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Conversion of biomass to solids
torrefaction & pellets & bio-oil

Esa Vakkilainen, LUT Energy

14.8.2011, Optimization of Bioenergy Use
JSS RE2: University of Jyväskylä

Contents

EU target for renewables

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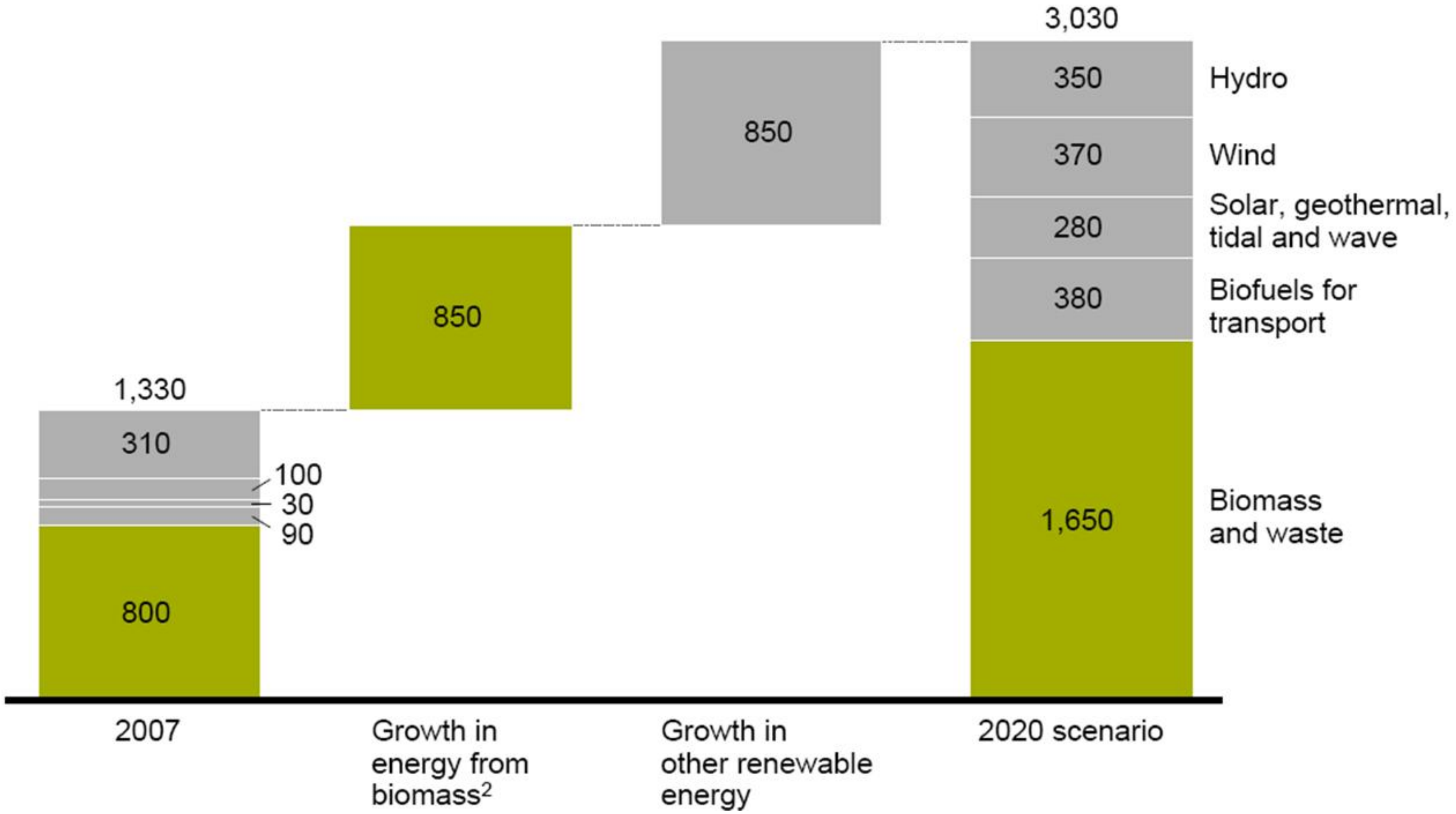
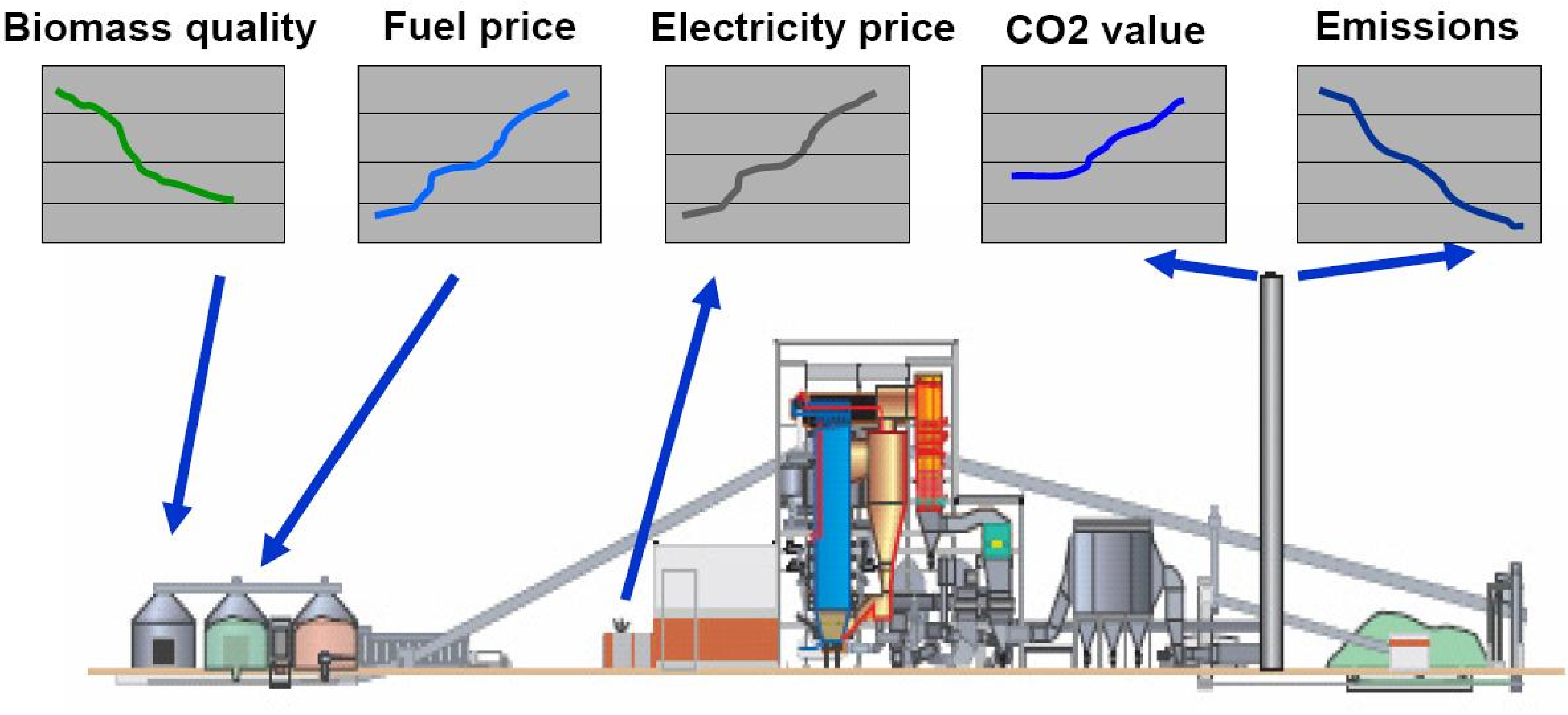
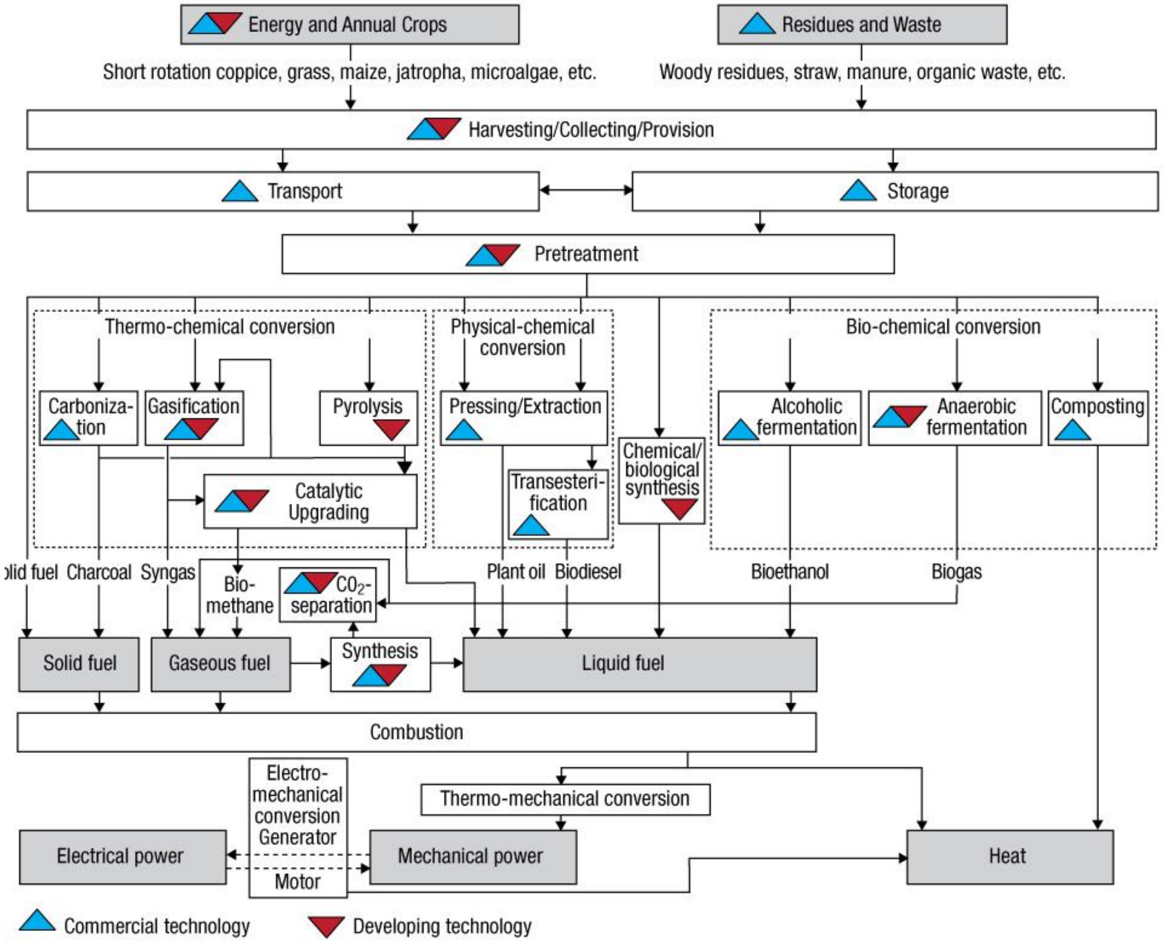


Biomass usage is changing



Rautanen, 2006

Paths of bioenergy conversion



Torrefaction

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Harvesting

↓

Transport

↓

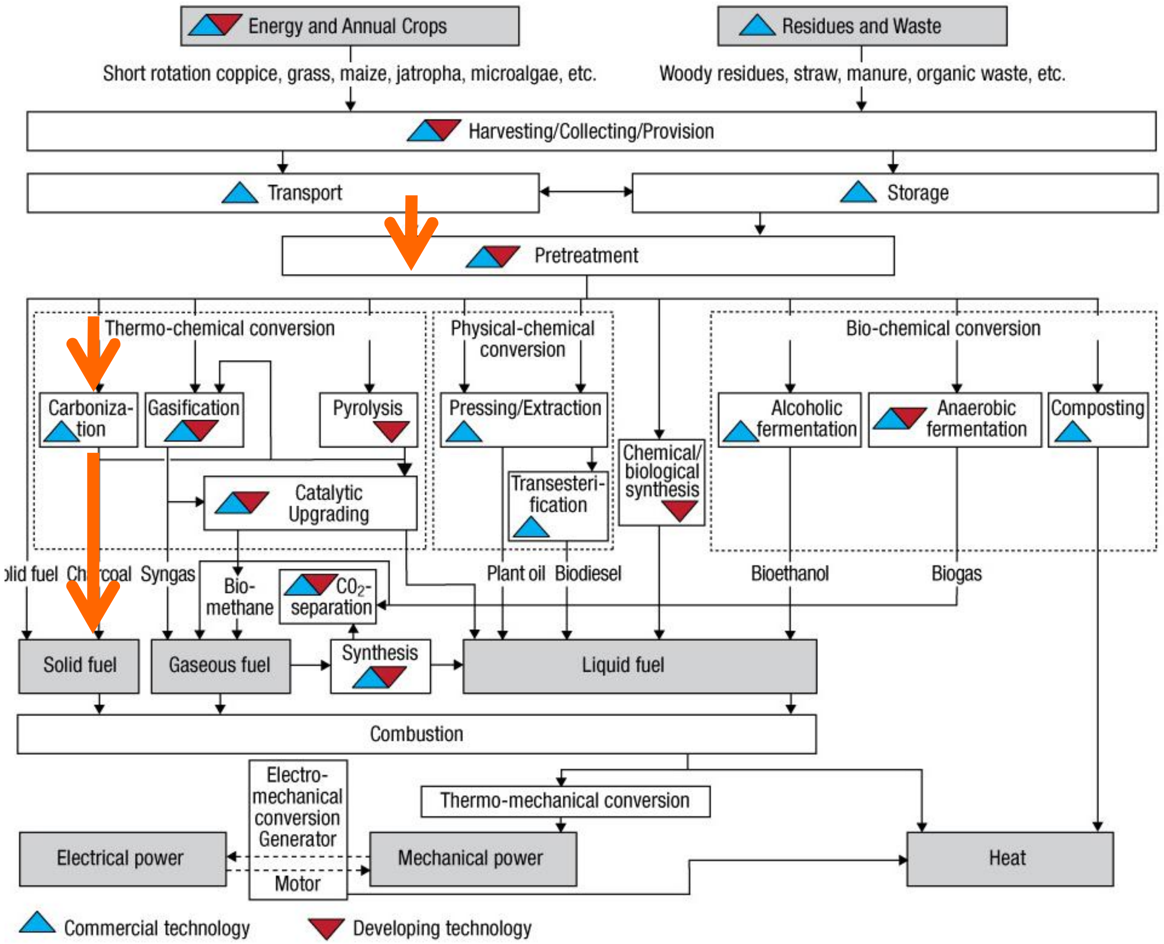
pretreatment

↓

Carbonization

↓

Biocoal



IEA Biomass Task 40

- Euroopan Union active
  - Austria; EBES, TU Vienna, OFI Vienna
  - Belgium; Thenergo, Torr-Coal Group, 4Energy Invest, biochar
  - Dutch; ECN, Topell, Stramploy, TU Eidenhoven
  - Finland; VTT, LUT

- USA and Canada are active

Heating of biomass changes it

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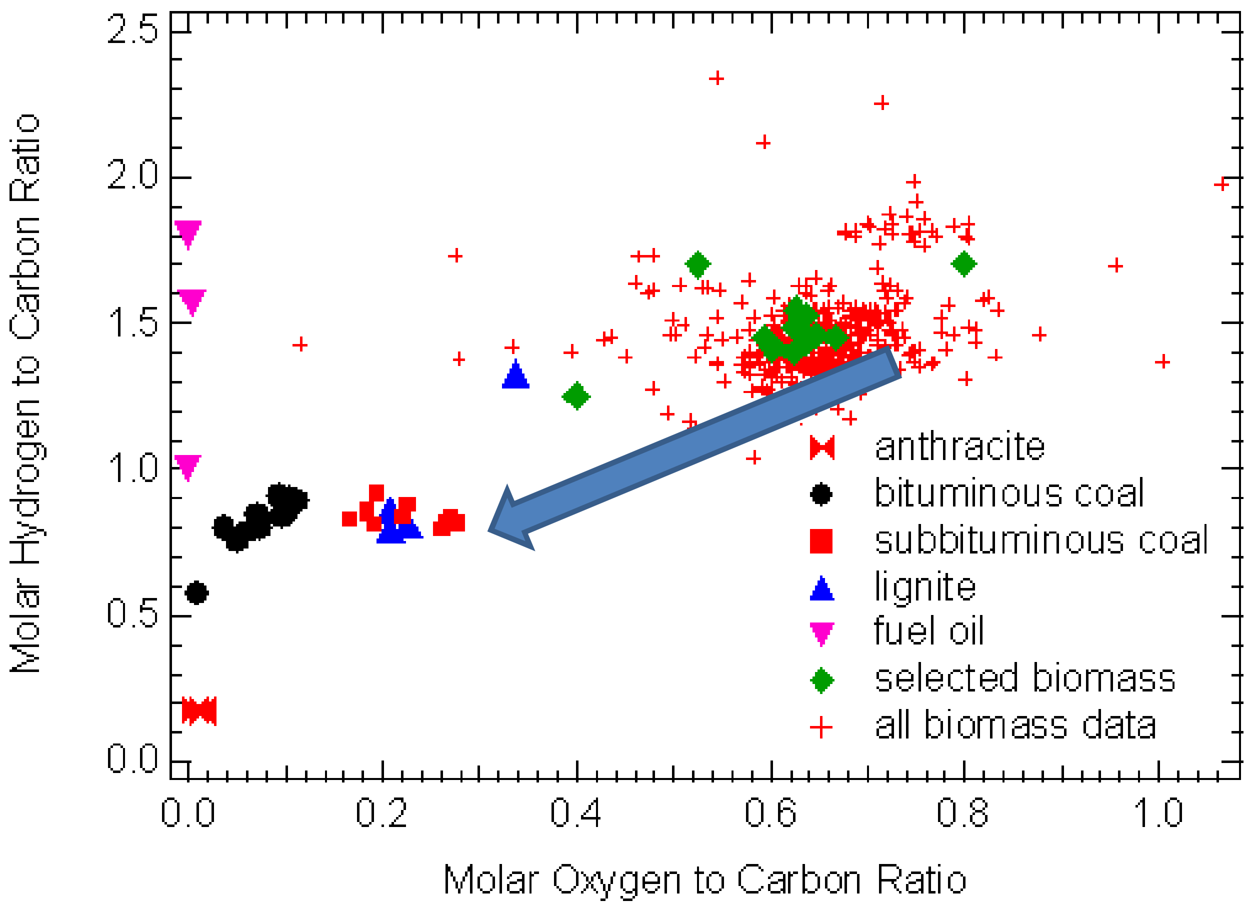

Baxter, Brigham Young University, USA, 2009

Pros and cons of torrefication

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- Mass loss 10 - 15 m-% (or up to 50 %)

- Heating value increases
  - 17 - 19 ➡ 19 - 23 MJ/kg (dry)
- Density increases
  - Density after treatment 180 - 300 kg/m^3
  - After pelletizing 750 - 850 kg/m^3
- Transport is cheaper

Biomass products

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		Wood (chips)	Torrefied biomass	Pellets	Top Pellet
Moisture	%	35	3	7	1
LHV (wet)	MJ/kg	10,5	19,9	16,2	21,6
LHV (dry)	MJ/kg	17,7	20,4	17,7	22,7
Density	kg/m^3	550	230	650	850

Bergman, 2005

Biomass co-firing in coal boilers

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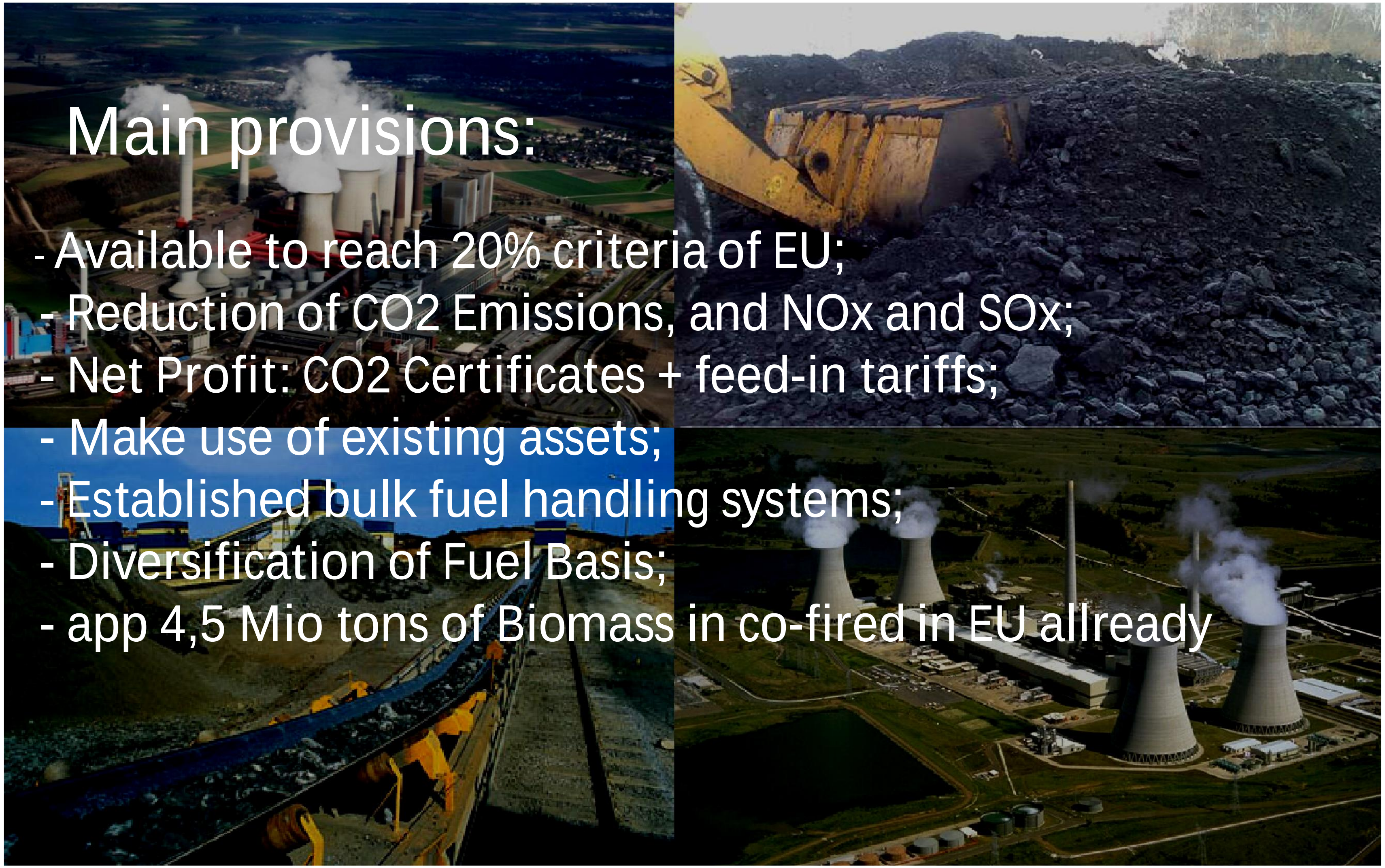
- 5 % energy is possible to substitute with no great losses or no large investments (even without drying).

