The different renewable product generation via thermal processes suited to forestry raw materials

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South african context

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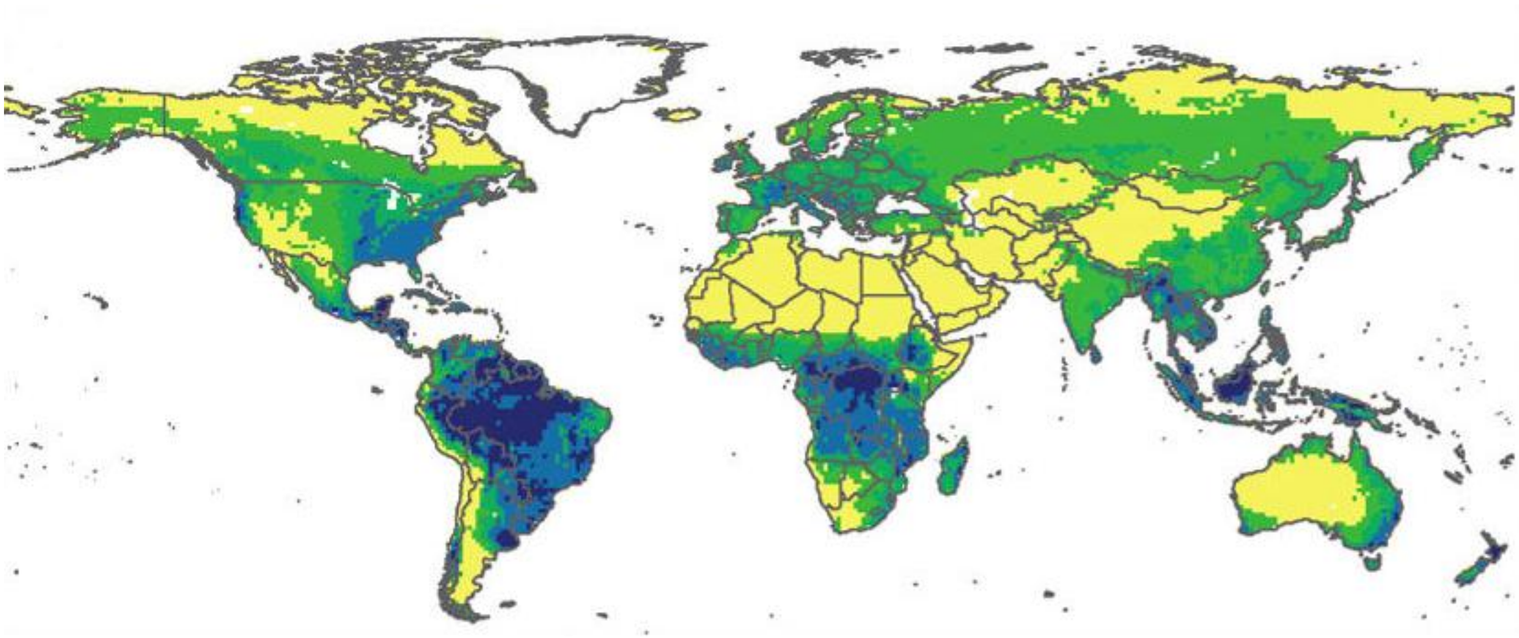
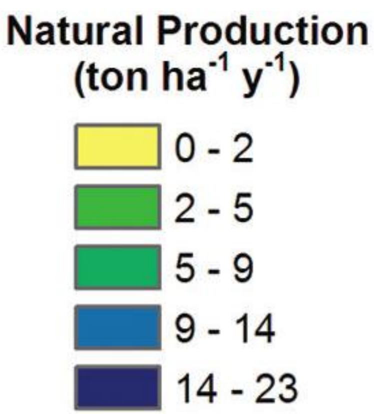
Keys-Challenges

Biomass potential





- Large availability of natural resources
- Conversion of plant biomass is an attractive option

