least-cost fuel option for seasonally-operating biomass cogeneration plants		
AM36	Fuel switch from fossil fuels to biomass residues in boilers for heat generation	24	
AM42	Grid-connected electricity generation using biomass from newly developed dedicated plantations	2	
AM82	Use of charcoal from planted renewable biomass in the iron ore reduction process through the establishment of a new iron ore reduction system	4	

CDM/JI Pipeline Analysis and Database - http://cdmpipeline.org

EXTRA SLIDES

Projects Found

Approved National Projects (12)

GEF_ID	Country	Project Name	Focal Area	Agency	Project Type	GEF Grant	Cofinancing	Status
6	Brazil	Hydrogen Fuel Cell Buses for Urban Transport	Climate Change	UNDP	FP	12,274,000	9,169,000	Project Completion
128	Brazil	Energy Efficiency Project	Climate Change	IBRD	FP	20,000,000	180,000,000	Project Closure
337	Brazil	Climate Change Enabling Activity	Climate Change	UNDP	EA	1,500,000	0	IA Approved
338	Brazil	Biomass Power Generation: Sugar Cane Bagasse and Trash	Climate Change	UNDP	FP	3,750,000	2,770,000	Project Closure
1612	Brazil	Second National Communication of Brazil to the UNFCCC	Climate Change	UNDP	FP	3,400,000	4,175,600	Project Completion
2941	Brazil	Market Transformation for Energy Efficiency in Buildings	Climate Change	UNDP	FP	13,500,000	64,825,000	Under Implementation
4718	Brazil	Production of Sustainable, Renewable Biomass-based Charcoal for the Iron and steel Industry in Brazil	Climate Change	UNDP	FP	7,150,000	32,700,000	Council Approved
3999	Brazil	Third National Communication to the UNFCCC	Climate Change	UNDP	FP	5,720,000	6,500,000	CEO Endorsed
4949	Brazil	Low-Carbon Urban Mobility for Large Cities	Climate Change	IADB	FP	6,000,000	77,170,000	Council Approved
4254	Brazil	Mitigation Options of Greenhouse Gas (GHG) Emissions in Key Sectors in Brazil	Climate Change	UNEP	EA	4,180,000	11,890,000	CEO Endorsed
2778	Brazil	Sugarcane Renewable Electricity (SUCRE)	Climate Change	UNDP	FP	7,800,000	62,800,000	CEO Endorsed
381	Brazil	Biomass Integrated Gasification/Gas Turbine Project	Climate Change	UNDP	FP	8,115,000	0	Project Completion
Subtotal						93,389,000	451,999,600	