- 5 - 15 % is possible but requires investments to fuel storage, handling, firing and reduction of investments (typically pellets or equal).

- 25 - 40 % is possible if biomass quality is good and the particle size is small (torrefied biomass = biocoal).

- 100 % conversion requires investment to new boiler.



Main provisions:

- Available to reach 20% criteria of EU;
- Reduction of CO2 Emissions, and NOx and SOx;
- Net Profit: CO2 Certificates + feed-in tariffs;
- Make use of existing assets;
- Established bulk fuel handling systems;
- Diversification of Fuel Basis;
- app 4,5 Mio tons of Biomass in co-fired in EU allready

Grindability of (torrefied) woody biomass

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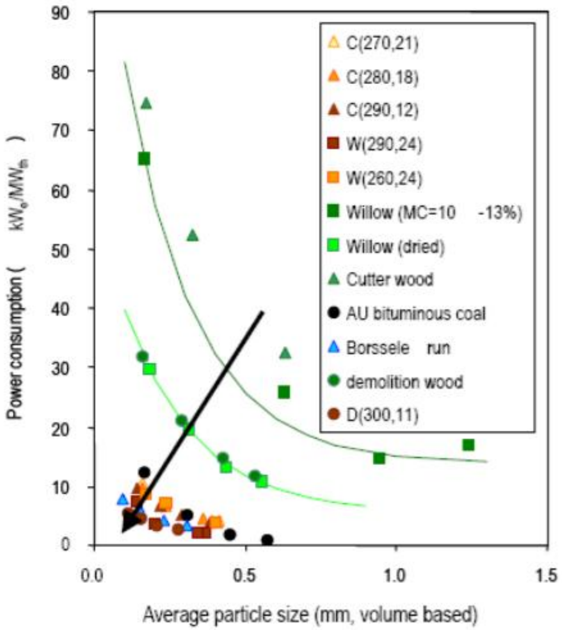
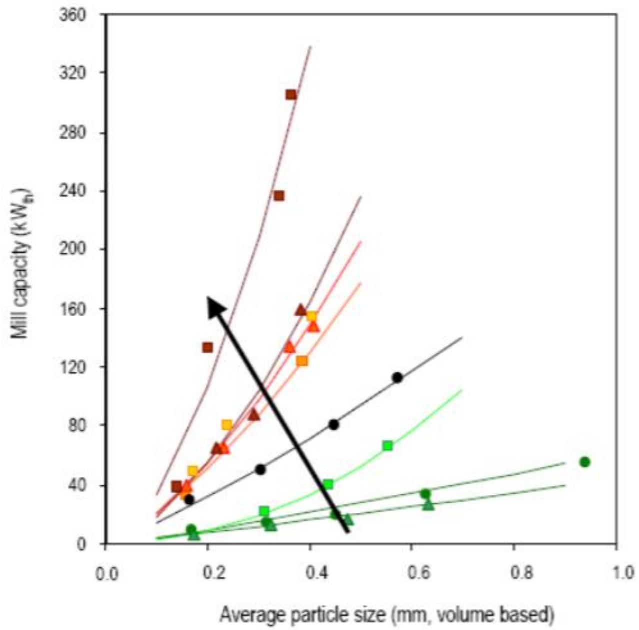
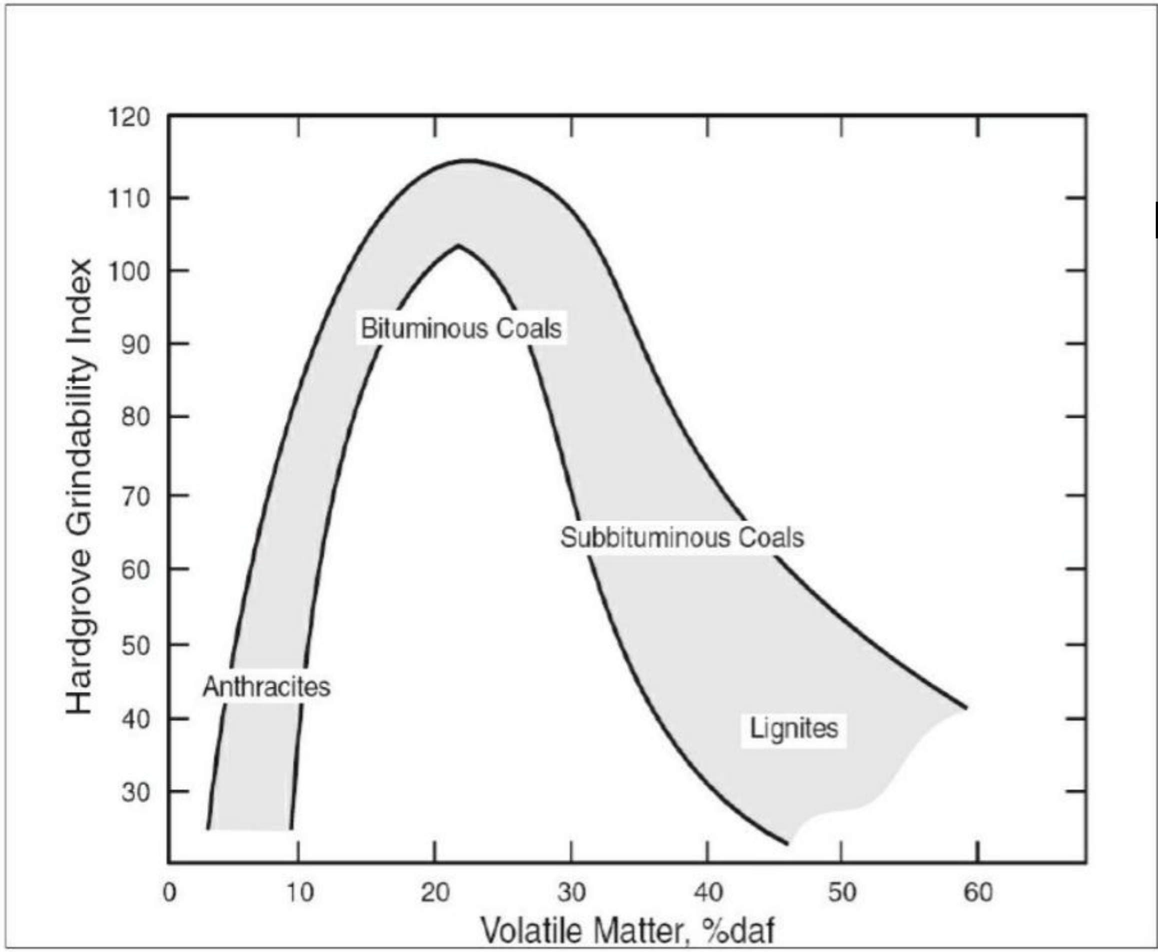




Size reduction results of various torrefied biomass and feed biomass. Coding: Biomass(torrefaction temperature, reaction time), W=willow, C=woodcuttings, D=demolition wood.

Jaap Kiel, 2011, ECN's torrefaction-based BO2-technology – from pilot to demo
IEA Bioenergy workshop Torrefaction, Graz Austria, 28 January 2011

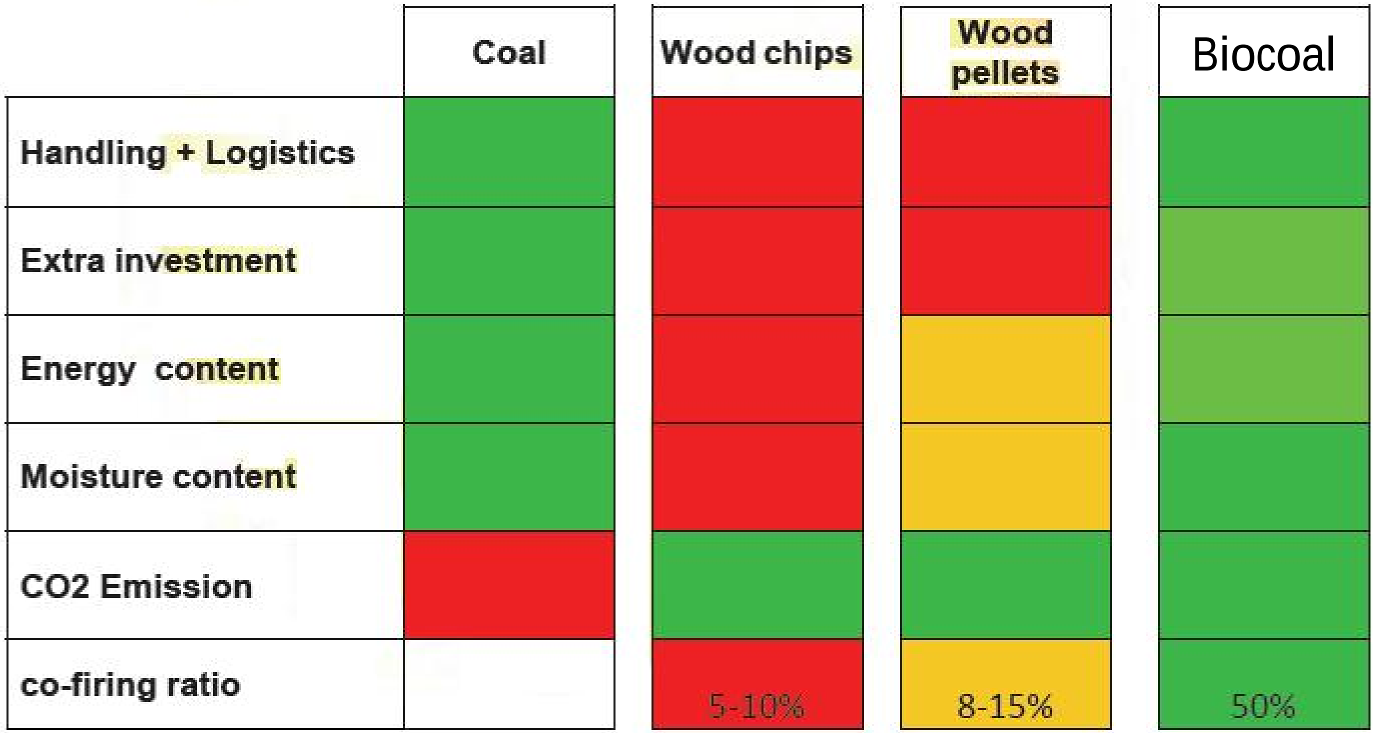
Hardgrove Index – charcoal 115

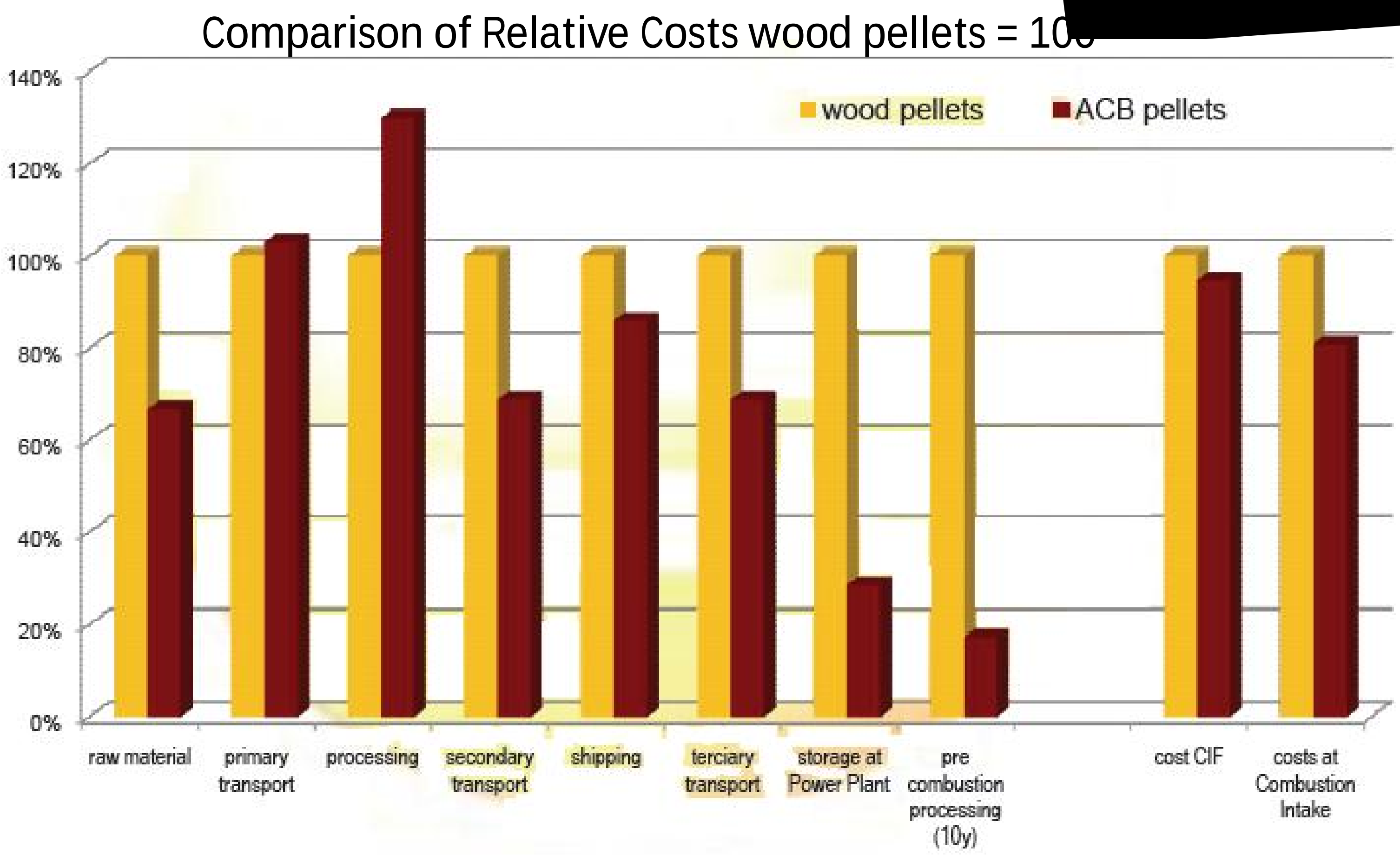


Pulverizing tendency of coal.

Issues in co-firing

- Characteristics of existing biomass types cause extra costs
- Not so with biocoal




Comparison of Relative Costs wood pellets = 100
140%
120%
100%
80%
60%
40%
20%
0%
wood pellets
ACB pellets
raw material
primary transport
processing
secondary transport
shipping
terciary transport
storage at Power Plant
pre combustion processing (10y)
cost CIF
costs at Combustion Intake

Economics

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- Increasing of the internal rate of return from 12% (wood pellets) to ~ 30% for the pellet production and logistics part of the production chain;
- Serious cost savings of 30-80% may be expected at the power station itself mainly due to decrease investment costs in pellet storage and the required processing line to boiler;
- In the case that pellets from torrefied wood are processed using infrastructure that is requiered for wood pellets, cost savings of the power station may increase the internal rate of return from 12% to 25%;
- Pellets from torrefied wood can be stored and processed together with coal.

Biofuel market price

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Product	Market-price (€/MWh)
Energy wood	15 - 20
Biocoal	30 - 40 (co-firing coal fired boilers)
Pyrolysis oil	50 - 70 (oil price)
Biodiesel (wood)	100+
Electricity	40 - 60

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Torrefication general

E. Vakkilainen

Bioenergy feedstock

Example Fuels

Bark

Screening Fines

Wood Chips

What is pellet

- Substantially increase in heating value (LHV) / volume
- Reduced transport cost
- Simplified transportation / handling
- Reduction of biological activity / stable storing
- Homogenous manageable fuel for power plants
- Wood pellets is a well-defined commodity product with standardized quality parameters.

Market size if 5 % of coal in electricity generation is replaced by industrial pellets

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- Germany: 33 TWh pellets corresponding with 7 million tonnes pellets annually
- Denmark: 3 TWh pellets corresponding with 0,7 million tonnes annually
- UK: 25 TWh pellets corresponding with 5 million tonnes annually

§ Pellet market is well over 15 million tonnes annually if and when coal fired condensing plants will use pellets to generate some renewable energy

§ In addition to electricity generation there will be demand on heating side

§ Limiting factor will be raw material availability

§ Future markets will be also small size heating boilers (10-50 MW)

Pellet markets

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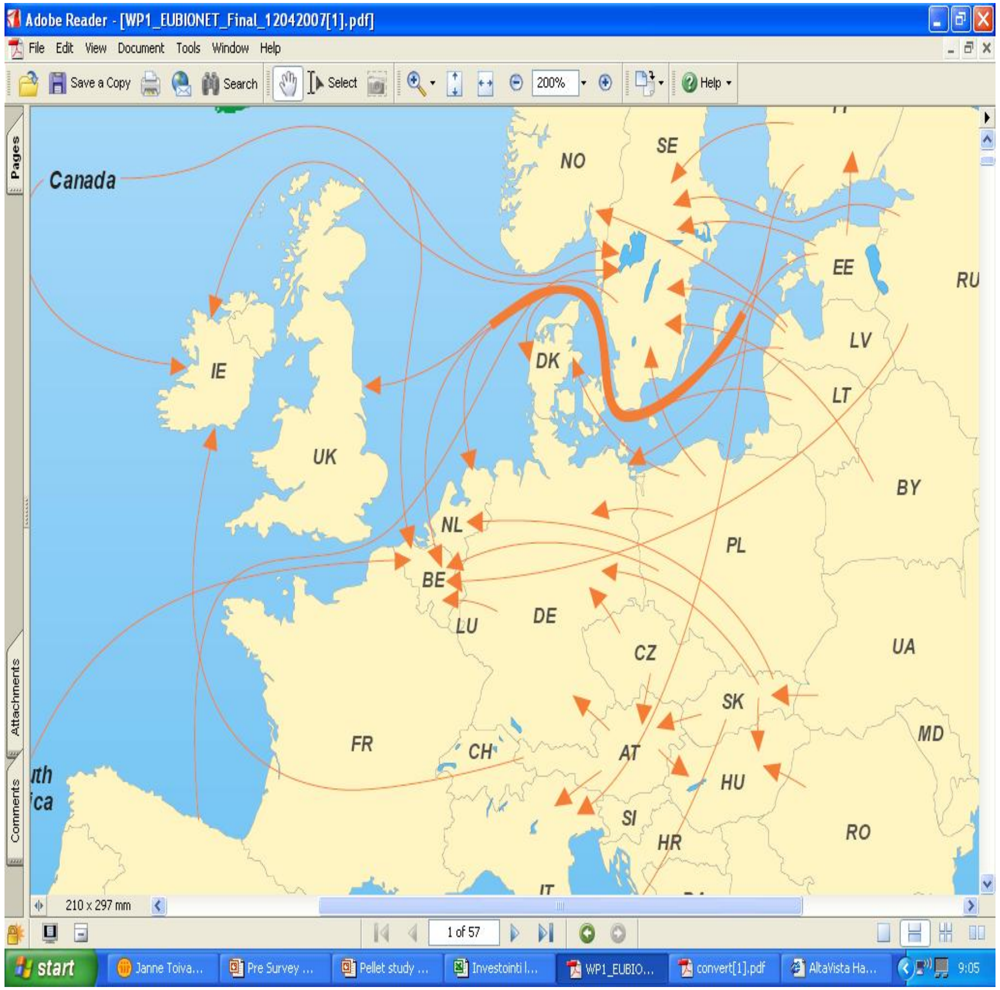
- Pellet price will follow coal price + emission payments. If 26 euro / MWh => which gives 94 euro / t pellet price (3.6 MWh/t)
  - Coal + emission payments will increase 2013
- Raw material markets are in Scandinavia, Russia and Canada
  - Canada and USA has published several pellet investments which are under construction => markets are Europe and Japan
- Markets will crow 40-50 % / year
  - Main market areas will be GER, UK and DEN