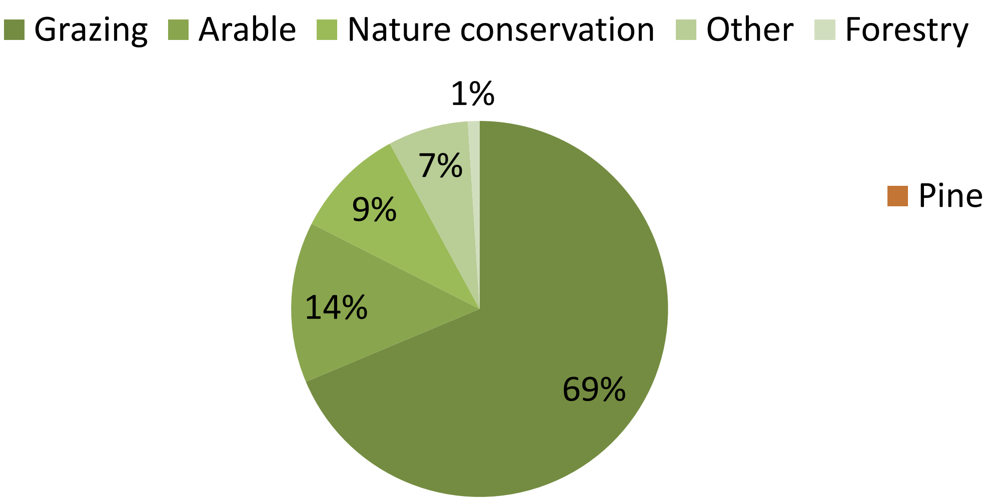
Campbell, 2008

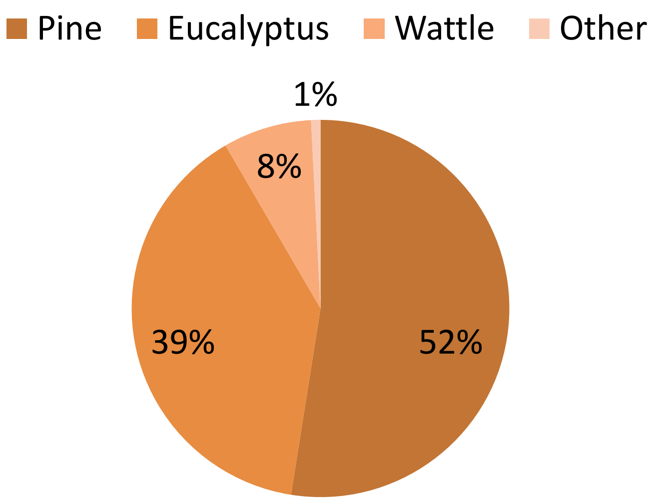
Why wood?

- One of the best renewable Carbon source (CO_2 sequestration)

- Wood resources in South Africa increasing, production of 16 m^3/hectare while:

    - a decrease of plantation area from 1997
    - a small land use in South Africa

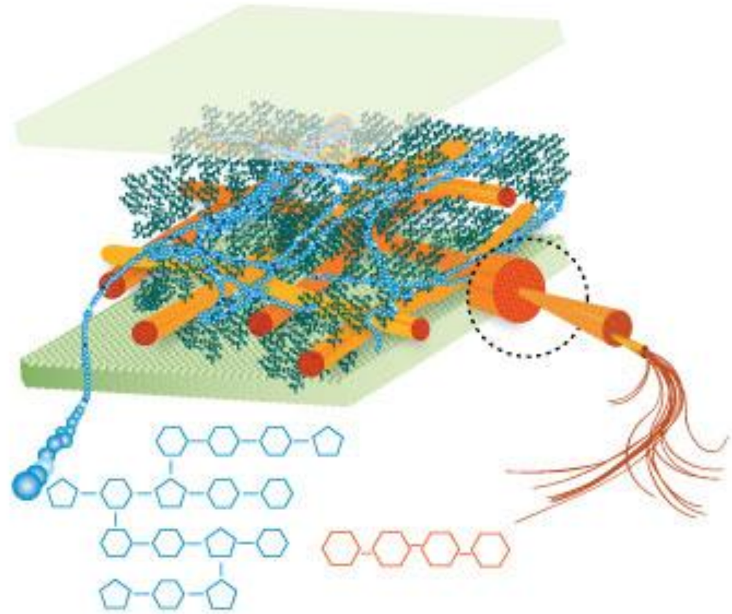




Godsmark, 2009

Why wood?