Pellet fuels

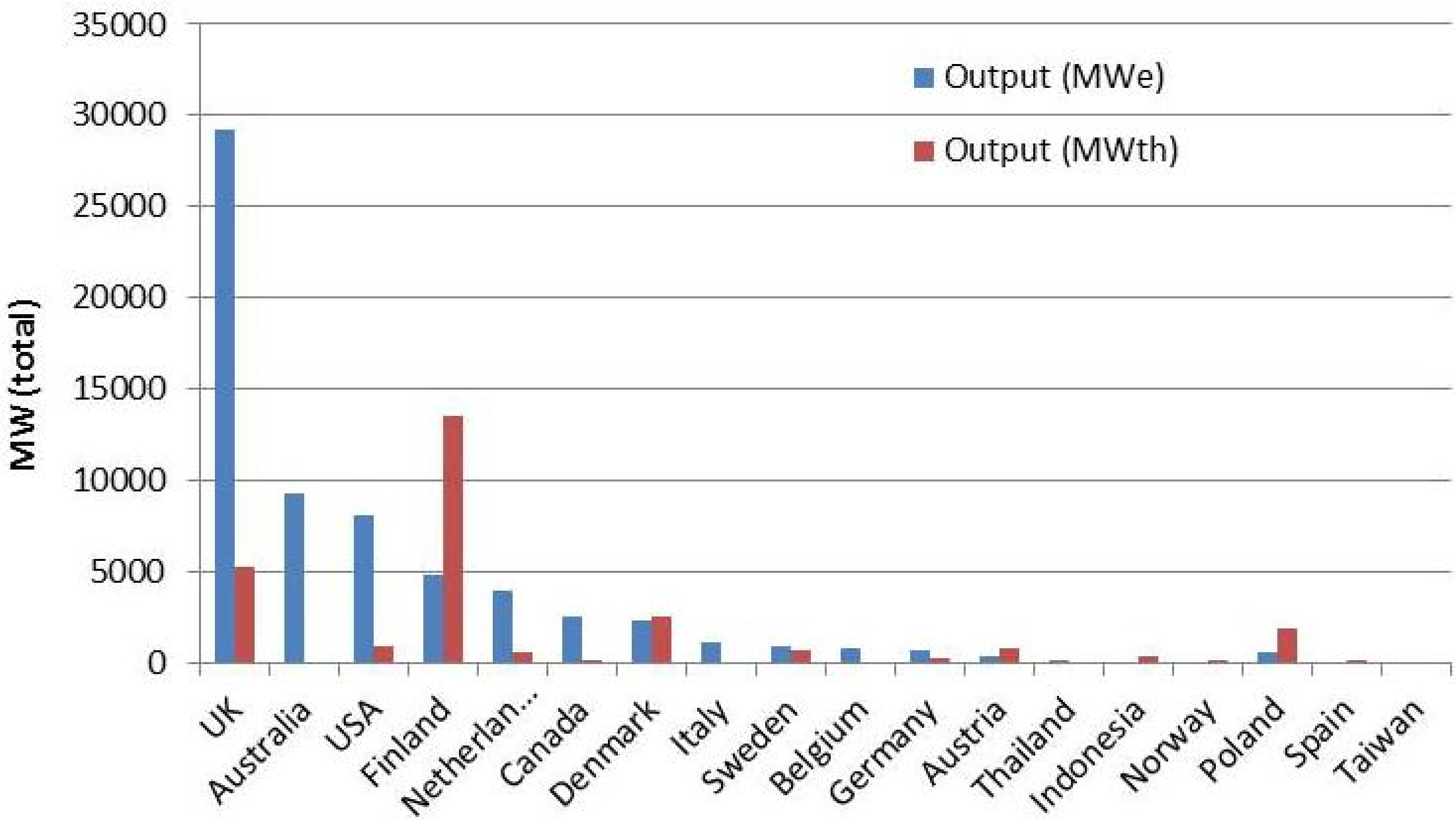
Table 2.9.1 Energy density at different moisture content in various wood fuels[2]

Wood fuels	Quantity	Moisture	Mass	NCV	Energy density*		
		M%	kg	MJ/kg	MJ	kWh	liter of oil
Stacked log woods							
Beech 33 cm	1 stacked m^3	15	445	15.3	6,797	1,888	189
Beech 33 cm	1 stacked m^3	30	495	12.1	6,018	1,672	167
Spruce 33 cm	1 stacked m^3	15	304	15.6	4,753	1,320	132
Spruce 33 cm	1 stacked m^3	30	349	12.4	4,339	1,205	121
Wood chips							
Beech	1 bulk m^3	15	295	15.3	4,505	1,251	125
Beech	1 bulk m^3	30	328	12.1	3,987	1,107	111
Spruce	1 bulk m^3	15	194	15.6	3,032	842	84
Spruce	1 bulk m^3	30	223	12.4	2,768	769	77
Wood pellets	1 bulk m^3	8	650	17.1	11,115	3,088	309

* In the range M 0-23% the relative correction factors have been applied.

http://nuke.biomasstradecentres.eu/Portals/0/D2.1.1%20-%20WOOD%20FUELS%20HANDBOOK_BTC_EN.pdf