Industrial pellet (Brown pellet) mill info for calculations

Pellet manufacturing from bark

Mill will be located in the plant where raw material is available => bark example

Line capacity 500 GWh / 280.000 t bark / 130.000 t pellet

Bark drying done by using pulp mill waste heat and primary heat

Main process equipments are: Sieving, drying, crushing, sieving, pelletizing, cooling and storage

Running hours 8000 hours annual

Operation done in three shifts

Pellet business

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- STRENGHTS
  - Urgent need to for alternative energy source
  - High energy and fossil fuel prices
  - Competitive price
  - Carbon prices will increase biomass profit
  - Can be burned in the coal boilers with coal, lower emissions
  - Transportable biomass fuel
  - Improved harvesting and boiler technology
- WEAKNESS
  - Efficient transportation of biomass
  - US and China policy not supporting yet
  - Over capacity allready in the market

Pellet business

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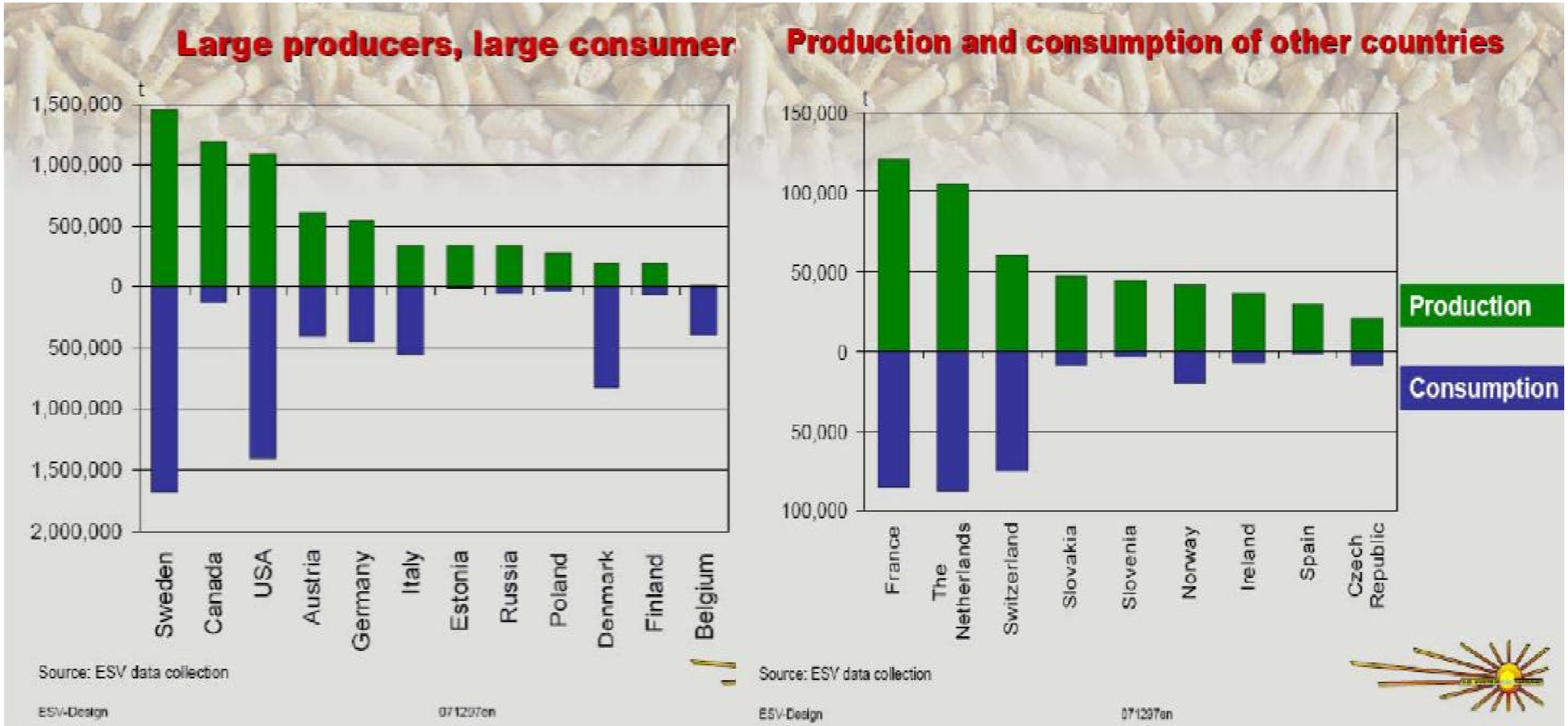
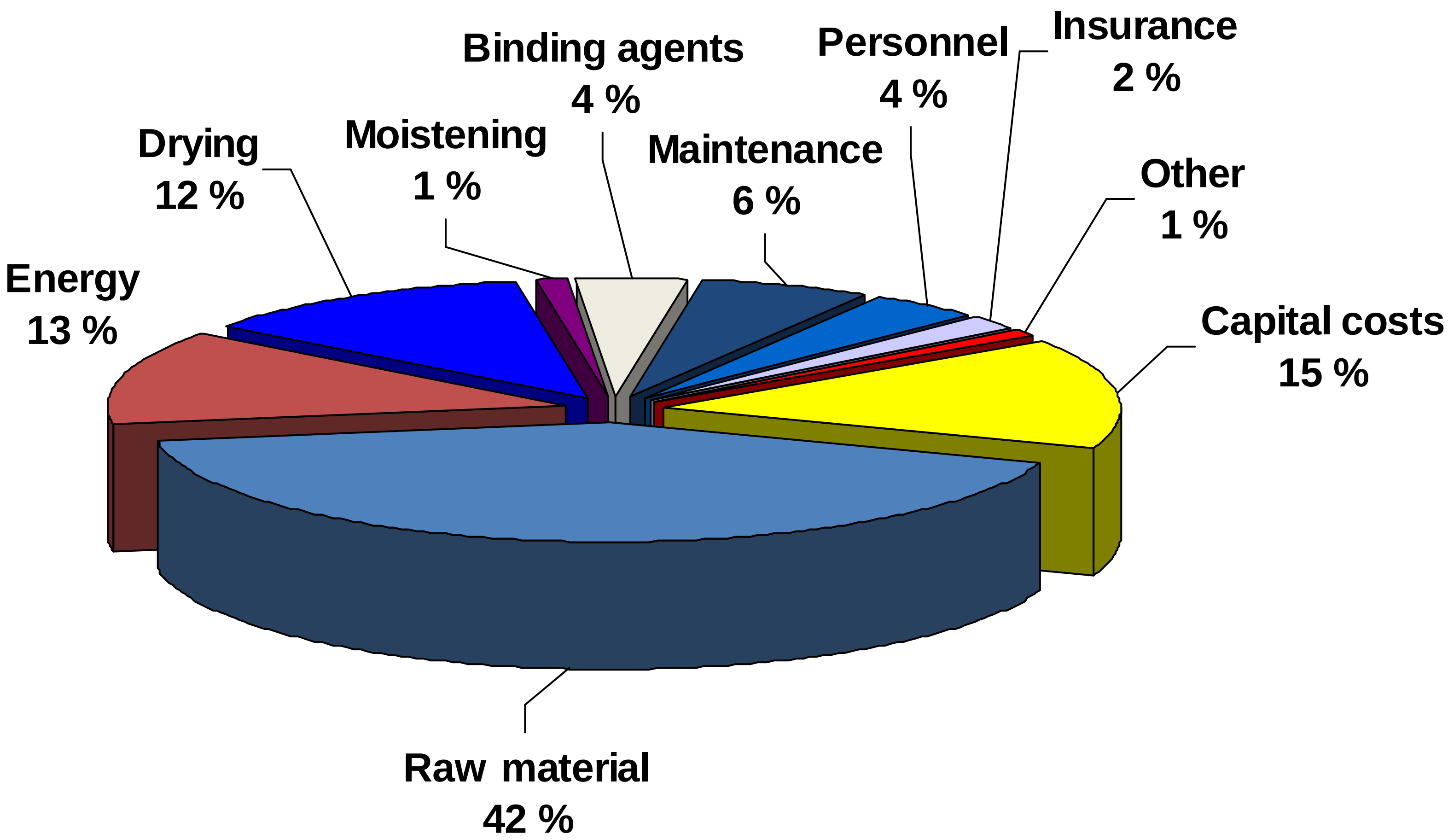
- OPPORTUNITIES
  - Biomass image and awareness of environmental issues
  - Emerging markets for biomass (bio diesel etc.)
  - Not utilized biomass available (Canada, Russia)
  - Demand from China and other Asian countries
  - TAX on CO_2 and fossil fuels
  - EU / Governments support
- THREATS
  - US and China policy
  - Agriculture will increase biomass production which will be alternative energy source as "Green energy" (lot of small players)
  - Transportation cost

Production and consumption in Europe



Rough cost structure of sawdust pellet production



Rough transport costs

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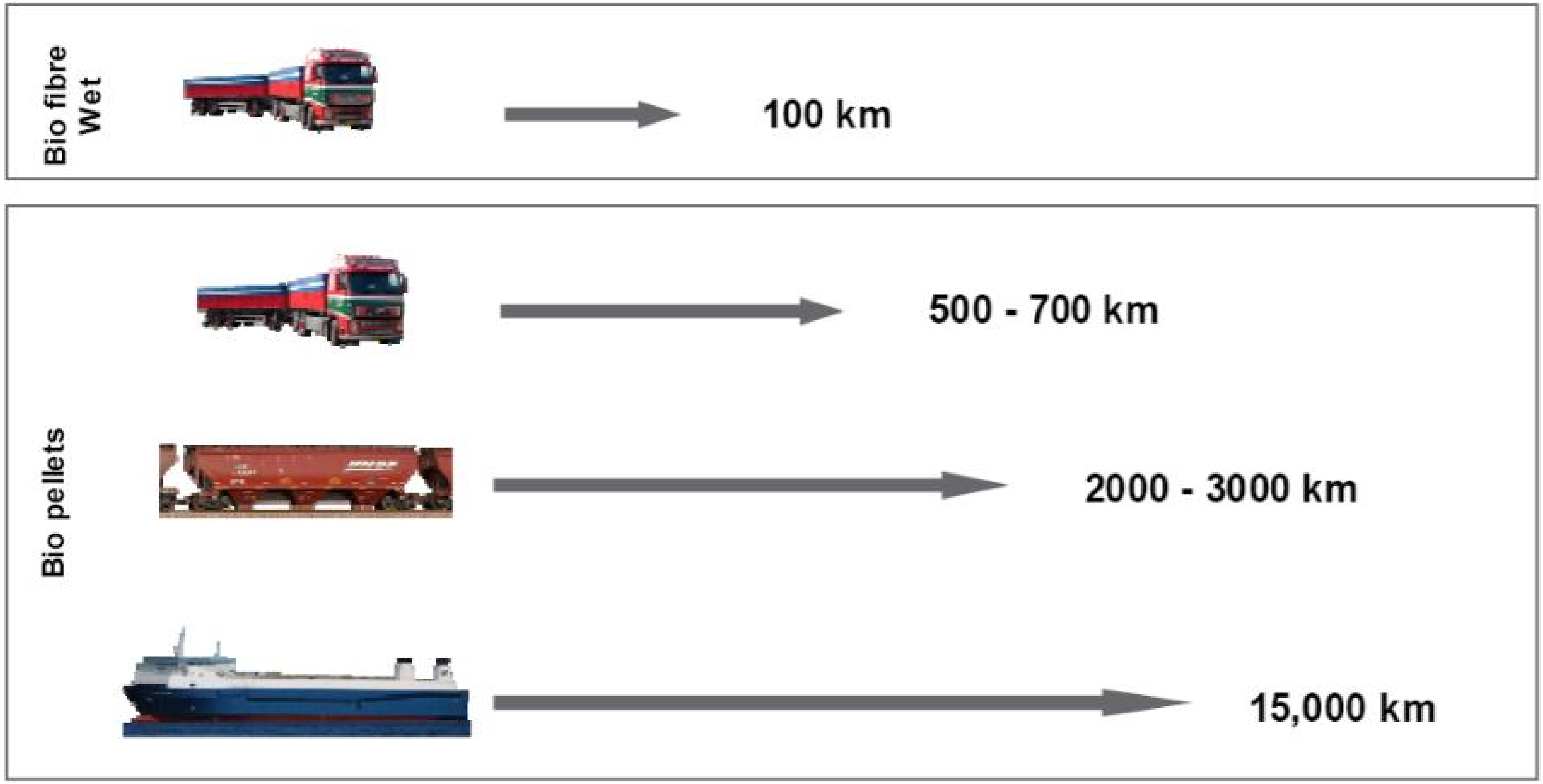

Wood preparation

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- Wood infeed

- Wood Receiving
- Wood Storing and Retrieving
- Debarking
- Chipping
- Chip Storage
- Screening
- Re-sizing
- Mixing and metering to drying

- Excellent “Micro-Chip” quality is produced by the HHQ-Chipper™ for pellet production.

Pelletizing

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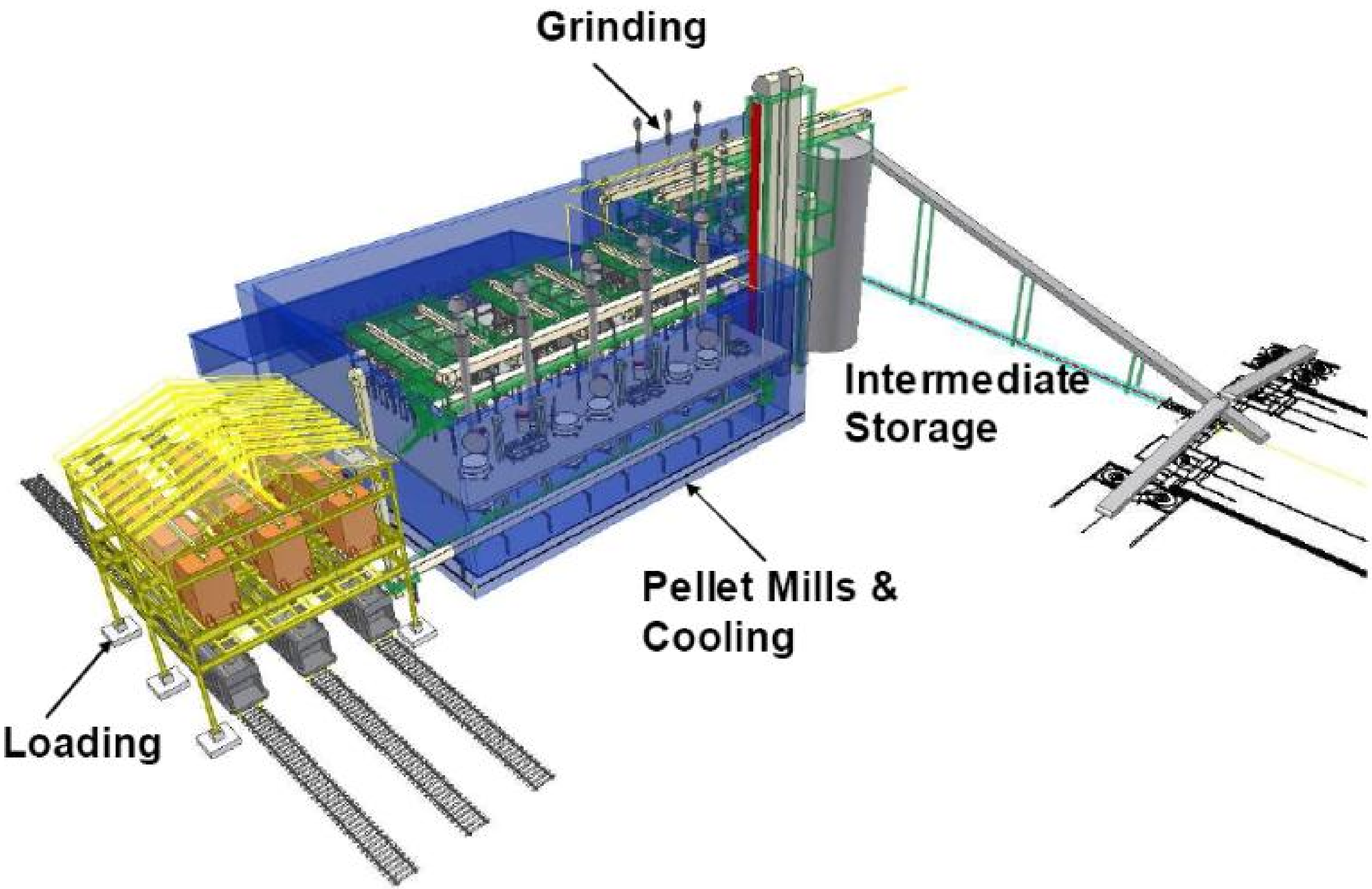
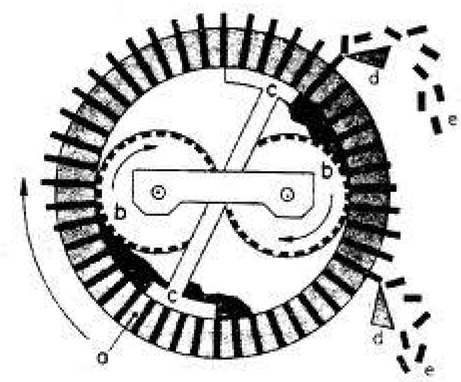


Pelletizing



Torrefication =
Conversion to coal like solids

What is this torrefier?

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What is the pyrolysis of the wood ?

- Pyrolysis is the thermal decomposition of wood in the absence of oxygen under at elevated temperaures.

- Result of the pyrolysis process are solid, liquid and gaseous products. Solid products remain in the form of charcoal, and liquid and gaseous products stand together in the form of vapor-gas mixture. Vapor mixture, if necessary, is divided by the cooling of the condensate and non-condensing gases. The condensate can be recycled to the acetic acid, methanol, tar and other products, and non-condensing gases are burned

- The distribution between solid, liquid and noncondensable gases depends on the biomass and conditions of pyrolysis (temperature and time)

Biomass torrefaction for energy

- Absence of oxygen requires air-tight system
- Torrefaction should be considered as a separate thermal regime, distinctly different from drying, slow pyrolysis or charcoal production
- Characteristic features:
  - Modestly exothermal reaction
  - Condensables composition and behaviour
  - Nature and behaviour of the solid product
- Optimum energy efficiency is crucial in view of overall cost and sustainability

Jaap Kiel, 2011, ECN's torrefaction-based BO2-technology – from pilot to demo
IEA Bioenergy workshop Torrefaction, Graz Austria, 28 January 2011

Ash and Moisture content

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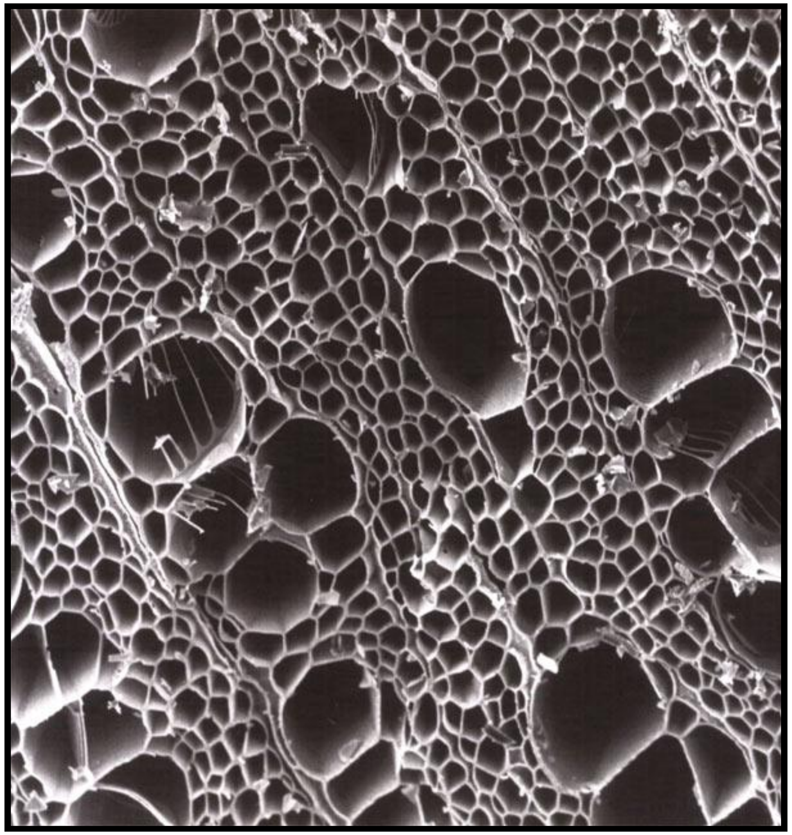
The ash content of charcoal ranges from 1 to 4%, while the ash content of coal from a large timber land delivery usually does not exceed 1.5%. Coal, discharged from the installation does not contain moisture, but it can absorbs from the air to a maximum moisture content of 10-15%.

Porosity of the charcoal

Charcoal	Spruce	Pine	Birch	Aspen
Density, g/ cm^3	0.271	0.347	0.424	0.309
Porosity, %	85	81	77	83



Charcoal has a high porosity, which explains its adsorption properties. The porosity of coal can be determined by its density given the density of the coal mass equal to about 1.8 g/cm^3.