Lignocellulosic structure
which leads
to remarkable products



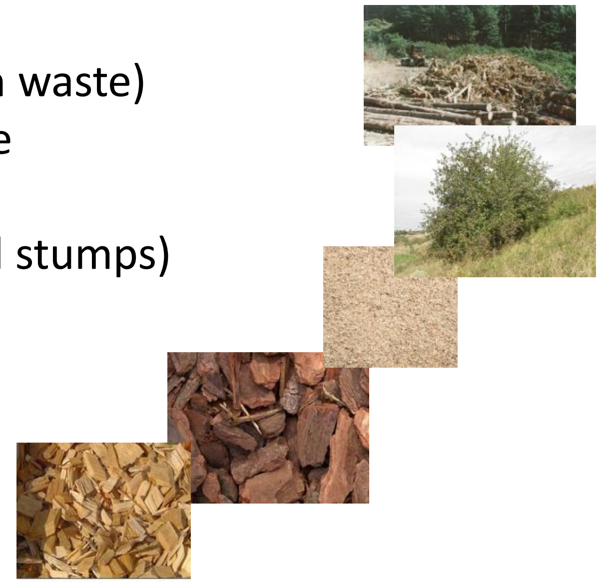
Hemicelluloses
Cellulose
Lignin

Woody biomass	Lignin (%)	Cellulose (%)	Hemicelluloses (%)	Reference
Pine	26.4	44.7	18.6	Hamelinck, 2005
Eucalyptus	27.7-25.9	49.5-57.3	13.1-16.8	Hamelinck, 2005; Kumar, 1992
Black Wattle	17.9-21.2	63.9	12.7	Lachke, 1988; Brown, 2007
Hardwood	16-25	40-50	35	Mohan, 2006
Softwood	23-33	40-50	28	Mohan, 2006
Pine bark	34	34	16	Arpiainen, 1989

Which type of forestry materials?

Untreated wood wastes:

- Dry urban wastes (construction and demolition waste)
- Wood from plantations Poplar, Eucalyptus, Pine
- Logging residues
- Shrubs and wood residues (twigs, branches and stumps)
- Sawdust
- Bark
- Wood chips
- Damaged wood from plantation fires



South Africa generated 13.9 tons of wood (pine, eucalyptus, wattle)/ha/year in 2008 which are mainly dedicated to: pulpwood, sawlogs, mining timber.

Godsmark, 2009

Why Thermo-chemical processes ?

- Carbon-neutral balance
- Lower emissions of NO_x, CO and hydrocarbons
- All the products from these processes can be used
- Improvement of efficiency of the energy conversion
- Production of sustainable energy sources
- Material cheap and readily available
- Relatively low capital investment
- Large range of potential products/feedstocks

Choice of conversion process depends upon the **type** and **quantity** of **biomass feedstock**, the **desired** form of the **energy**, end **use** requirements, environmental standards, economic conditions and project specific factors.

But ?

- **High moisture content** inhibits pyrolysis, leads to energy loss because used to evaporate water,