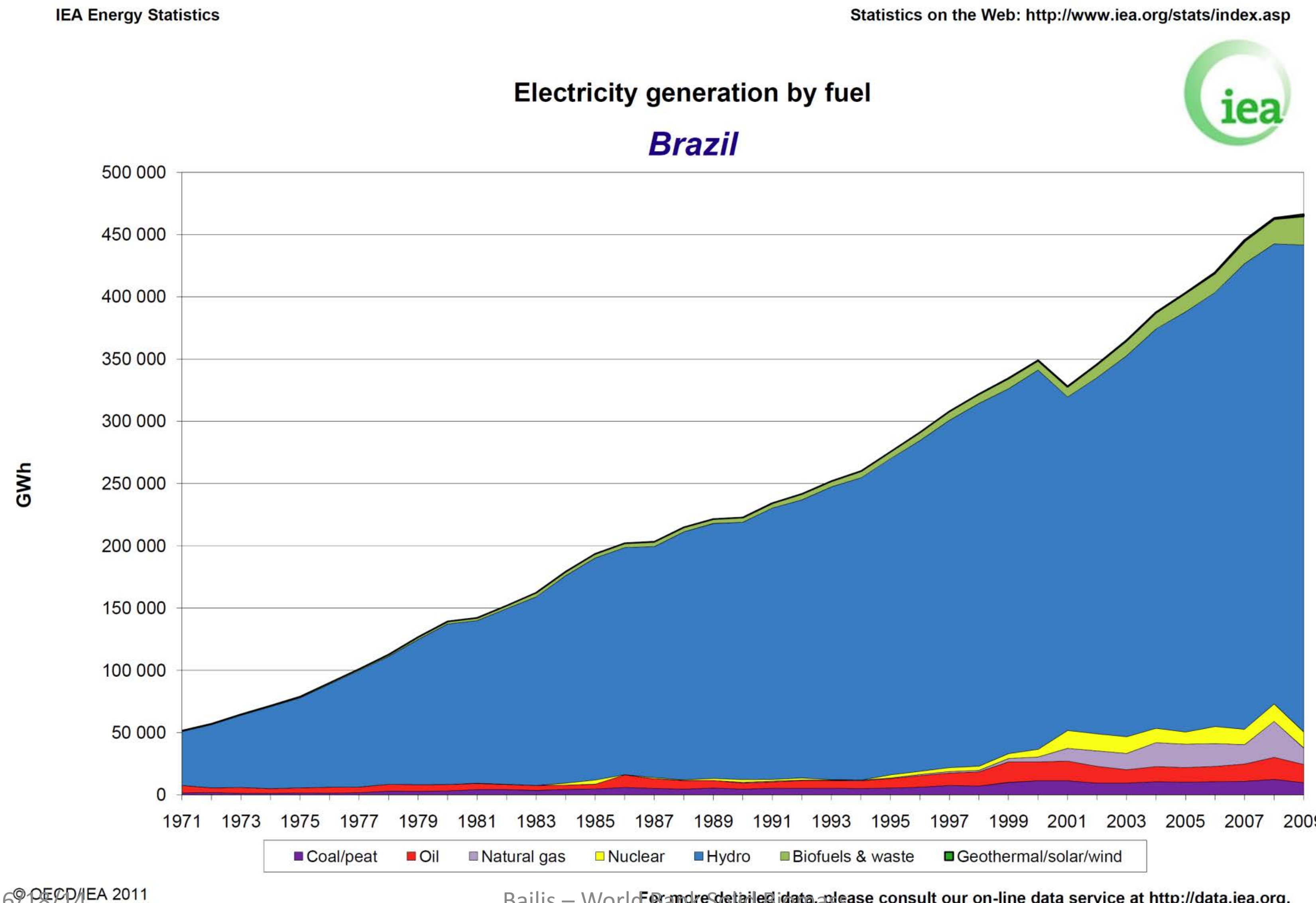
Global co-firing capacity

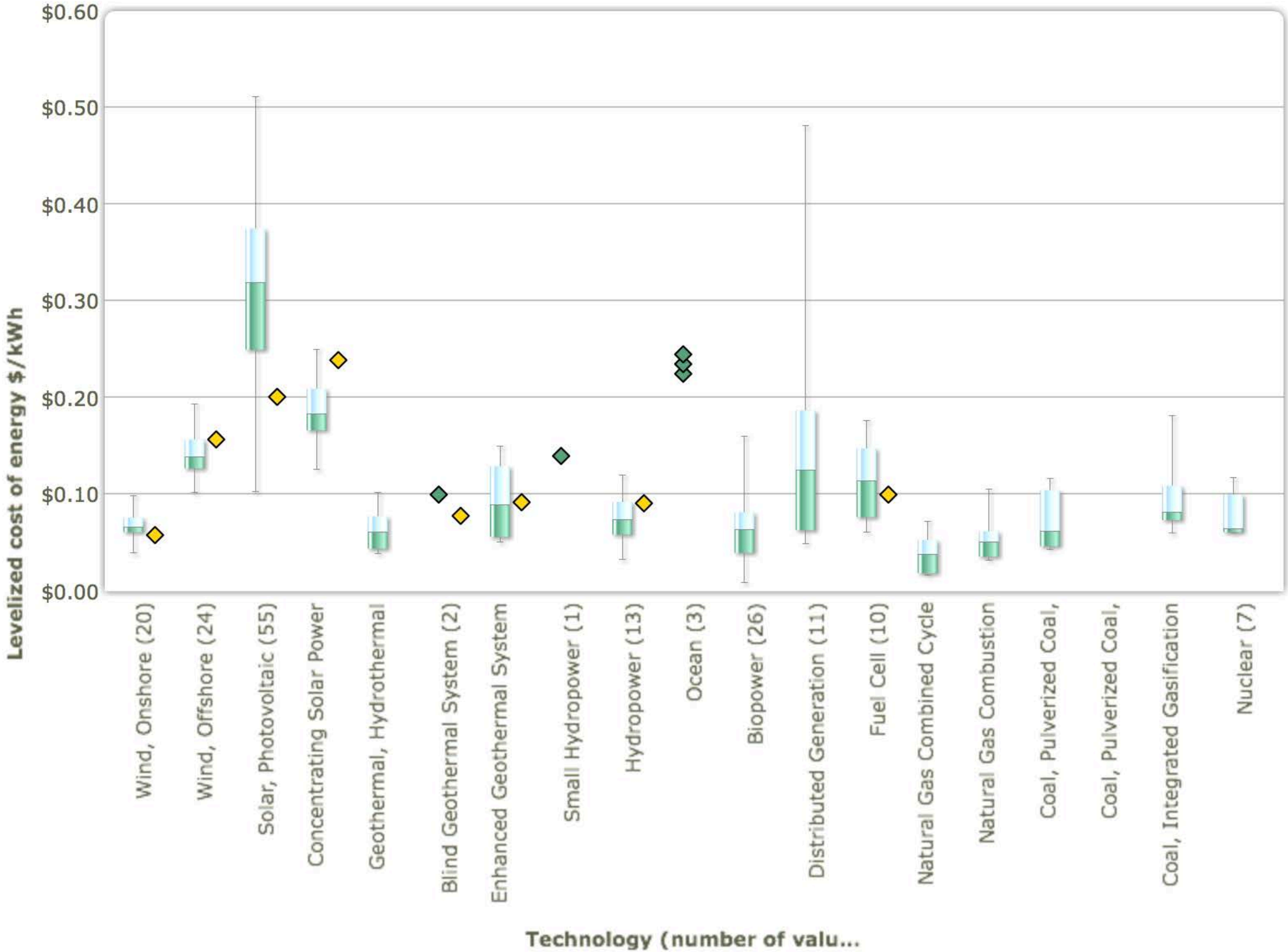


Source: IEA Bioenergy Task 32

http://ars.els-cdn.com/content/image/1-s2.0-S0960148110003125-gr2.jpg

Brazil – power production





$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
Levelized cost of energy $/kWh
Wind, Onshore (20)
Wind, Offshore (24)
Solar, Photovoltaic (55)
Concentrating Solar Power
Geothermal, Hydrothermal
Blind Geothermal System (2)
Enhanced Geothermal System
Small Hydropower (1)
Hydropower (13)
Ocean (3)
Biopower (26)
Distributed Generation (11)
Fuel Cell (10)
Natural Gas Combined Cycle
Natural Gas Combustion
Coal, Pulverized Coal,
Coal, Pulverized Coal,
Coal, Integrated Gasification
Nuclear (7)
Technology (number of valu...