Spontaneous ignition

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Spontaneous ignition of charcoal - the result of its autoxidation, developing an avalanche, with a rapid increase in temperature under the influence of available coal paramagnetic centers.

Coal charred at low temperatures and containing up to 30% volatile compounds has the greatest ability for spontaneous ignition, spontaneous ignition temperature of such coal below 150^{o}C . Coals with a low content of volatile compounds may ignite spontaneously at temperatures above 250^{o}C.

The stabilization of the hot charcoal can be accomplished by a controlled cooling of charcoal with air. Than the minimal temperature of the spontaneous ignition of charcoal is 340^{o}C.

Raw material

- Raw material for the thermal treatment is usually a s
wood.

- Raw material for charring can be divided into 3 groups. The first group includes birch and hardwood – beech, ash, hornbeam, elm, oak, maple; the second - deciduous - aspen, alder, linden, poplar, willow; third group consists of conifers - pine, spruce, cedar, fir, larch.

- Output of coal from softwood slightly higher than that of hardwood, but the quality of coal from the hardwood is higher.

- The content of the bark in the raw material increases the ash content of coal, so the presence of the bark is not desirable, but in industrial practice removal of the bark is usually not produced.

- Different kind of waste from wood industry can be also used as raw material, which by their chemical composition not much different from the stemwood.

Charcoal briquettes production

- mechanical strength 6.9-9.8 MPa;
- density 900-1000 kg/m3;
- calorific value 30-32 MJ/kg;
- low water absorbency

Briquette production

1. grinding of coal → 2. preparaion of the briquette mass → 3. pressing → 4. drying

- Briquettes are made using binders, which can be: products of thermal processing of solid fuels and oil refining, food processing plant materials - dextrin, starch, molasses, lignosulphonate, willow pitch, etc.

- Optimal conditions for briquettes production are: the mass fraction of binder 15-20%, water 40% of the mass of absolutely dry raw material, cooking time 60-90 minutes the mixture, pressing pressure 5 MPa, the drying temperature of 500-550oC.

Torrefaction

- Special case of the pyrolysis. The process in relatively low temperature range 225–300^{o}**C**;

- Increased calorific value;

- Decomposition of hemicellulose;

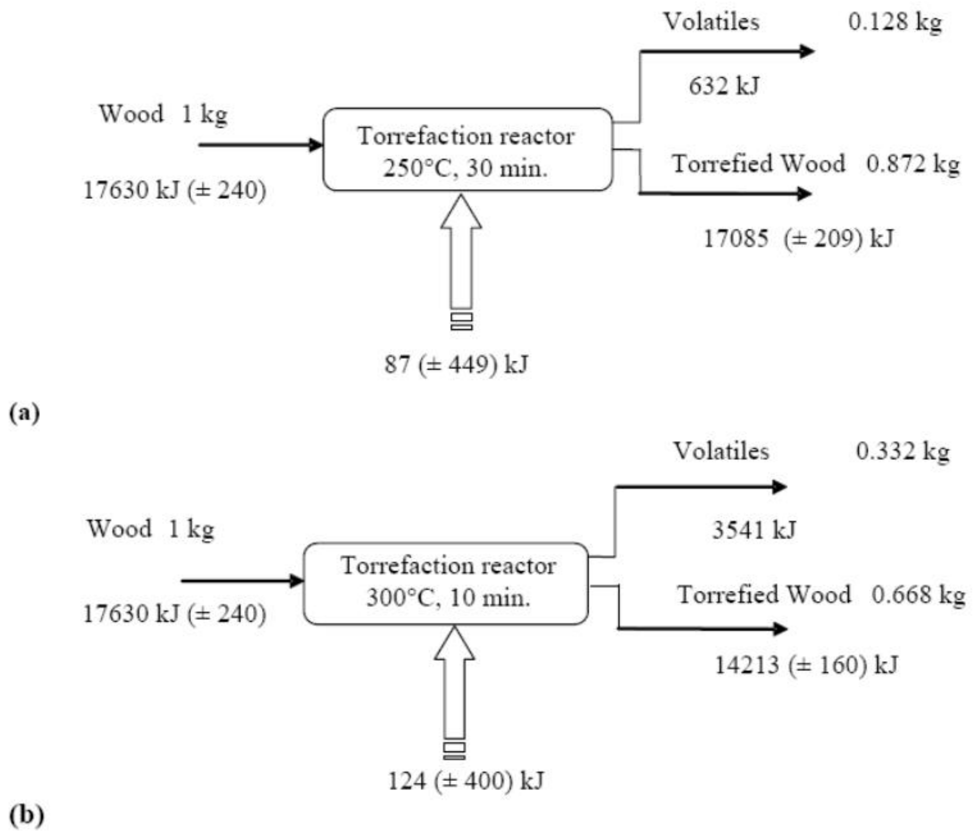
- Dehydrogenation (chemical elimination of water);

- Elimination of CO2 and CO;

- Elimination of volatiles;

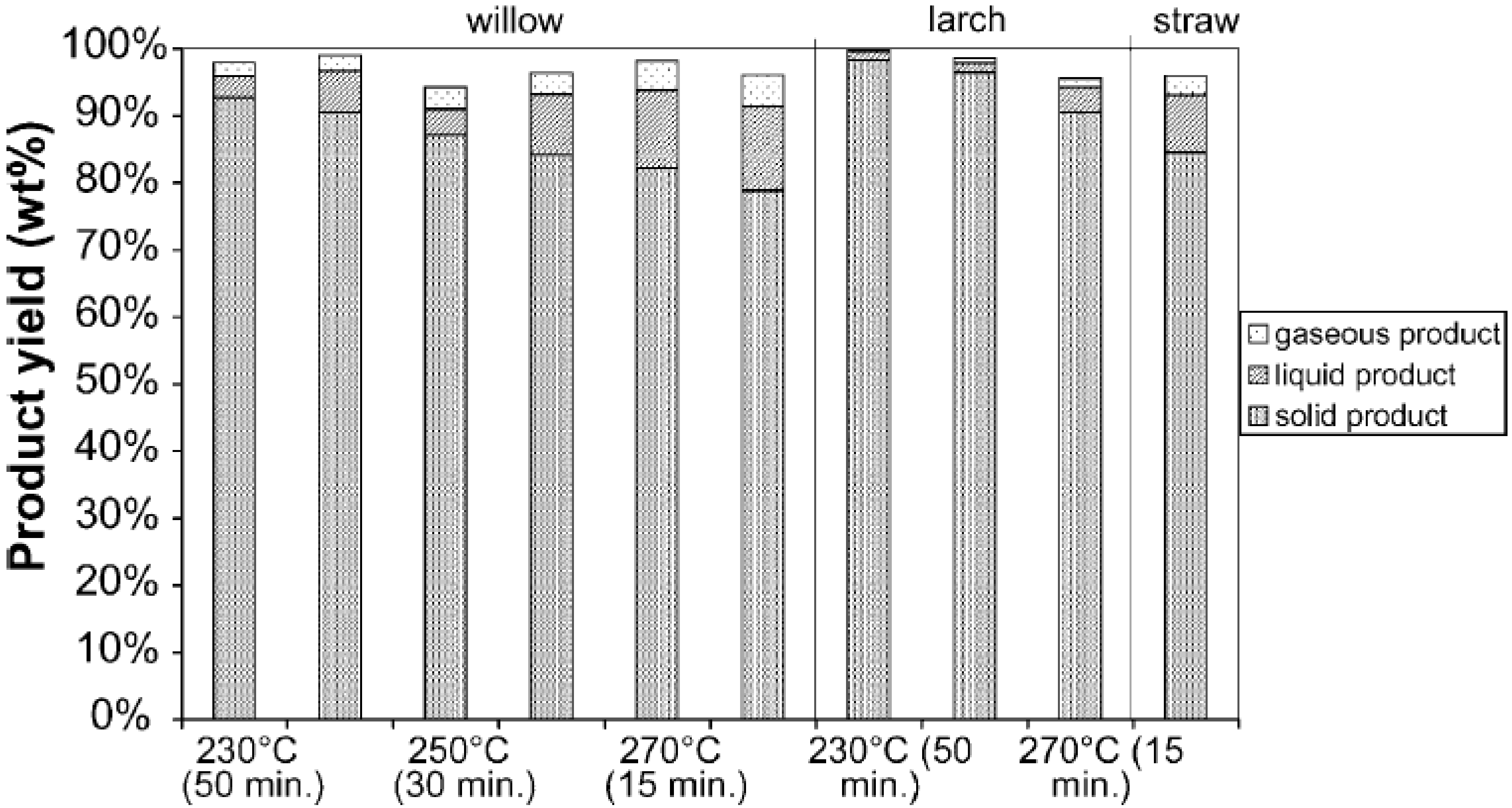
- Cracking of organic structures.

Mark J. Prins research



Overall mass and energy balances for torrefaction of (dry) willow at temperature and reaction time of (a) 250°C and 30 minutes (b) 300°C and 10 minutes.

Mark J. Prins research



Overall mass balance of several torrefaction experiments.

Torrefaction

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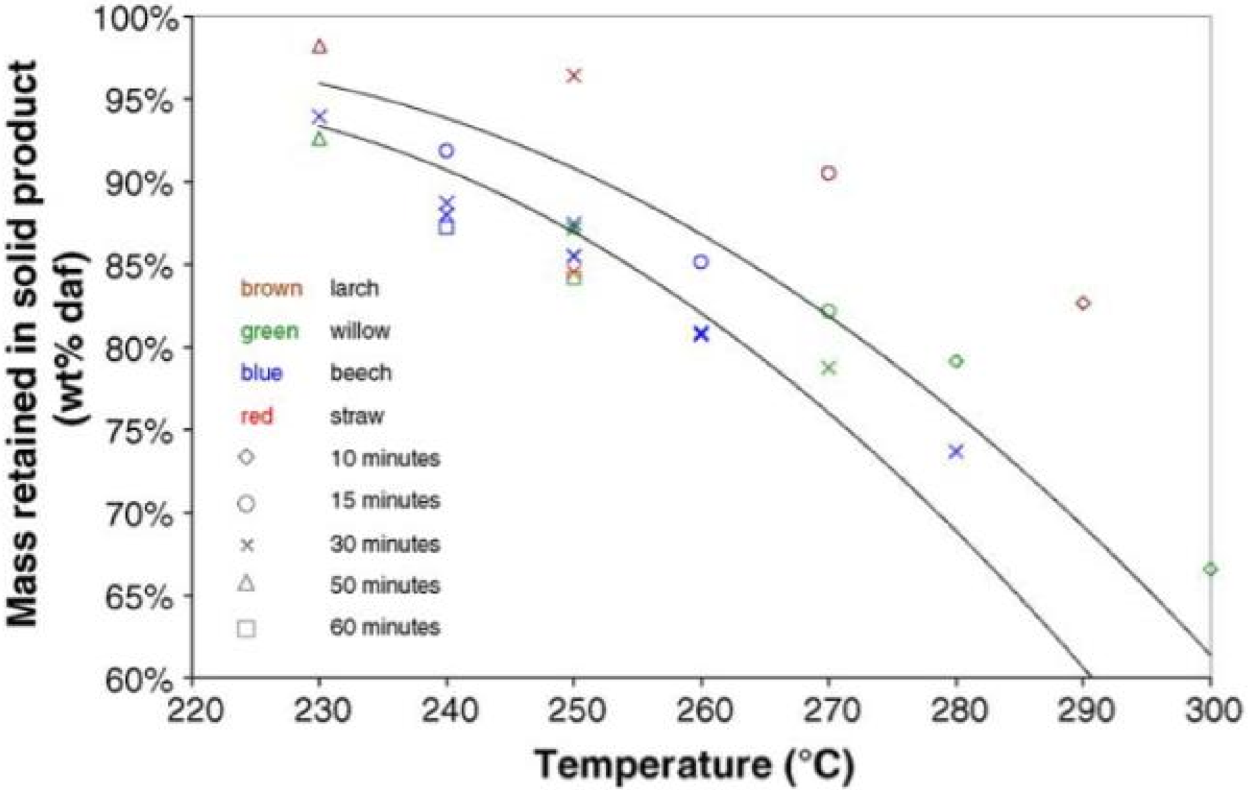
Mark J. Prins research



Yield of torrefied wood as a function of temperature and residence time, for different biomass types; solid lines from kinetic model for torrefaction of willow at 15 min (upper line) and 30 min (lower line) residence time.

Torrefaction

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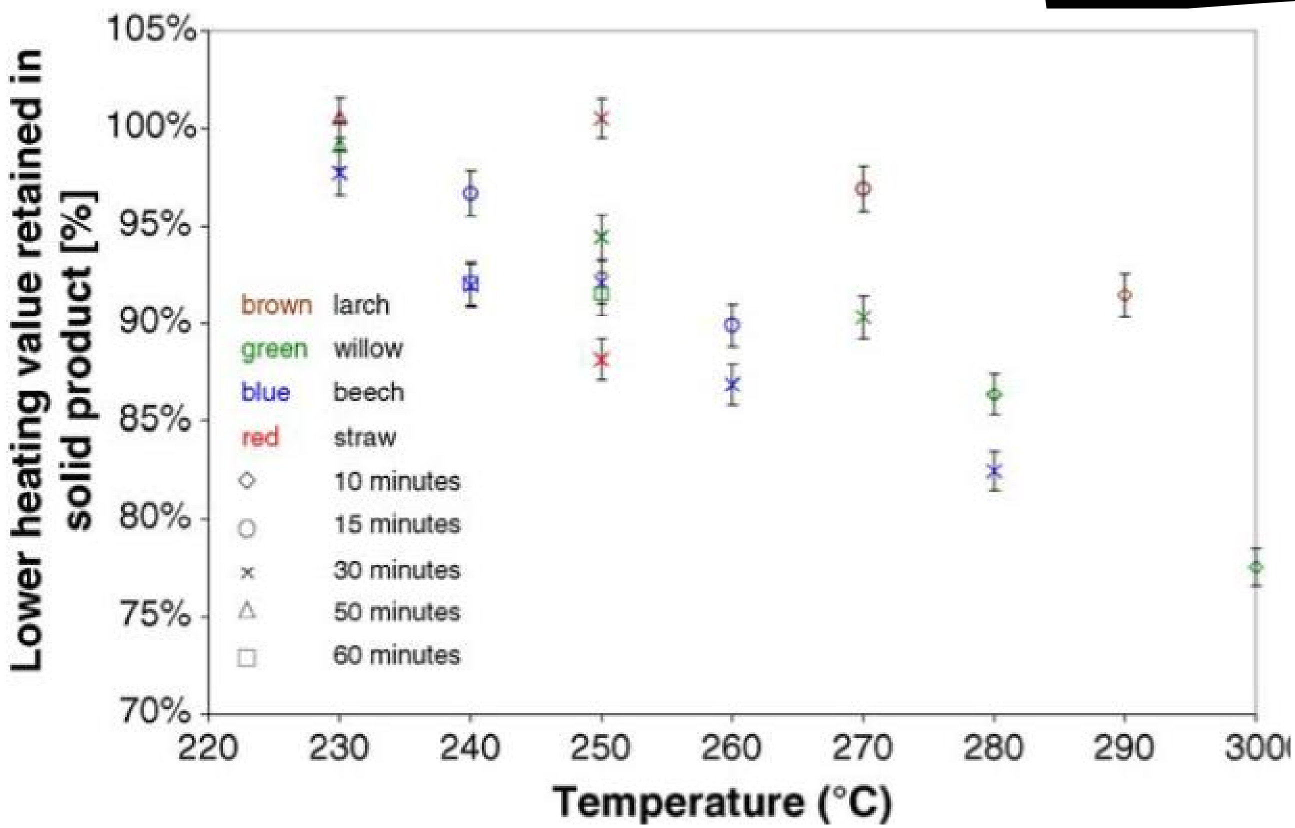
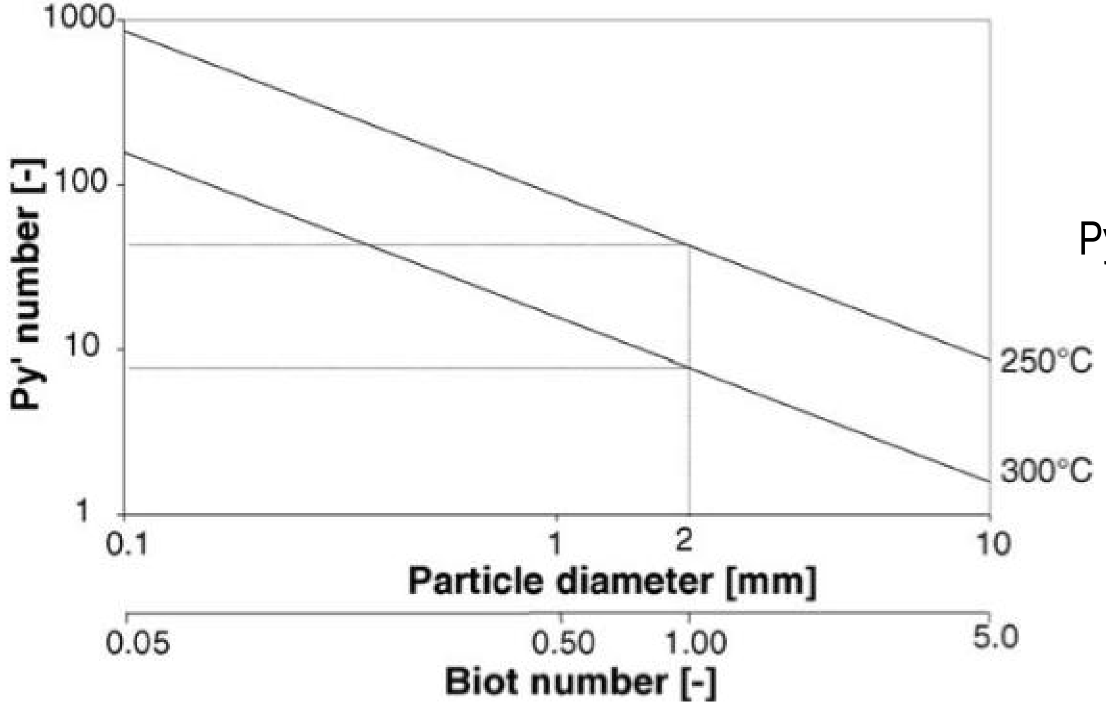
Mark J. Prins research



Lower heating value retained in torrefied wood on dry basis as a function of temperature and residence time, for different biomass types.