- Often **low density**, which makes them bulky and hard to store,

- Often **no homogeneous** form,

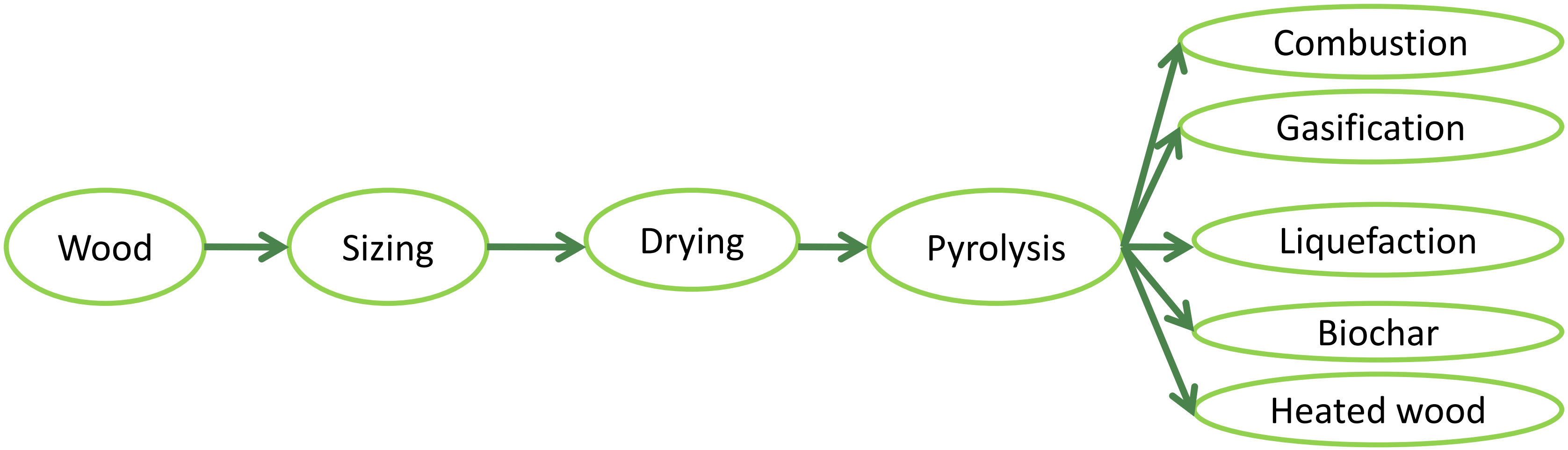
- Contain a fairly large amount of **inorganic substances**, which remains as **ash**,

- **Environmental impact of pre-treatments** used to separate or remove products.

Thermo-chemical processes

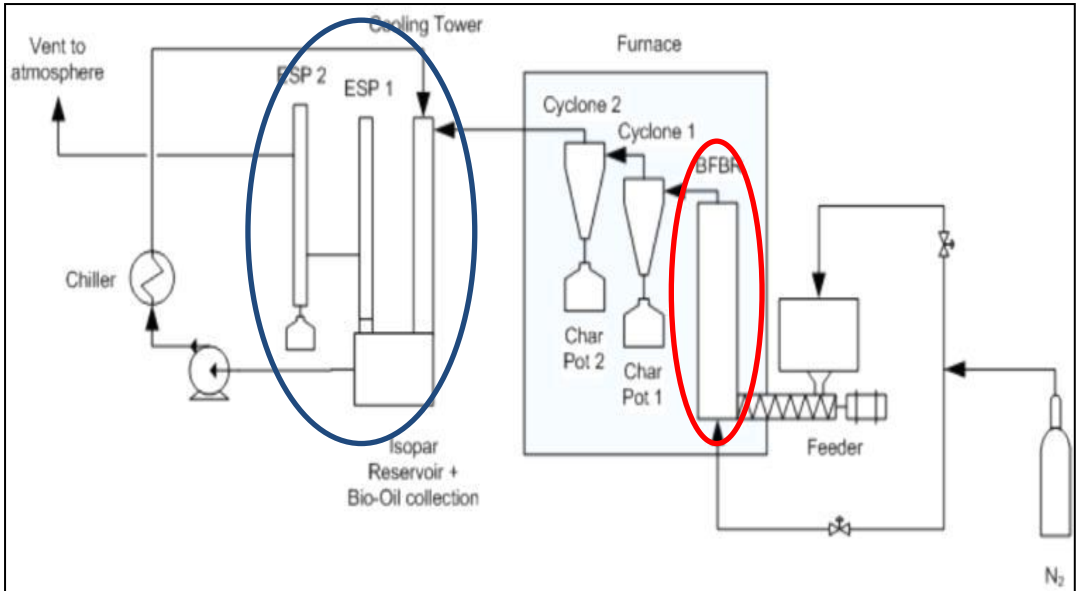
Thermal Process	Temperature (ºC)	Atmosphere	Products	Energy efficiency (%)
Combustion	> 900	O_2 (air)	CO_2+ H_2O + N_2 + ashes to be treated	65
Pyrolysis	< 600	Inert gas or low pressure	Char + tars + gas, which proportions are related to the pyrolysis parameters	45
Gasification by Fast Pyrolysis	> 700	Inert gas or low pressure	Mainly gas (CO, H_2, CH_4, C_2H_4…) with low quantity of char used	75
Gasification	> 800	Air or H_2O vapour	Gas (H_2, CO, CO_2, CH_4, N_2)	50-60
Liquefaction by Fast Pyrolysis	< 550	Low pressure	High viscosity liquid (phenols)	75
Direct liquefaction	300-350	CO high pressure	High viscosity liquid (phenols) non soluble in water	80