Current status

GLOBAL ANNUAL GROWTH RATE OF RENEWABLE CAPACITY in 2012 and 2007-2012 (REN21, 2013)

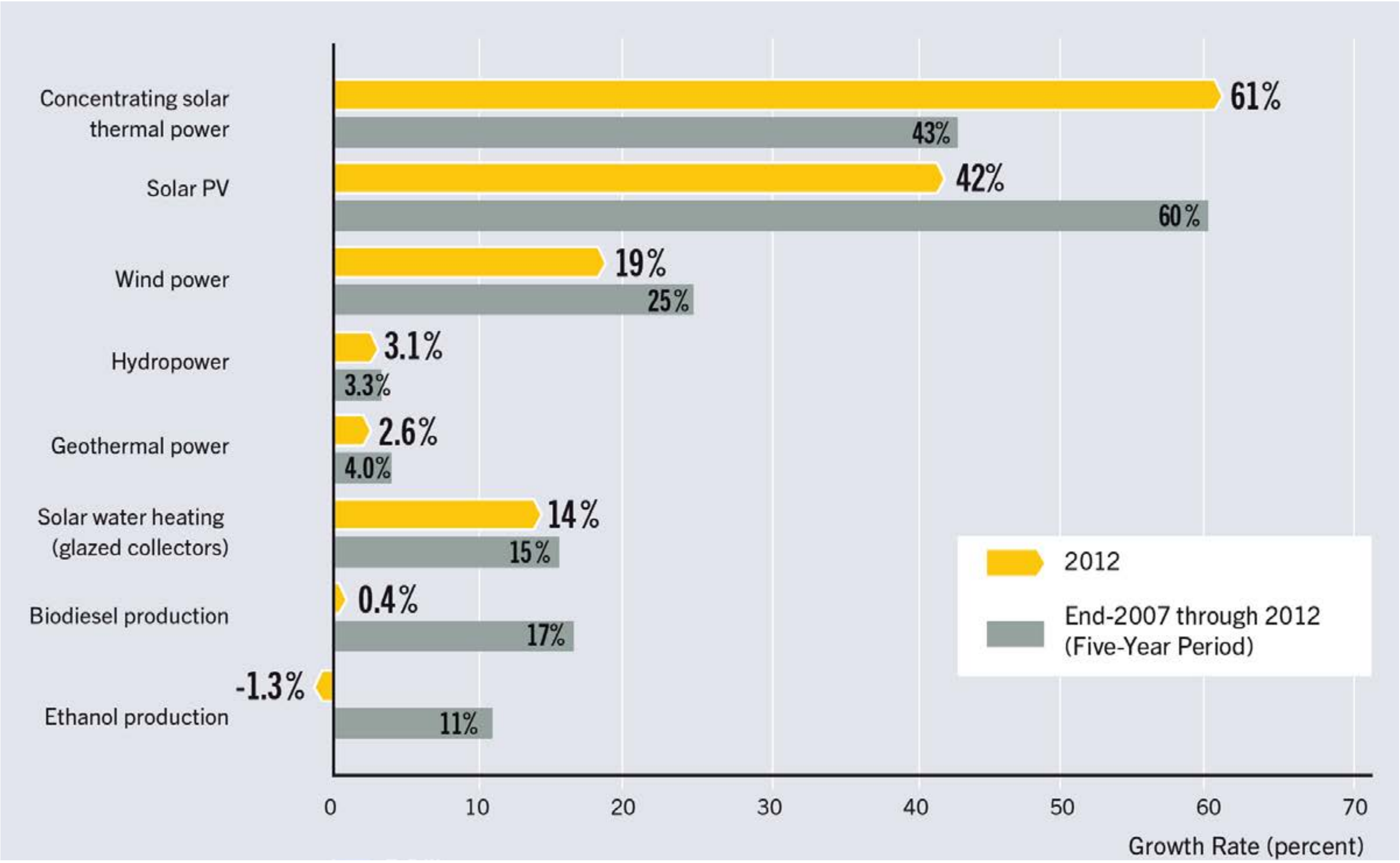


FIGURE 6. WOOD PELLET GLOBAL PRODUCTION, BY COUNTRY OR REGION, 2000–2012