Mark J. Prins research



Biot number: $$Bi = \frac{\alpha r_p}{\lambda}$$

Pyrolysis number: $$Py' = \frac{\alpha}{K_1 \rho c_p r_p}$$

α - the external heat transfer coefficient in W/m^2 K;
r_p the radius of the particle in m (assuming spherical particles);
λ - the thermal conductivity in W/m K,
ρ - the density in kg/m^3;
c_p - the heat capacity in J/kg K of the biomass particle

Torrefaction

Mark J. Prins research

Composition of wood and torrefied wood (for willow)

	Wood	Torrefied wood (250°C, 30 min.)	Torrefied wood (300°C, 10 min.)
C, %	47.2	51.3	55.8
H, %	6.1	5.9	5.6
O, %	45.1	40.9	36.2
N, %	0.3	0.4	0.5
Ash, %	1.3	1.5	1.9
LHV (MJ/kg)	17.6	19.4	21.0

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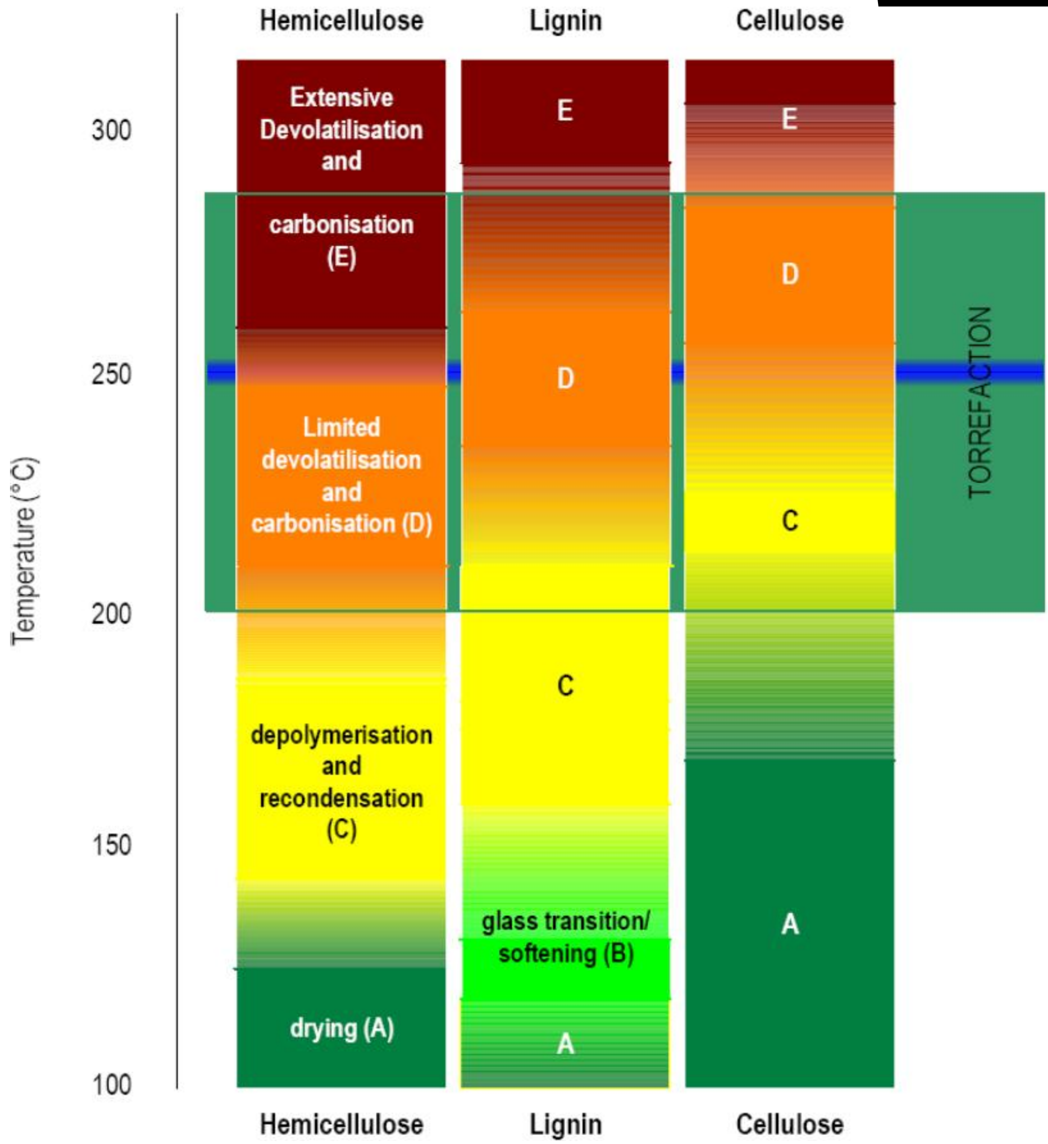
Processes during torrefication

E. Vakkilainen

Biomass component reactions



Jaap Kiel, 2007,
Torrefaction for biomass upgrading into commodity fuels

Torrefaction modeling

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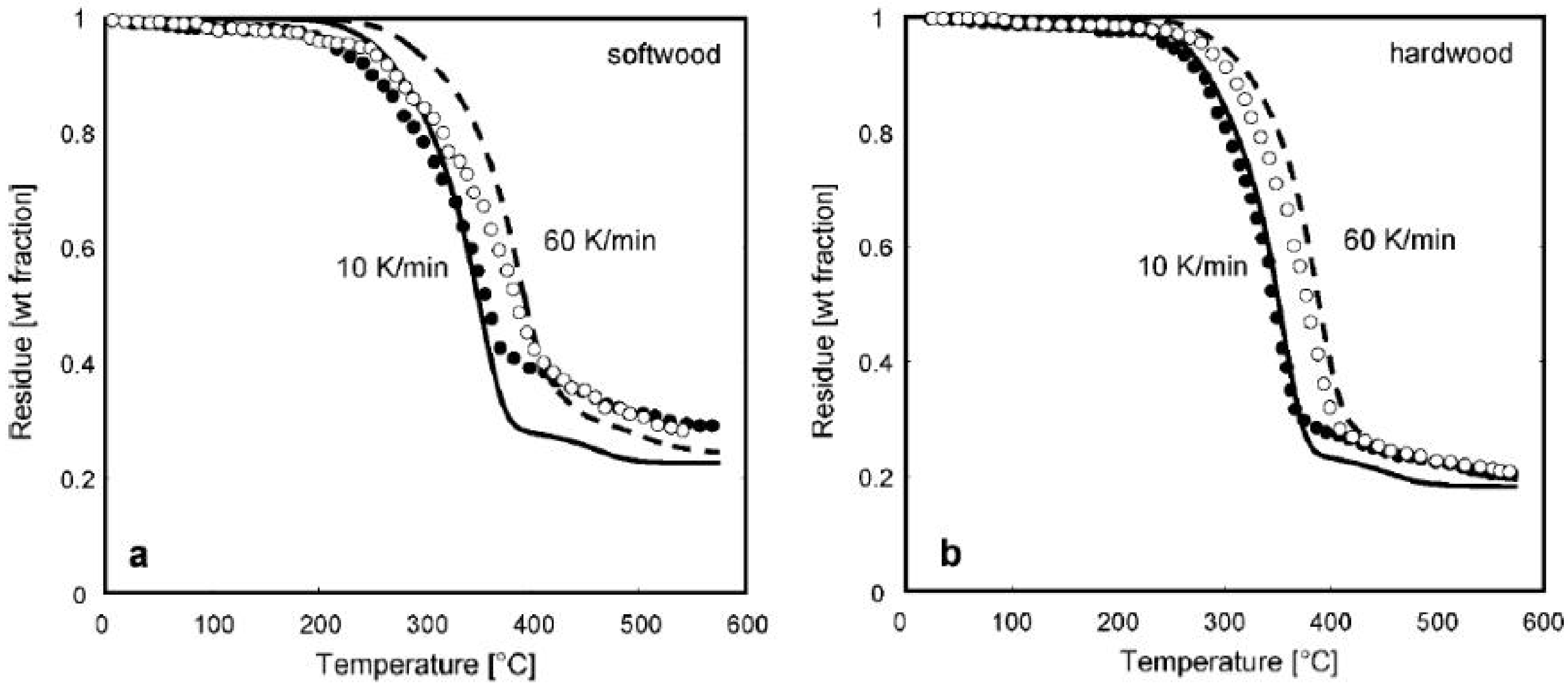
- External and internal heat transfer
- External and internal mass transfer
- Volume and porosity development
- Drying is controlled by heating rate
- Devolatilization rate correlations need validation by measurements
- Tar formation is based on measurements (little understood)
- Water-gasification reaction $C + H_2O \rightarrow CO + H_2$ endothermic
- Boudouard reaction $C + CO_2 \rightarrow 2CO$ endothermic
- Oxygen-gasification $C + \frac{1}{2} O_2 \rightarrow CO$ normally negligible
- Shift conversion $CO + H_2O \leftrightarrow CO_2 + H_2$ exothermic

Järvinen, M. P., 2002, Numerical modeling of the drying, devolatilization and char conversion processes of black liquor droplets. Doctoral Dissertation, Acta Polytechnica Scandinavica, Mechanical Engineering Series No. 163, Espoo 2002, 77 p.

Decomposition of wood



Ranzi, Eliseo ; Cuoci, Alberto ; Faravelli, Tiziano ; Frassoldati, Alessio ; Migliavacca, Gabriele ; Pierucci, Sauro and Sommariva, Samuele, 2008, Chemical Kinetics of Biomass Pyrolysis. Energy Fuels, 2008, Vol. 22, No. 6, pp. 4292 – 4300.

Pyrolysis of celulose

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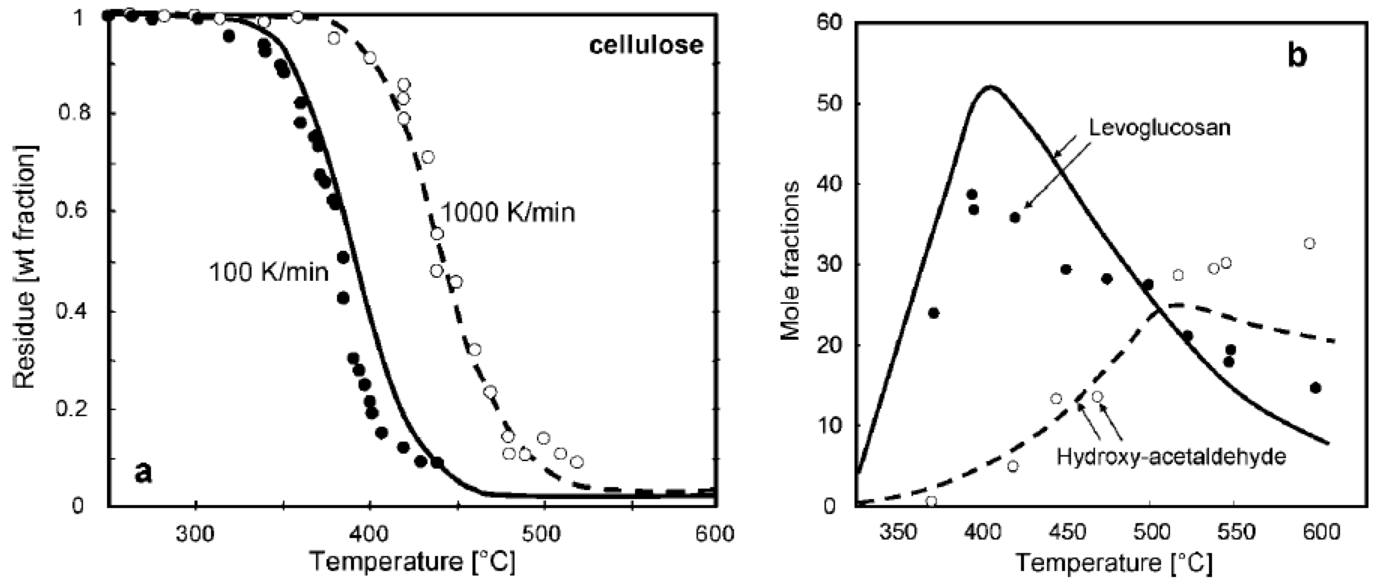
Cellulose → Active Cellulose → Decomposition products

Cellulose → Char + H_2O

Active Cellulose → Levoglucosan



Ranzi, Eliseo ; Cuoci, Alberto ; Faravelli, Tiziano ; Frassoldati, Alessio ; Migliavacca, Gabriele ; Pierucci, Sauro and Sommariva, Samuele, 2008, Chemical Kinetics of Biomass Pyrolysis. Energy Fuels, 2008, Vol. 22, No. 6, pp. 4292 – 4300.

Main pyrolysis stages

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Temperature	Process	Products	Heat
< 150°C	Drying	H_2O, turpentine	IN
150-280°C	Beginning of the decomposition. Depolymerization reactions	Acetic acid, methanol, CO, CO_2	IN
280-400°C	Formation, evaporation of the main products of decomposition of cellulose and lignin. Devolatilization reactions	Organics, tars, CO, CO_2	OUT
450-600°C	Carbonization of the charcoal	CO, H_2	IN

Product yield of the thermal decomposition of some wood species

Raw material		Thermal products, % of mass of absolutely dry wood				
		Charcoal	Tars	Acids, alcohols and others	Gases	Water of the decomposition
Spruce	wood bark	37.9 42.6	16.3 18.4	6.3 1.9	18.2 19.8	22.3 17.4
Pine	wood bark	38.0 40.6	16.7 18.9	6.2 6.7	17.7 19.7	21.4 16.9
Birch	wood bark	33.6 37.9	14.3 24.0	12.3 4.7	17/0 18.6	22.8 14.8
Aspen	wood	33.0	16.0	7.3	20.4	23.3

Gas compositions

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The composition of gases by charring of wood at 400°C (in volume percentage)

Wood species \ Gas componets	CO2	CO	CH_4	C_2H_4	H_2
Birch	49.0	28.4	18.2	1.4	3.0
Pine	49.5	28.5	18.0	1.0-	3.0
Sruce	48.0	28.0	19.0	1.0	4.0

75-90 m^3 of non-condensable gases are formed in the pyrolysis of the 1 m^3 of wood. Lower heating value of the 1 m^3 of non-condensable gases can be determined with equation, [kJ/m^3]

$$Q_{LHV} = 127.5 \cdot CO + 108.1 \cdot H_2 + 358.8 \cdot CH_4 + 604.4 \cdot C_2H_4,$$

where CO, H_2, CH_4, C_2H_4 – volume content of these gases in the mixture, [%].

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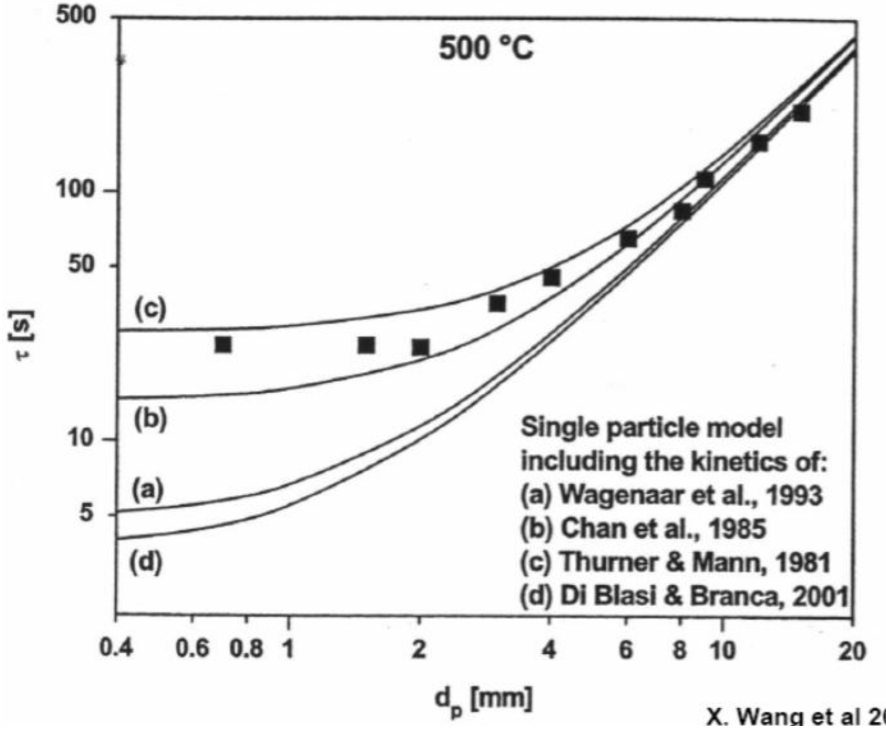
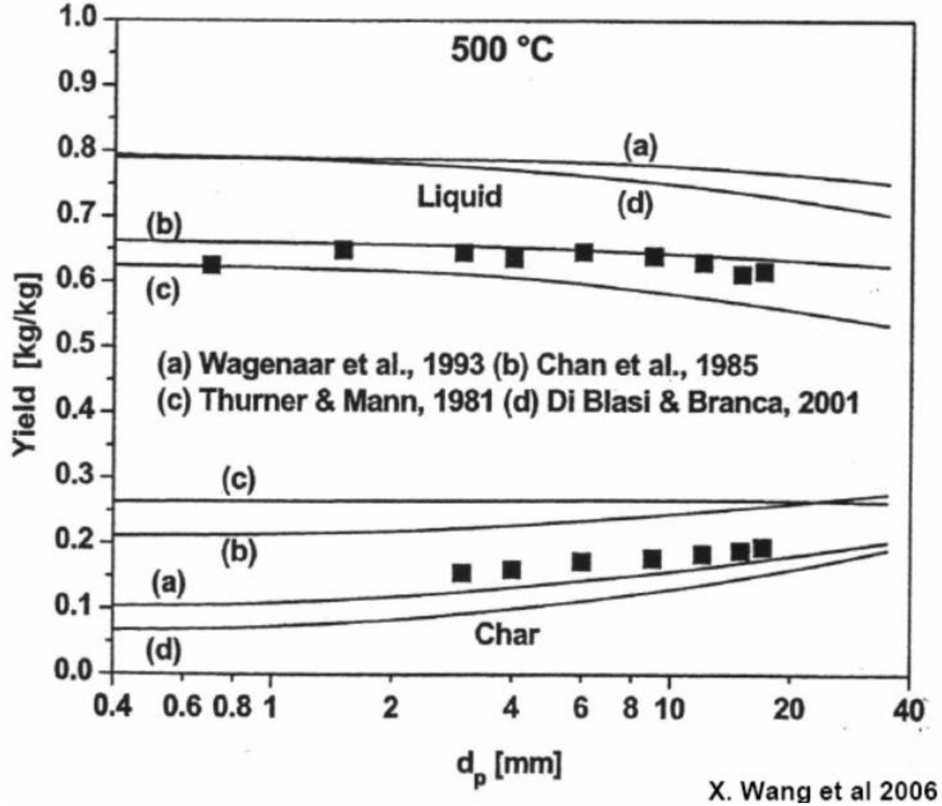
Time to complete Pyrolysis as f(size)



X. Wang et al 2006

Charcoal yield as f(size)

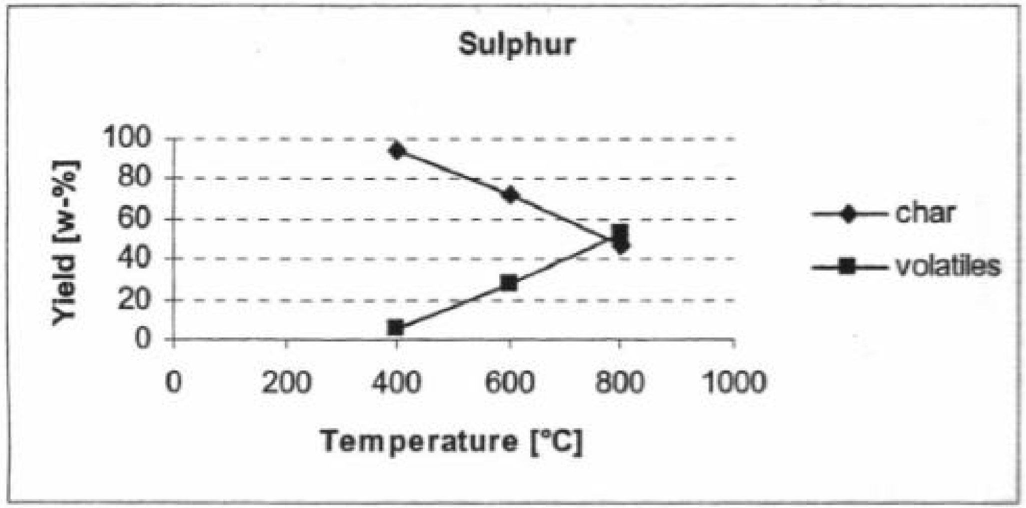


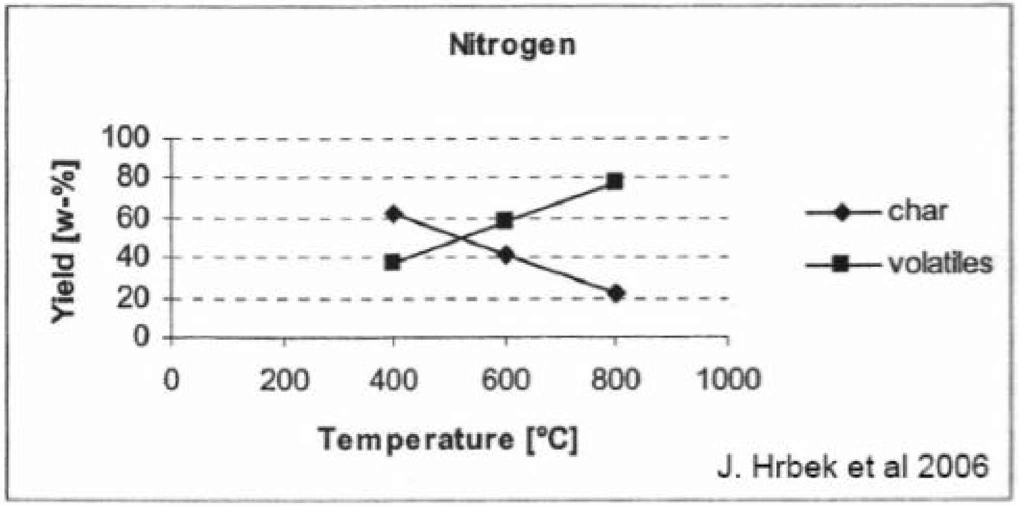
X. Wang et al 2006

Charcoal parameters depending on final temperature of charring

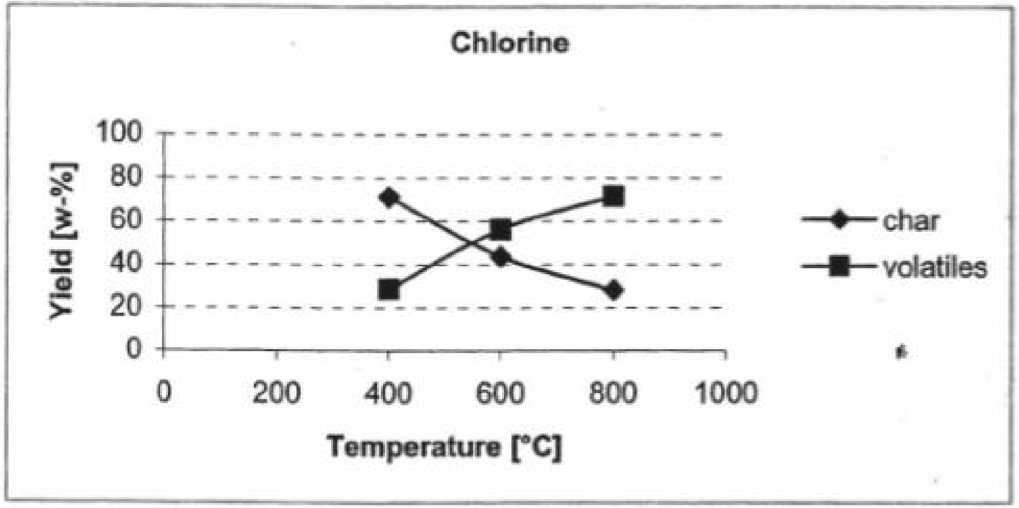
Final temperature of charring, °C	Yield of absolutely dry charcoal from the absolutely dry wood, %	Charcoal composition, %			Heating value, MJ/kg
		C	H	O + N	
350	45.2	73.3	5.2	21.5	31.56
400	39.2	76.1	4.9	19.0	32.74
450	35.0	82.2	4.2	13.6	33.12
500	33.2	87.7	3.9	8.4	34.21
550	29.5	90.1	3.2	6.7	34.42
600	28.6	93.8	2.6	3.6	34.50
650	28.1	94.9	2.3	2.8	34.71
700	27.1	95.1	2.2	2.7	34.88

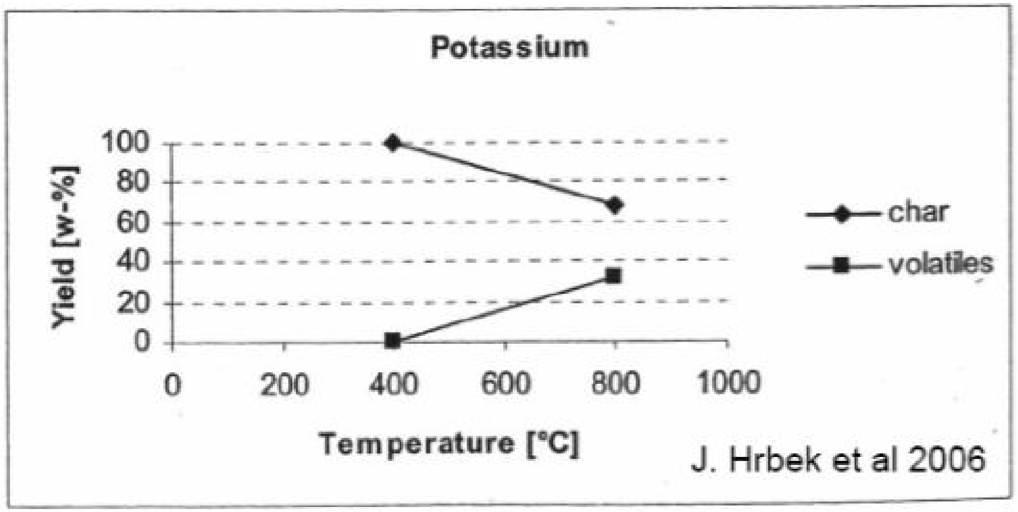
Species Migration





Species Migration





J. Hrbek et al 2006

Changes during wood pyrolysis

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The general changes that occur during pyrolysis are

1. Heat transfer from a heat source, increases the temperature inside the fuel
2. The initiation of primary pyrolysis reactions at this higher temperature releases volatiles and forms char
3. The flow of hot volatiles toward cooler solids results in heat transfer between hot volatiles and cooler unpyrolyzed fuel;
4. Condensation of some of the volatiles in the cooler parts of the fuel, followed by secondary reactions, can produce tar;
5. Autocatalytic secondary pyrolysis reactions proceed while primary pyrolytic reactions simultaneously occur in competition; and
6. Further thermal decomposition, reforming, water gas shift reactions, radicals recombination, and dehydrations can also occur, which are a function of the process's residence time/ temperature/pressure profile.