Pyrolysis, the key



Process	Temperature (°C)	Pressure (kPa)	Heating rate (°C min^{-1})	Residence time	Particle size	Atmosphere
Fast	450-600	101	100-300	2 s	2-5 mm	N_2 or Ar
Slow	400-500	101	5-50	5-30 min	Large	N_2 or Ar
Vacuum	350-500	10	5-50	2-30 s	large	Vacuum

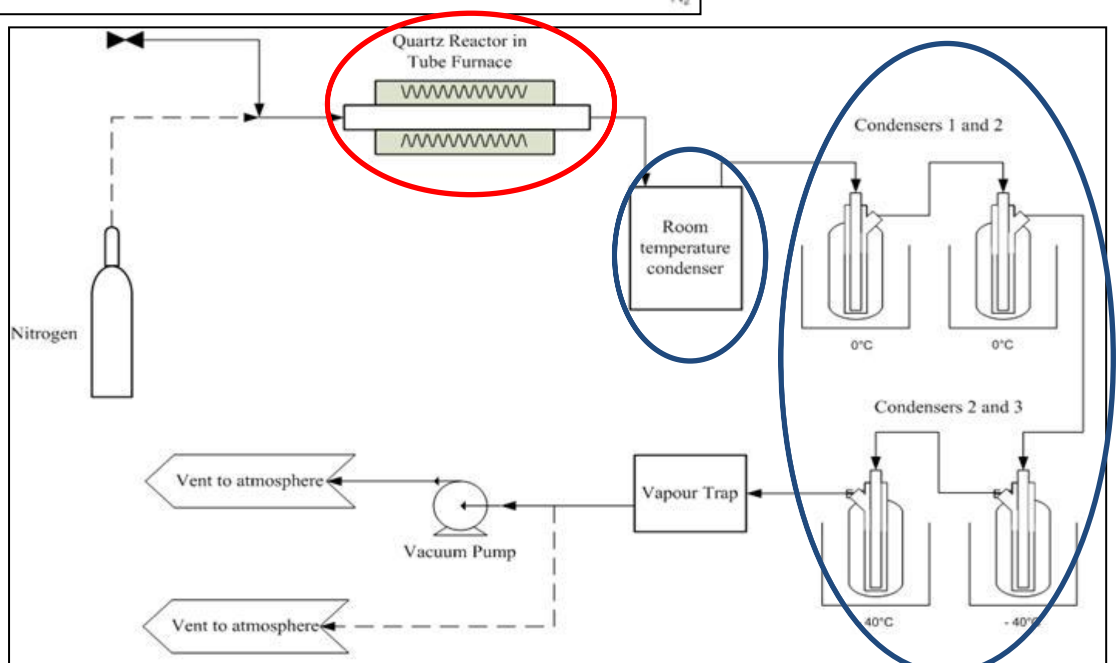
Pyrolytic reactors



Fast pyrolysis

Bubbling Fluidized Bed reactor

Electrostatic separator

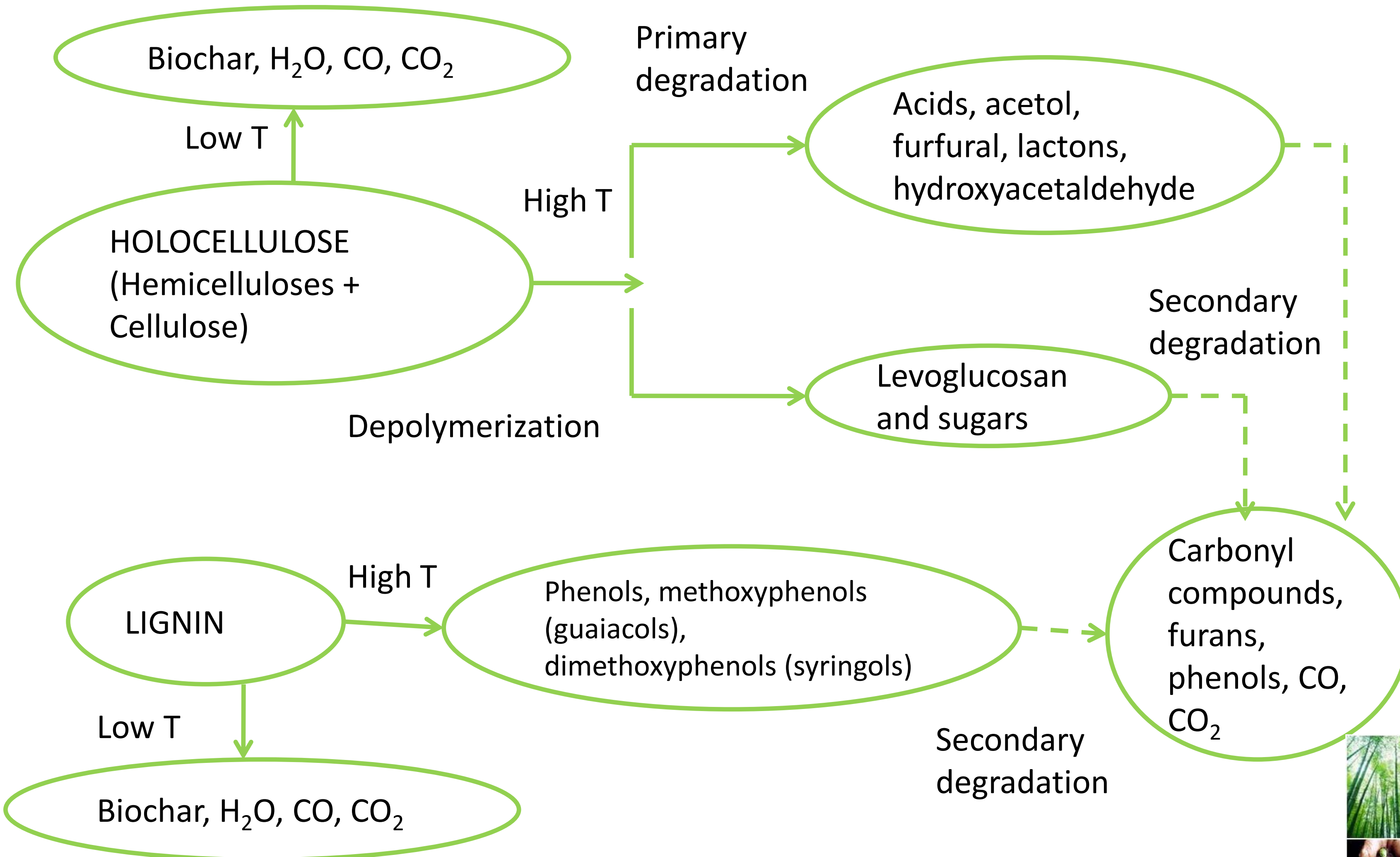


Slow/Vacuum pyrolysis

Fixed bed reactor

Series of condensers

Mechanisms of degradation



BIOMASS

Pyrolysis

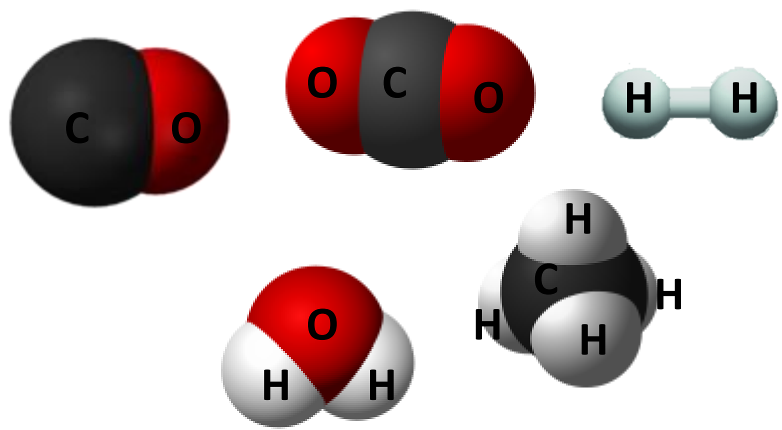
LIQUID (Bio-oil)

Dark brown, smoky odour, highly oxygenated, viscous, corrosive, acidic, unstable, 300-400 compounds

SOLID (Biochar)

Brittle, high C content, low density

GAS



Yields of renewable forestry products

Wood biomass	Process	YLiquid (wt.%)	YBiochar (wt.%)	YGas (wt.%)	*Reference*
100 % white wood	FP	70	18	12	*Dynamotive, 2001*
75/25 white wood/bark	FP	65	22	13	*Dynamotive, 2001*
50/50 white wood/bark	FP	63	23	14	*Dynamotive, 2001*
100 % bark	FP	58	27	15	*Dynamotive, 2001*
Eucalyptus	FP	76	13	11	*Dynamotive, 2001*
Eucalyptus	FP	71	29		*Oasma, 2010*
Eucalyptus	SP	46	38	16.0	*Pimenta, 1998*
Pine	FP	65-75	5-18	5-20	*Wagenaar, 1993*
Pine	SP	21-30	23-36	11-23	*Sensoz, 2002*
Black wattle	VP	27	38	35	*Uras, 2010*
Softwood bark	VP	23-28	57-57	15-21	*Darmstadt, 2000*

- Maximization of bio-oil yield for Fast Pyrolysis
- Influence of the feedstock nature
- Good distribution in product yields for Slow and Vacuum pyrolysis

Influence of parameters

Size of particles (SP)
Moisture content (MC)
Ash content (AC)