Mohan, Dinesh ; Pittman, Charles U. Jr. and Steele, Philip H., 2006, Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. Energy Fuels, 2006, Vol. 20, No. 3, pp. 848 – 889.

Wood pyrolysis bio-oil appearance

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- from almost black or dark red-brown to dark green, depending on the initial feedstock and the mode of fast pyrolysis.
- varying quantities of water exist, ranging from 15 wt % to an upper limit of 30-50 wt % water, depending on production and collection.
- pyrolysis liquids can tolerate the addition of some water before phase separation occurs.
- bio-oil cannot be dissolved in water.
- miscible with polar solvents such as methanol, acetone, etc., but totally immiscible with petroleum-derived fuels.

Mohan, Dinesh ; Pittman, Charles U. Jr. and Steele, Philip H., 2006, Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. Energy Fuels, 2006, Vol. 20, No. 3, pp. 848 – 889.

Wood pyrolysis bio-oil properties

- bio-oil density is 1.2 kg/L, compared to 0.85 kg/L for light fuel oil
- viscosity varies from as low as 25 cSt to as high as 1000 cSt (measured at 40 °C) depending on the feedstock, the water content of the oil, the amount of light ends that have collected, the pyrolysis process used, and the extent to which the oil has been aged
- it cannot be completely vaporized after initial condensation from the vapor phase at 100 °C or more, it rapidly reacts and eventually produces a solid residue from 50 wt % of the original liquid

Mohan, Dinesh ; Pittman, Charles U. Jr. and Steele, Philip H., 2006, Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. Energy Fuels, 2006, Vol. 20, No. 3, pp. 848 – 889.

Wood pyrolysis bio-oil ageing

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- it is chemically unstable, and the instability increases with heating
- it is always preferable to store the liquid at or below room temperature; changes do occur at room temperature
- temperature, but much more slowly and they can be accommodated in a commercial application
- ageing of pyrolysis liquid causes unusual time-dependent behavior properties such as viscosity increases, volatility decreases, phase separation, and deposition of gums, change with time is large

Mohan, Dinesh ; Pittman, Charles U. Jr. and Steele, Philip H., 2006, Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. Energy Fuels, 2006, Vol. 20, No. 3, pp. 848 – 889.

Wood pyrolysis product distribution vs. dense bed temperature

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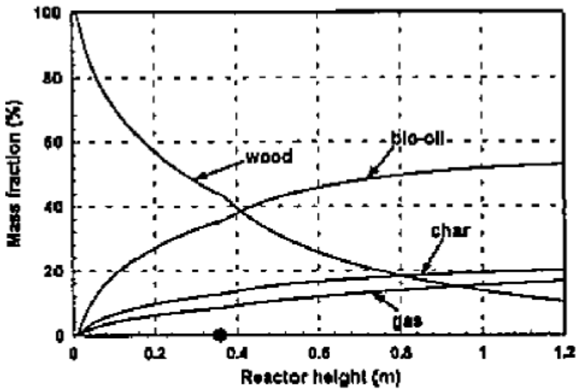
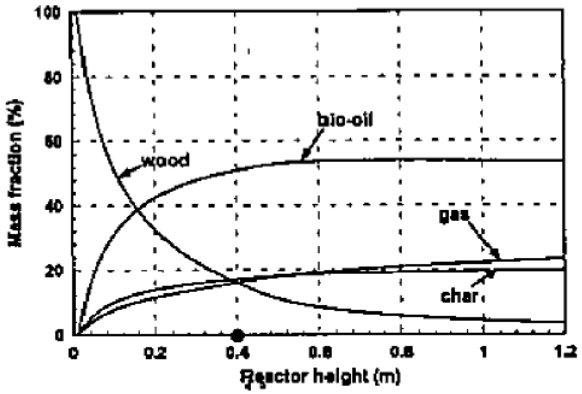
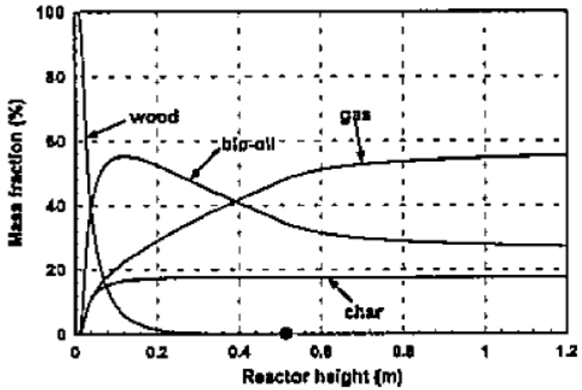
450 °C



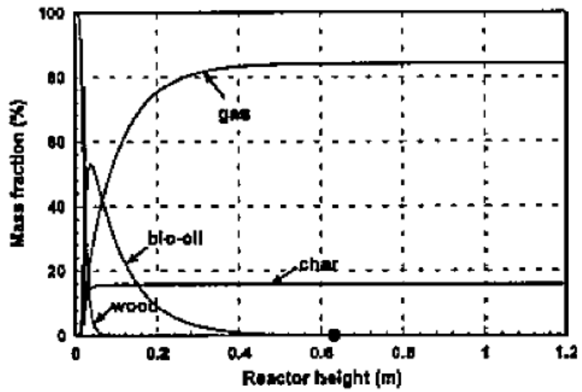
500 °C



600 °C



700 °C



Luo, Zhongyang ; Wang, Shurong and Cen, Kefa, 2005, A model of wood flash pyrolysis in fluidized bed reactor. Renewable Energy, Vol. 30, No. 3, March 2005, pp. 377-392.

Tar classification

	Type	Examples
1	GC undetectable tars	Biomass fragments, the heaviest tars i.e. pitch
2	Heterocyclic compounds that generally exhibit high water solubility	Phenol, cresol, quinoline, pyridine
3	Aromatic components. Light hydrocarbons, which are important from the point of view of tar reaction pathways, but not in particular towards condensation and solubility	Toluene, xylenes, ethylbenzene (excluding benzene)
4	Light PAHs (2-3 rings), condensate at relatively high concentrations and intermediate temperatures	Naphthalene, indene, biphenyl, antracene
5	Heavy PAHs (≥4 rings), condensate at relatively low concentrations and high temperatures	Fluoranthene, pyrene, crysene
6	GC detectable, not identified compounds	Unknowns

Biomass tar formation temperature

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	Range (^oC)	Products	
Primary	400 – 600	Acids, phenols, ketones, guaialcols, furans, furfurals	
Secondary	600 – 800	Phenols, heterocyclic ethers monoaromatic hydrocarbons	
Tertiary	800 - 1000	Non-substituted polyaromatic hydrocarbons	

Brown, David ; Gassner, Martin ; Fuchino, Tetsuo and Maréchal, François, 2009, Thermo-economic analysis for the optimal conceptual design of biomass gasification energy conversion systems. Applied Thermal Engineering, Vol. 29, No. 11-12, August 2009, pp 2137 - 2152.

Improved properties compared with biomass due to same chemical reactions

- Increased heating value (LHV)
  - removement of H_2O and CO_2
- Reduced water retention force (is not hydrophobic !!)
  - breaking cell structures and reduction of hydrophilic –OH groups
- Better grindability due to embrittlement
  - Devolatilization of hemicellulose which binds with pectin to cellulose to form a network of cross-linked fibres
- Slower biodegregation
  - Thermal modified polysaccharides are more resistant to microorganismen

Martin Englisch, 2011, Fundamentals and basic principles of torrefaction
IEA Bioenergy workshop Torrefaction, Graz Austria, 28 January 2011

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Operating commercial torrefication

E. Vakkilainen

Types of installations (Charcoal production)

Batch processes	Yield
Earth pits and mounds	>10 %
Brick, concrete, and metal kilns	20-25%
Retorts	30%
Continuous process	
Retorts and Lambiotte retorts	30-35 %
Multiple hearth reactors	25-30%

Current technologies

Earth pits and mounds

Brick kilns

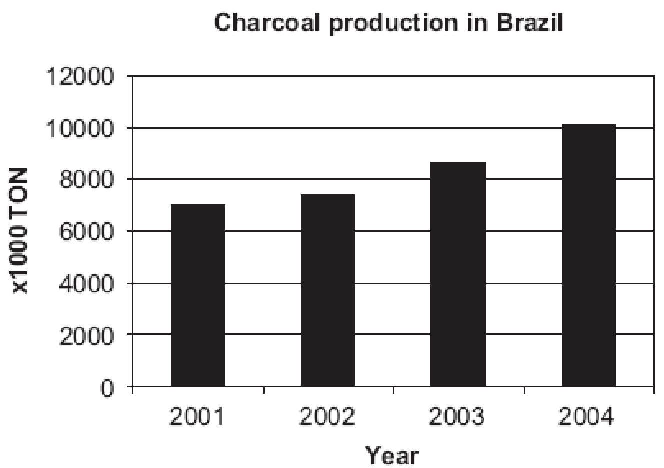
Current technologies

Retorts

Current technologies

The carbonization kilns used in Brazil are of three types:

- internal heating by controlled combustion of the raw material,
- external heating by combustion of firewood, fuel oil or natural gas;
- heating with re-circulated gas (retort or gas converter).



Charcoal production in Brazil and charcoal consumption in the iron and steel industry in Brazil

Biocoal production in Brazil

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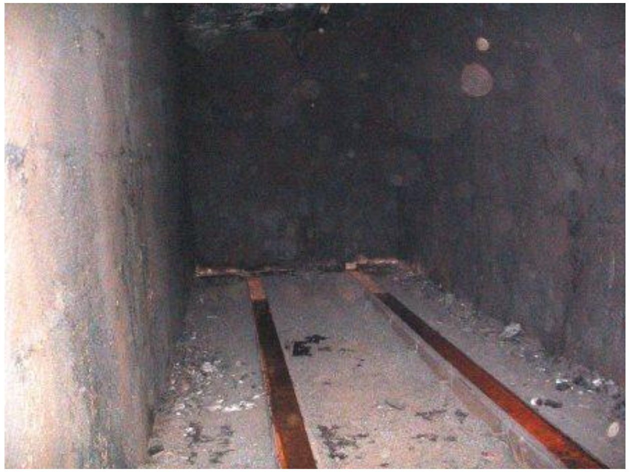
Current technologies

Metal kilns – external heating (Brazil)

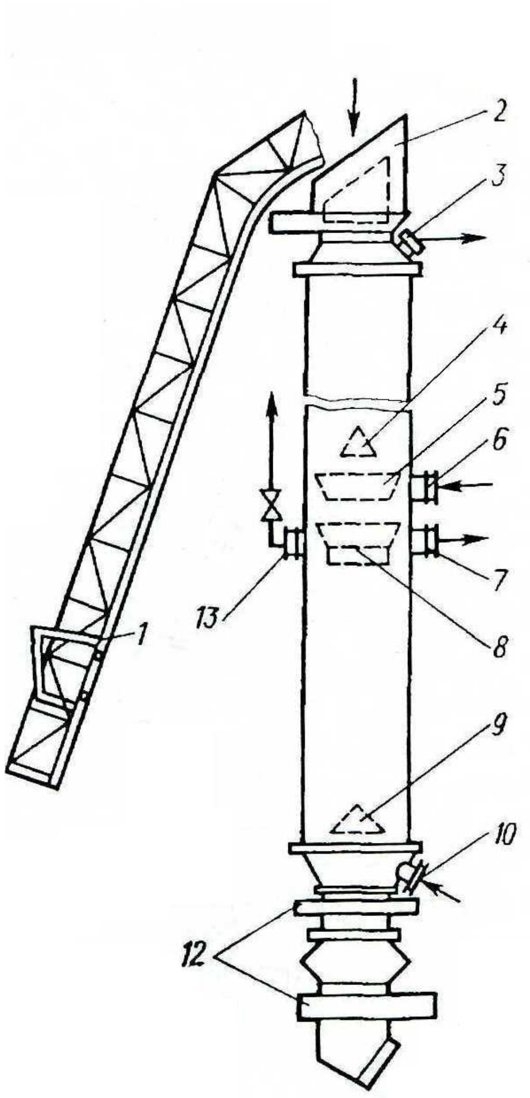
Current technologies

Metal kilns – extarnal heating (Brazil)



Current technologies

Continuous retort



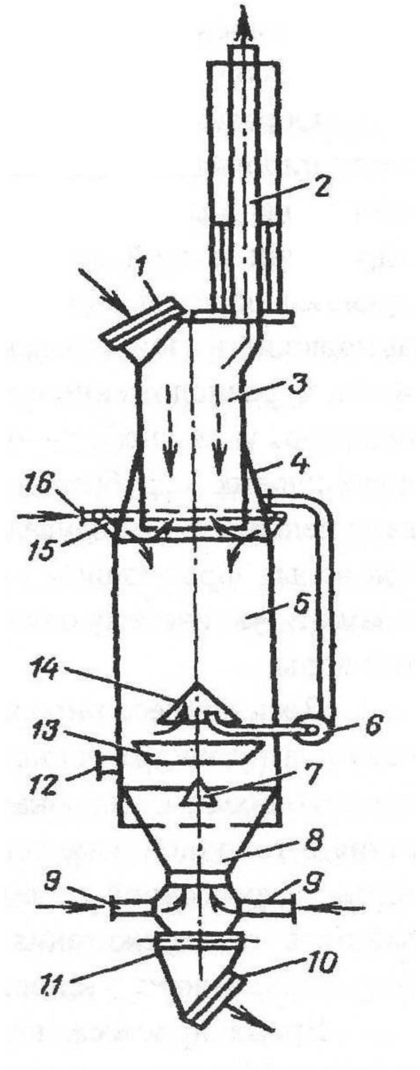
Production capacity – 7 000-14 000 t/a of charcoal (special harvested wood)

The possibility to automate all operations

1- wood elevator; 2- hydraulic gate; 3- outlet of the vapor mixture; 4,9- unloading hoppers; 5- cone of hot gas; 6- inlet of the heat transfer agent; 7,13- outlet of the warm gas; 8- cone of the warm gas; 10- outlet of the cool gas; charcoal elevator; 12- floodgates

Current technologies

Lambiotte retort



Production capacity – 2 000-6 000 t/a of charcoal (special harvested wood)

The possibility to automate all operations

1- loading of the wood; 2- outlet of the vapor mixture into the atmosphere; 3- drying zone; 4- combustion zone (vapor mixture); 5- pyrolysis zone; 6- fan; 7,14 spreading cone; 8- cooling zone; 9- inlet of cooling gas; 10- outlet of the charcoal; 11- damper; 12- outlet of the hot gas; 13- dividing cone; 15- inlet of the air; 16- air collector.

www.lambiotte.com

Current technologies

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Industrialized charcoal production in the Netherlands

Metal kilns equipped with vapour incinerators (shown here in France) can help reduce environmental pressure by increasing charcoal yields

Charcoal production in Russia

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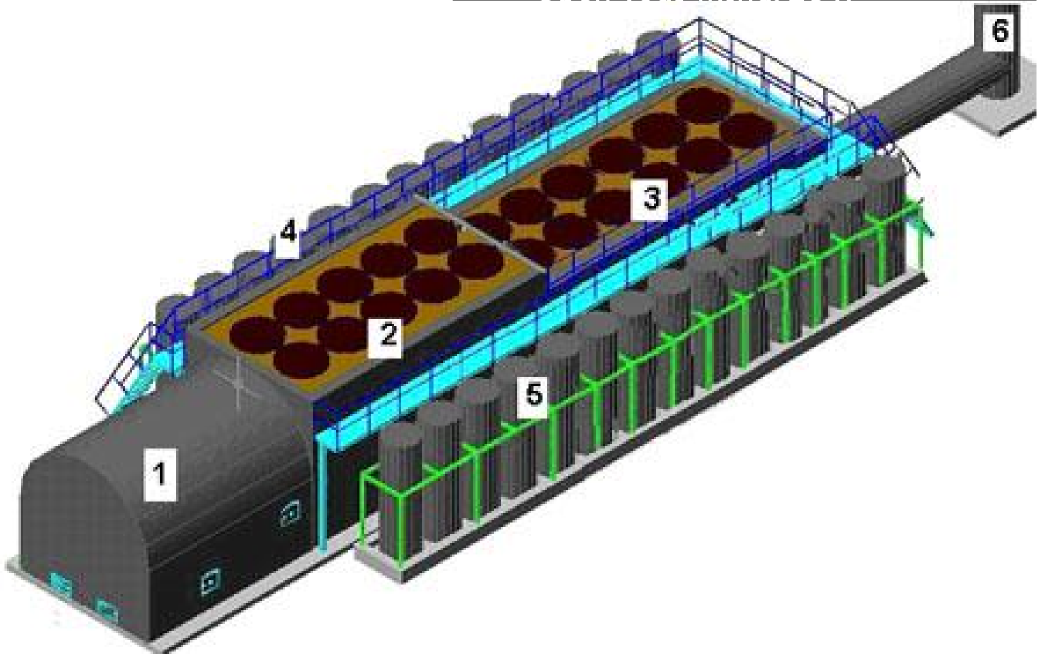

- Productivity – 1800 t/a charcoal (18000 m3/year raw material);
- Continuity of production;
- Fixed Carbon – 75-94 %; Moistuure – < 6%; Ash – 2.5-4 %;
- Charcoal Yield – 30-40%;
- "Clean production"
- Capital cost – 240,000 EUR (the installation with 1000 t/a charcoal – 110,000 EUR).

1 - furnace; 2 - pyrolysis chamber; 3 - drying chamber; 4 - retort with woody biomass; 5 - retort from the cooling coal; 6 - stack

Saint Petersburg State Forest- Technical Academy

Demonstration reactor in Canada "HNEI Flash Carbonization"

- Batch operation – 10 t/day charcoal;

- Bomass loaded to a canister then heated up to 350 ^{o}C at 0.7 MPa for 30-90 min;

- Charcoal yield 40-50 % ;

- Fixed carbon – 70-80 %;

- Catalytic after burner for tars eliminates smoke from reactor effluents;

- Capital cost $200,000.

Current technologies

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Maximizing Charcoal Yield

- Low pyrolysis temperature (<400ºC) (but also lower fixed carbon content)

- High process pressure (1 MPa) (higher concentration of pyrolysis vapor increases rate of secondary reactions)

- Long vapor residence time (extended vapor/solid contact promotes secondary coke forming reactions)

- Low heating rate (slower formation and escape of organic vapors)

- Large biomass particle size (low thermal conductivity of biomass results in slow heat and mass transfer rate within particles)

Current technologies

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EBES AG – European Bio Energy Services

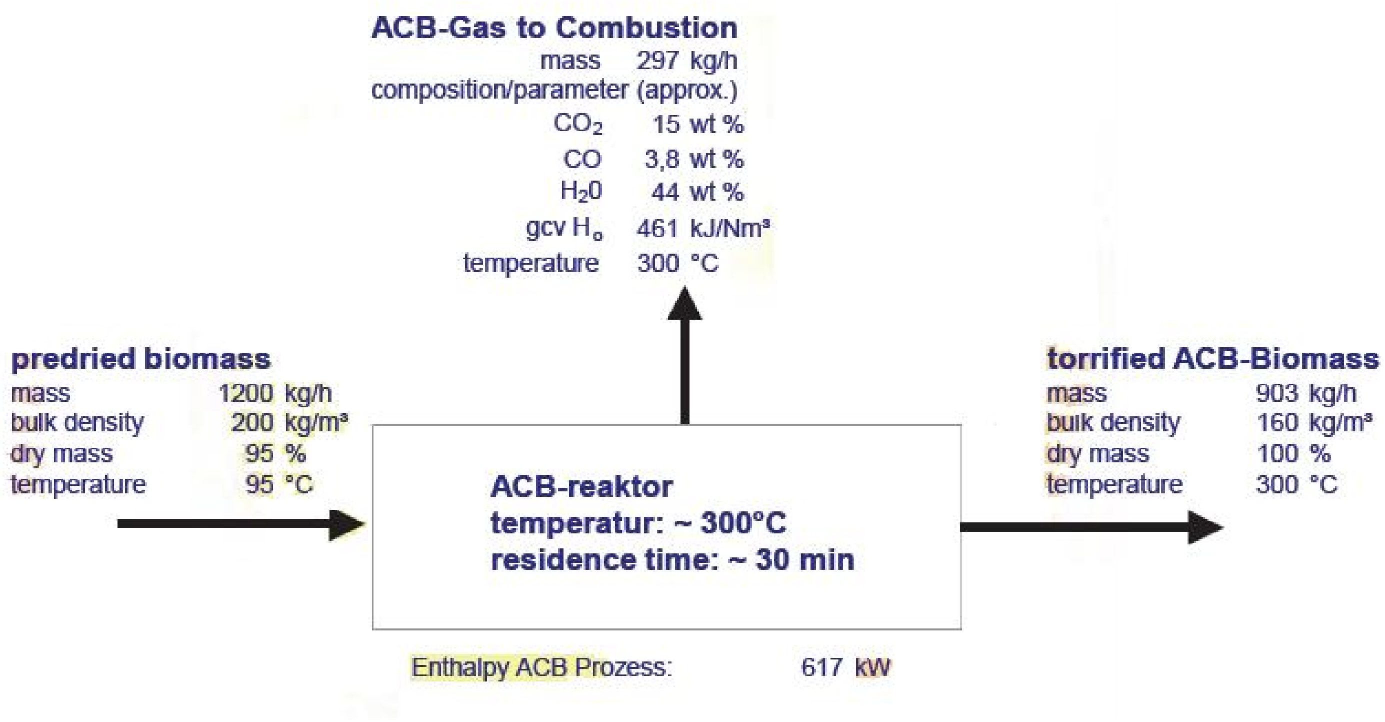
The ACB Pilot Reactor at 50kg/h

ACB - Accelerated Carbonisation Biomass

Current technologies

EBES AG – European Bio Energy Services

Mass and Energy Balance for Wood



ACB - Accelerated Carbonisation Biomass

Current technologies

EBES AG – European Bio Energy Services

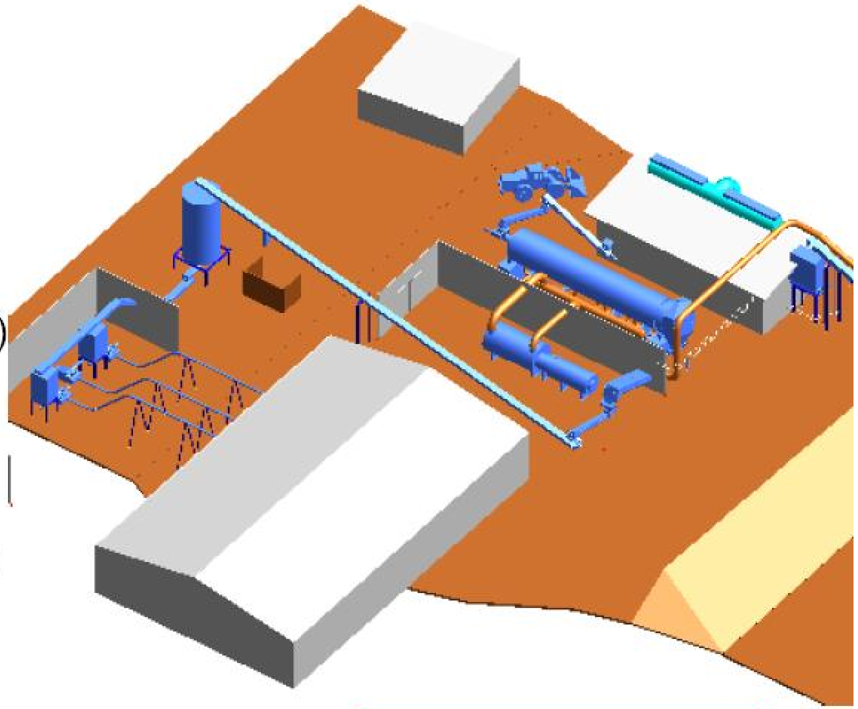
Degree of torrefaction in %

$$torrefaction = 100 - \frac{V_{,dry,torr}}{V_{,dry,raw}} \cdot 100$$

V - volatiles determined according EN 15148

Design Data of the Bioendev Torrefaction-IDU

- Fuel handling & Integration with new CHP
- Fuel capacity
  in: 24 MW (4.9 ton/h)
  out: 23-19 MW (4.3-3.3 ton/h)
- Gas thermal power 0.8-4.2 MW (LHV)
- Gas heat. value: 2.2-8.7 MJ/Nm$^3_{wet}$ (67-87%)
- Multi fuel: moisture 30-55%
- Operation: 250-300C, 25-10 min
- Products: Torrefied chips + densified biocoal
- Costs: ca 110 MSEK (11 MEuro)



metso BioEndev

Martin Nordwaeger et al., 2011, Biomass torrefaction-benefits of extensive parametric studies
IEA Bioenergy workshop Torrefaction, Graz Austria, 28 January 2011

Current technologies

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EBES AG – European Bio Energy Services

Raw material

- Wood residues
- Agricultural (by)products
  - straw
  - miscanthus
  - FFB
  - Grass/Hay
  - Bagasse
- Other Solid Biomasses
  - Bark
  - Nutshell, Husk

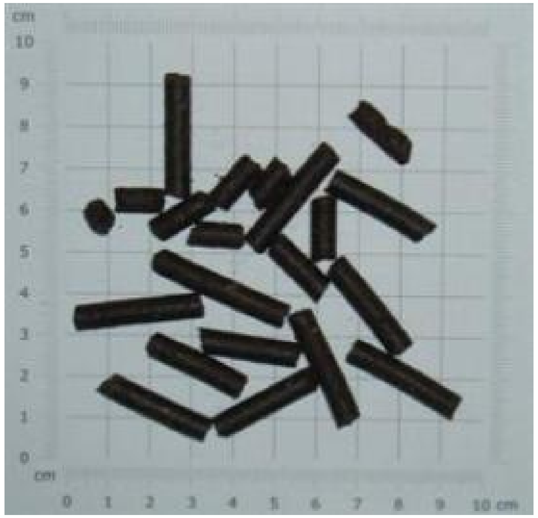
Current technologies

EBES AG – European Bio Energy Services

Torrefaction, properties
By the example of miscanthus

Raw material:
- gcv (db): 17.500 J/g
- BD: 150 kg/m³

Torrified material:
- gcv (db): 23.300 J/g
- BD: 200 kg/m³



ACB-pellets:
- gcv (db): 23.300 J/g
- BD: > 700 kg/m³

Current technologies

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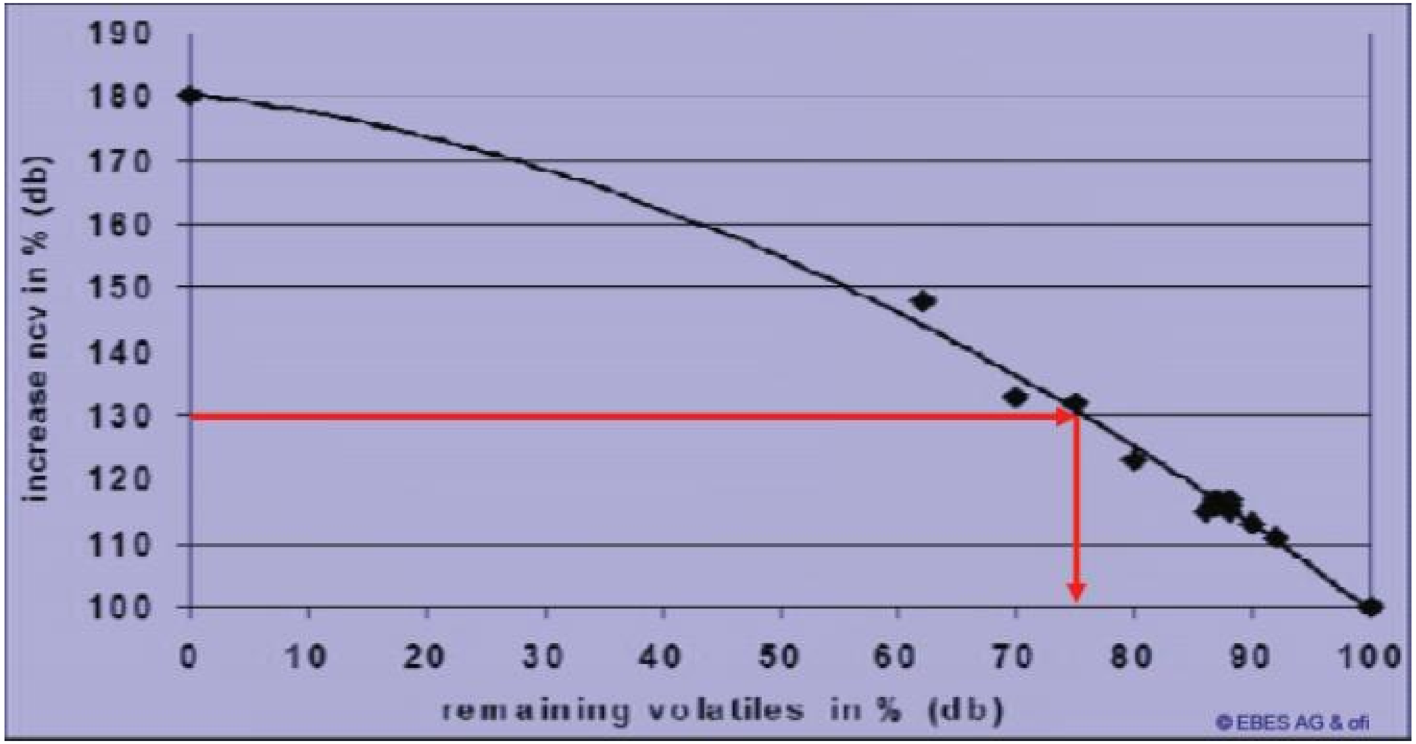
ACB - Made to Measure for Client



Example wood:

- GCV raw material, db: 20.000 J/g
- GCV ACB Product required, db: 26.000 J/g
- Degree of torrefaction necessary: 25%

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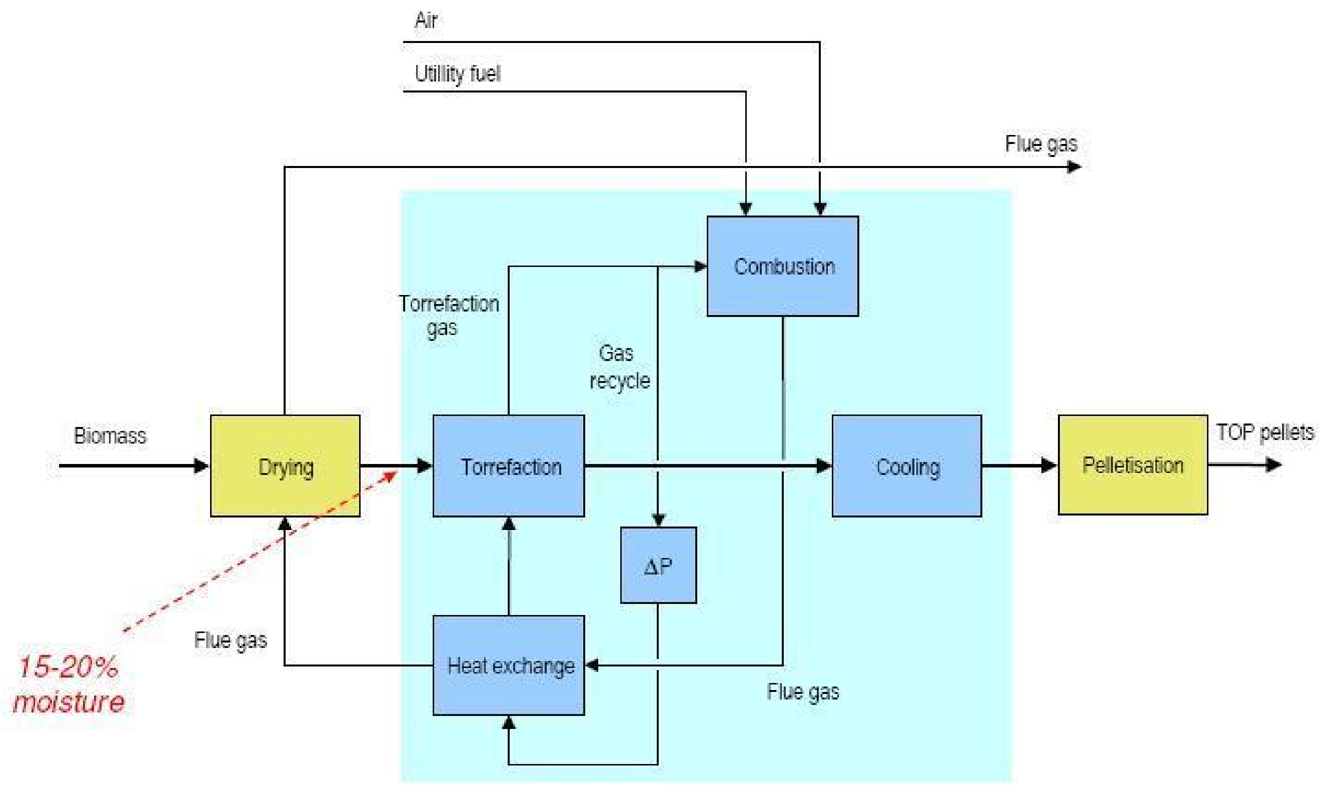
EBES AG – European Bio Energy Services

Key data per Standard Unit

- Annual production 50.000 mt
- Annual Input 125.000mt at 50% moisture
- Investment: 10 mio EUR
- Investment per tonne/year: 200 EUR
- Site requiremnts: 2500m² plus storage area
  2000 kVA electric connection
  logistical infrastructure
- Emissions: standard wood combustion

Energy research Centre of the Netherlands (ECN) 2005



Plant-layout of the ECN TOP technology. Only the integrated drying torrefaction part of the process is shown (not size reduction and pelletisation)

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Energy research Centre of the Netherlands (ECN) 2005

- Production capacity – 60000 t/a TOP pellets
Total production cost including depreciation and financing amount – 40-50 EUR/t TOP pellets
- Capital investment – 5.5-7.5 millions EUR

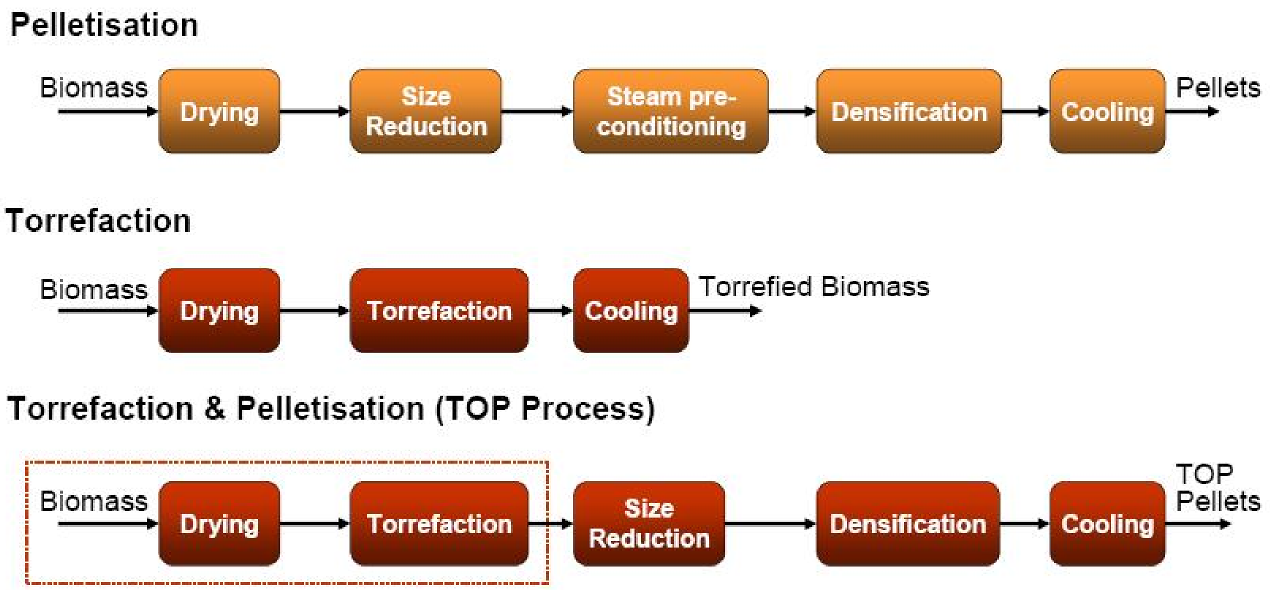
Cost-breakdown (in €/GJ) of pellet production in South-Africa and enduser application in NW-Europe.

	TOP Process	Pelletisation process
Feedstock	0.7	0.7
Pellet production	2.0	2.2
Logistics	1.8	2.9
Integral costs at delivery power station	**4.5**	**5.8**

University of Aberdeen, United Kingdom 2007

A Foresighting Study into the Business Case for Pellets from Torrefied Biomass as a New Solid Fuel.

- The Idea based on ECN Torrefaction technology



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Output of plant 47MWth = 80,000 t/a TOP pellets

- Feedstock prices:
  - Current market prices
- Process costs estimated on basis of:
  - Mass & Energy balance
  - Equipment design
- Three Cases:
  - 1 – Sawmill co-products (50% MC)
  - 2 – Forest residues (35% MC)
  - 3 – Wood industry co-products (25% MC)

Raw material

Any ligno-cellulosic biomass:
Forest Residues;
- Co-products from sawmilling industry;
- Co-products for wood processing industry;
- Short rotation coppice plantations.

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Costs of Producing TOP Pellets

Feedstock Supply & Production Costs for 80,000 t/y TOP pellets (€/t)

	Sawmill Co-Products	Forest Residues	Wood Processing Co-products
Moisture Content (%)	50	35	25
Feedstock Required (kt/y)	200	146	118
Total Capital Investment (M€)	7.2	6.5	6.1
Feedstock Cost / 1 t TOP	75	55	37
TOP Production Cost	50	37	34
Delivered Cost of TOP	133	100	80

University of Aberdeen, United Kingdom 2007

Costs of Producing TOP Pellets

Feedstock Supply & Production Costs for 80,000 t/y TOP pellets (€/GJ)

	Sawmill Co-Products	Forest Residues	Wood Processing Co-products
Moisture Content (%)	50	35	25
Feedstock Required (kt/y)	200	146	118
Total Capital Investment (M€)	7.2	6.5	6.1
Feedstock Cost / 1 t TOP	3.6	2.6	1.8
TOP Production Cost	2.4	1.8	1.6
Delivered Cost of TOP	6.4	4.8	3.8

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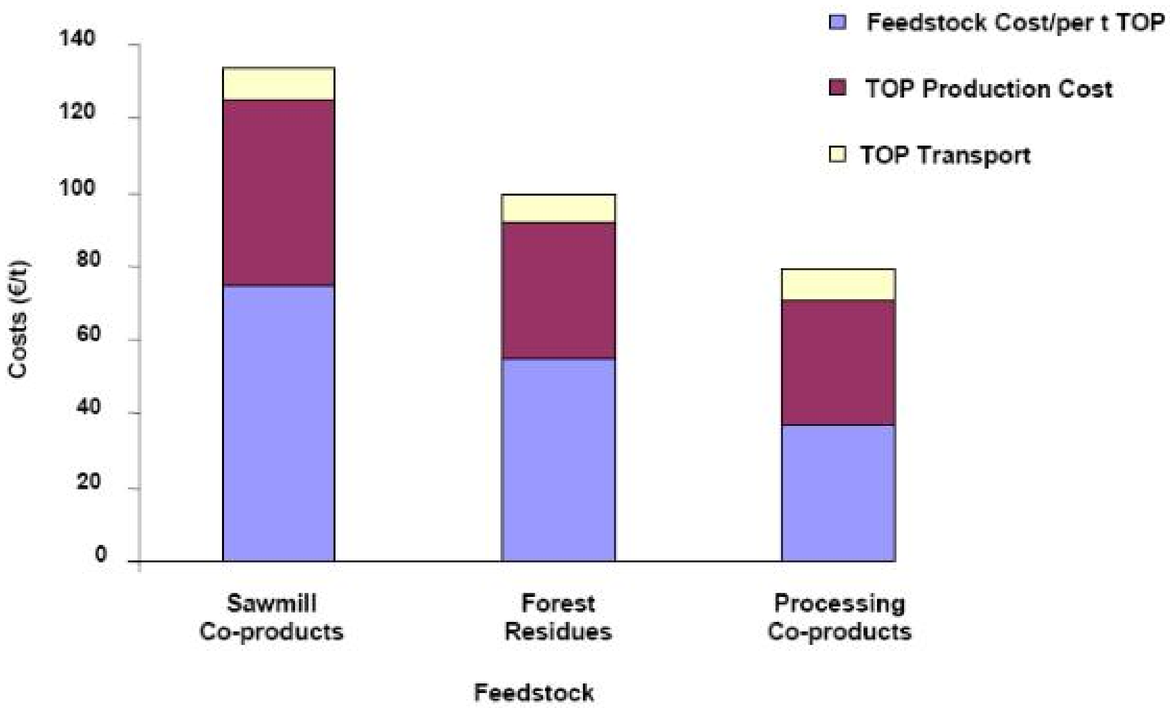
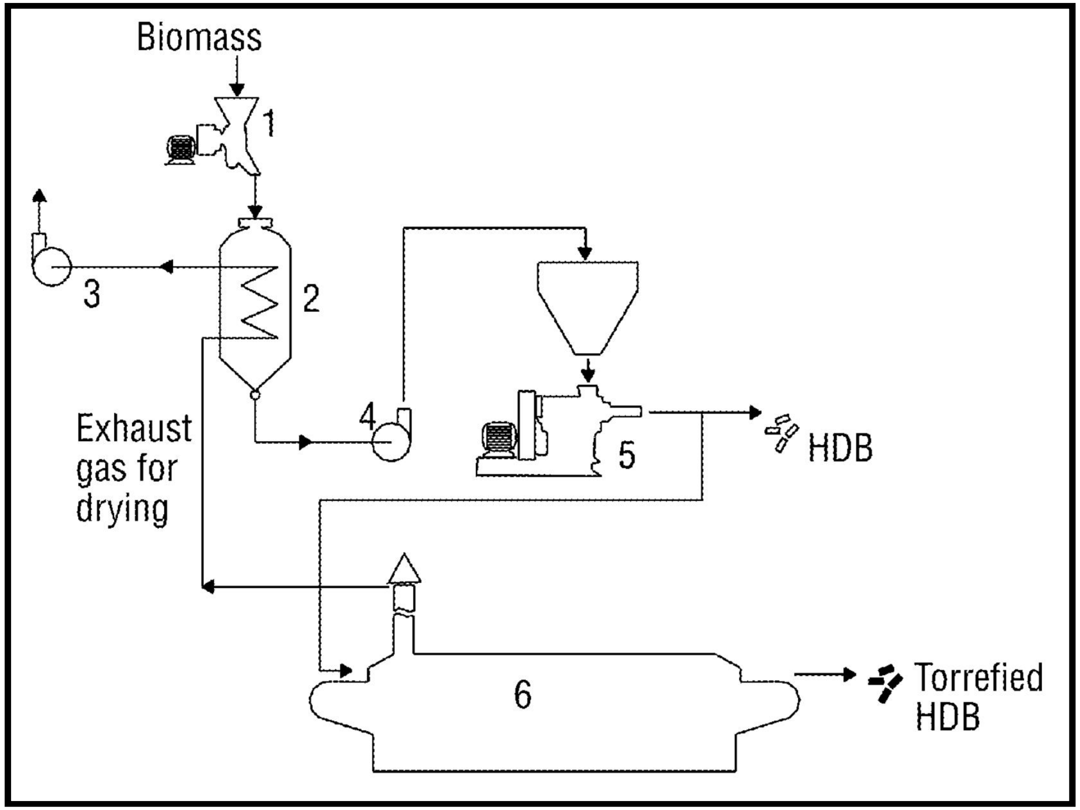
University of Aberdeen, United Kingdom 2007

Costs of Producing TOP Pellets



High density briquette factory. Brazil 2005



Flowsheet of a briquette factory with a torrefaction system installed. 1, grinder; 2, drying silo; 3, exhauster; 4, pneumatic loader; 5, extruder; 6, torrefactor.

- Production capacity – 1200 t/a torrefied briquettes (raw material – briquettes from wood residues);

- The useful life is 10 years and applied linear depreciation 10 %;

- Factory operates 8 hours a day, 300 days a year.

Current technologies

High density briquette factory. Brazil 2005

- Total investment ~ 100,000 EUR (Briquette factory with a torrefaction system installed);

- Raw material cost HDB ~ 3100 EUR/a; HDB_{280} ~ 4,600 EUR/a; Total ~7,500 EUR/a;

- Variable unit cost: HDB ~ 52 EUR/t; HDB_{280} ~74 EUR/t;

- Price of HDB on the retail market ~ 72 EUR/t; HDB_{280} ~ 180 EUR/t; Price of the charcoal ~ 400 EUR/t.

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Recent developments in torrefaction

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Possible Dryer Heat Sources

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- **Typical heating air temperature is 70-100 °C**

- **Possible heat dryer sources for drying**
  - Warm water
    - 45-60 °C
    - Pre-heating of the dryer inlet air
  - Hot water
    - 70-80 deg °C
    - Pre-heating of the dryer inlet air
    - Could also be the only heat source for dryer
  - Low pressure steam
    - 4 bara / 145 deg °C
    - Mainly to boost the drying air temperature
  - Heat from Recovery Boiler or Lime Kiln flue gases
    - Hot water approx. 115 deg °C

Possible challenges

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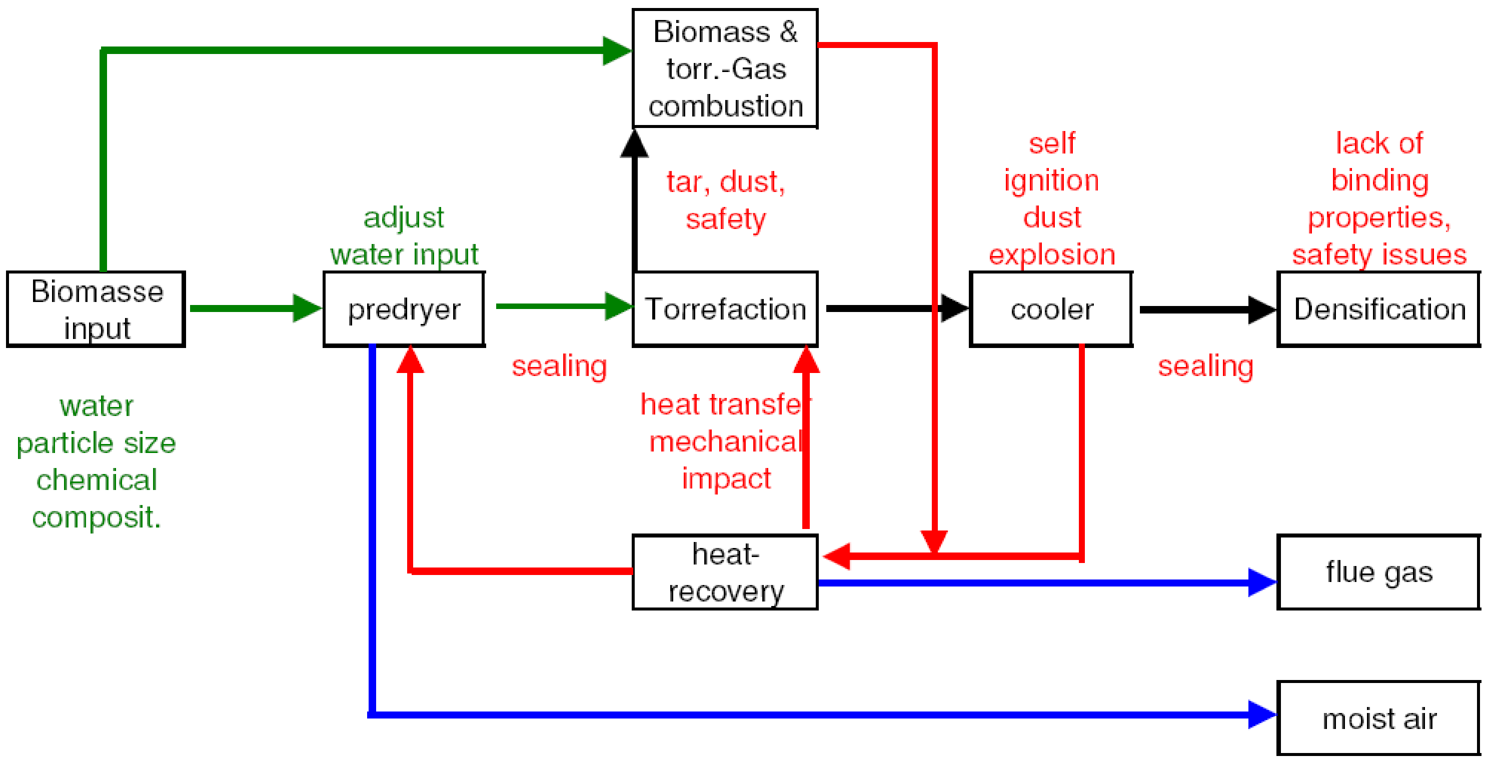

Martin Englisch, 2011, Fundamentals and basic principles of torrefaction
IEA Bioenergy workshop Torrefaction, Graz Austria, 28 January 2011

Condensable and dust

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Martin Englisch, 2011, Fundamentals and basic principles of torrefaction
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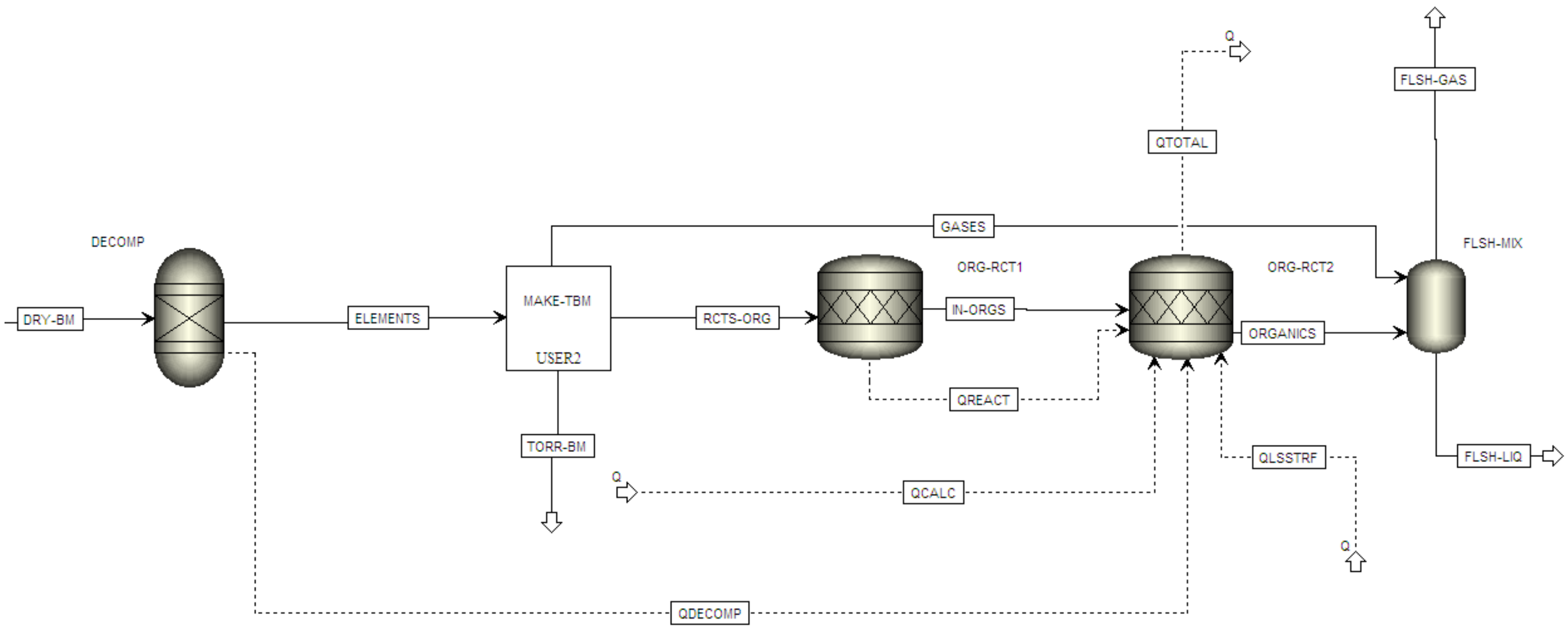
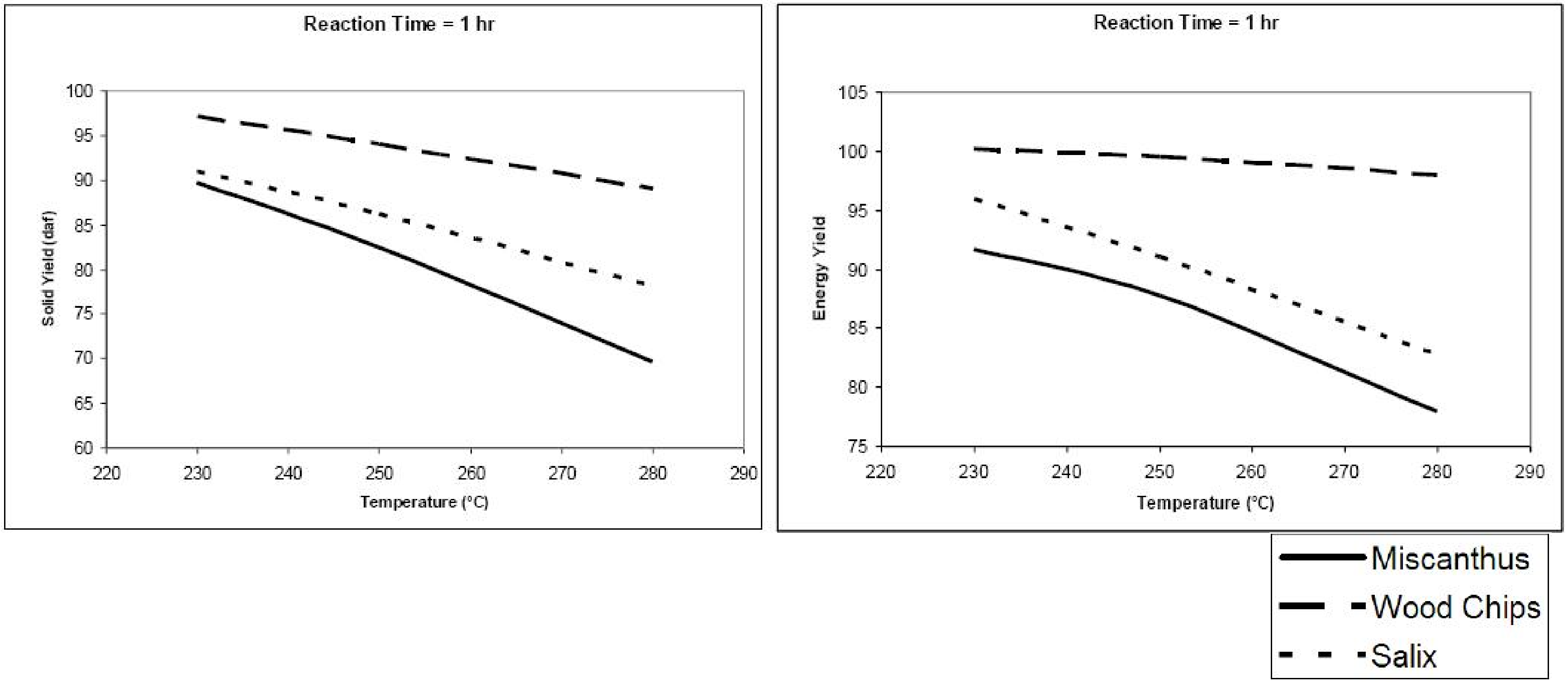
Torrefaction reactor in Aspen Plus



Ryan Dudgeon, 2009, An Aspen Plus Model of Biomass Torrefaction
EPRI, Final Report Presentation, August 26, 2009

Torrefaction reactor in Aspen Plus



Ryan Dudgeon, 2009, An Aspen Plus Model of Biomass Torrefaction
EPRI, Final Report Presentation, August 26, 2009

How to model everything?

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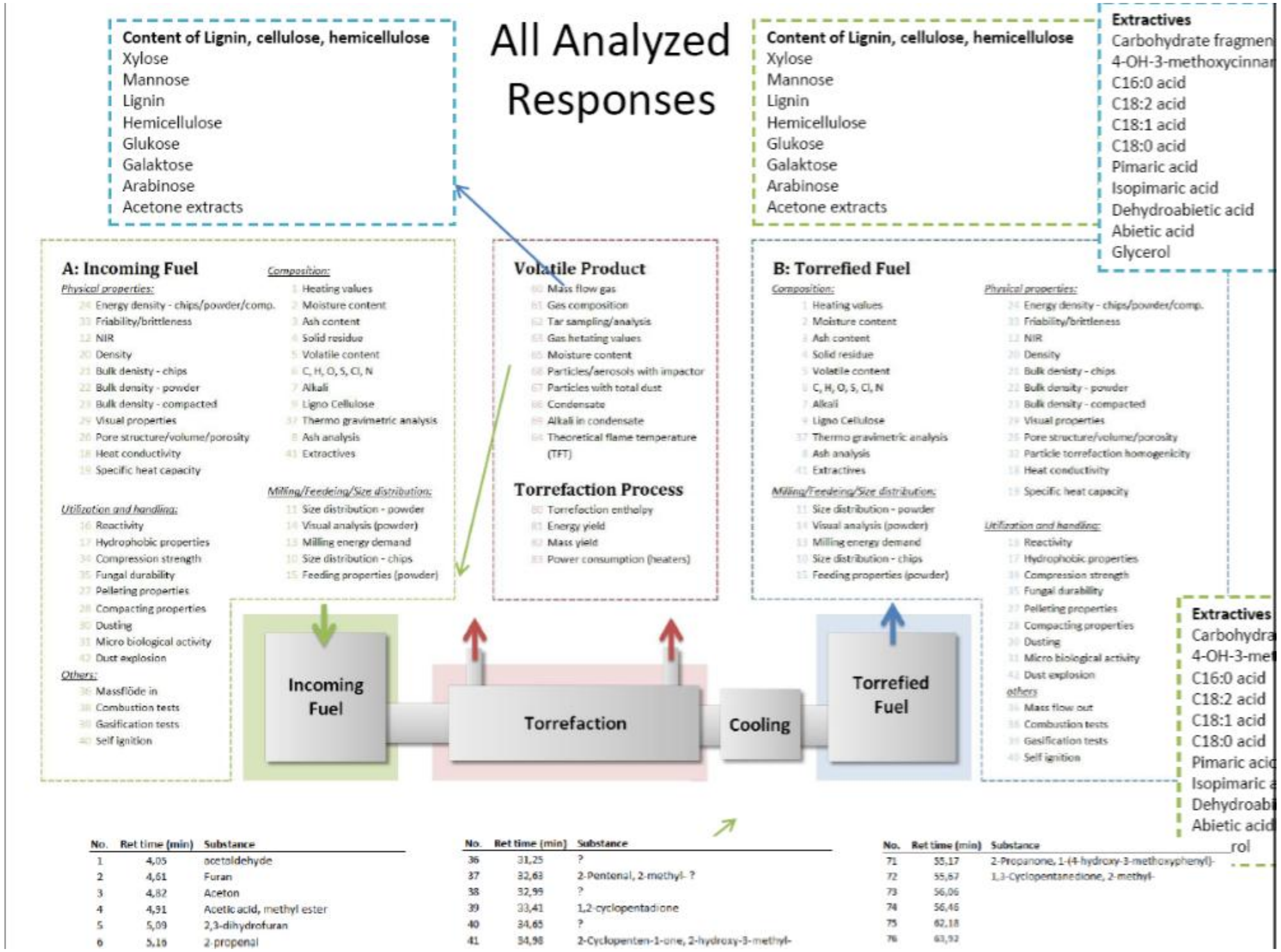

Martin Nordwaeger et al., 2011, Biomass torrefaction-benefits of extensive parametric studies
IEA Bioenergy workshop Torrefaction, Graz Austria, 28 January 2011

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Other uses

E. Vakkilainen

Biocoal spreading to increase growth

University of Helsinki, 2010

Biocoal spreading is safe

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	Wood	Biocoal
	mg/kg	mg/kg
As	0.2	0.3
Cd	0.2	0.3
Cr	1.5	2.3
Cu	4	6.0
Hg	0.015	0.023
Ni	2	3.0
Pb	7	10.6
V	3	4.5
Zn	30	45.2

Summary

- First demonstration calculation of a CFB gasifier was performed by three-dimensional furnace model CFB3D.
- The results are promising: visualization of the process helps to understand the different phenomena and can be used to support the development of gasifier designs.
- The applied reaction rate correlations are based on literature and thus the results are only indicative.
- Many other empirical model parameters are rough estimates as well.
- Validation studies are necessary for improving the prediction capability of the model.

Open your mind. LUT.
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