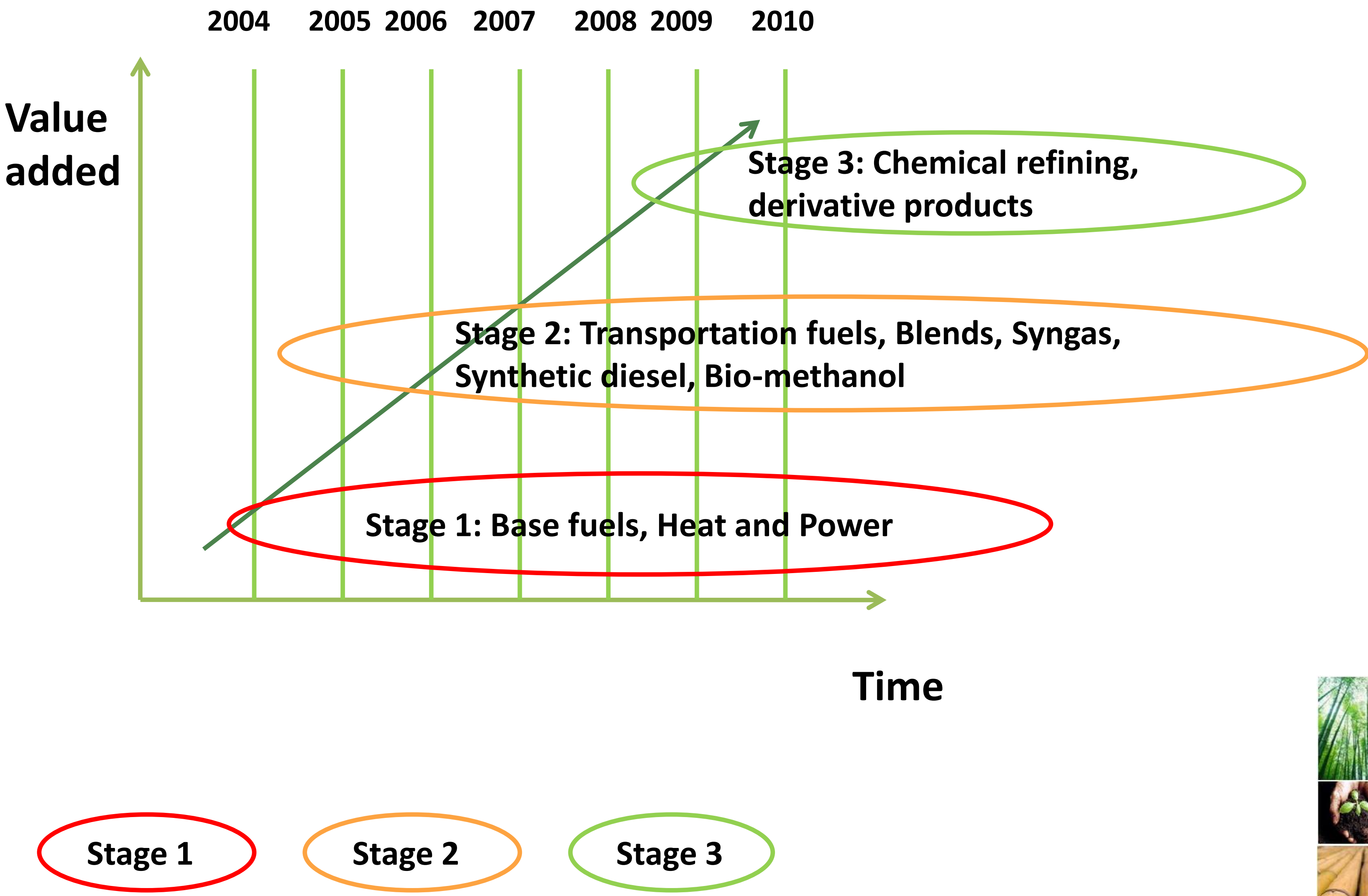
Temperature (T)
Pressure (P)
Heating rate (HR)
Residence time (RT)
Flow of nitrogen (FN)

	SP (µm)	**MC**	**AC**	**T (°C)**	**P (kPa)**	**HR (°C min^{-1})**	**RT**	**FN**
Ybio-oil	< 450 **(-)**	Slightly ↗ cont. **(+)**	High cont. **(-)**	500-900 **(-)**	**(+)**	Higher rate **(+)**	Long time **(=)**	**(=/+)**
HHV oil		Slightly ↗ cont. **(+)**			10 **(-)**	Low rate **(+)**	Long time **(=)**	
Ychar	2500 **(+)**	Slightly influence	High cont. **(-)**	500-900 **(-)**	**(+)**	Low rate **(+)**	Long time **(-)**	High flow **(-)**
HHV char			High cont. **(-)**	500-700 **(+)**	**(-)**	Low rate **(+)**	Long time **(+)**	High flow **(-)**
BET surface area			High cont. **(-)**	350-500 **(+)**	**(-)**	Optimal rate ~10	Optimal time~2h	

Toxicity of renewable products

Product	Health-Environmental Impacts
Bio-oil	- Presence of Polycyclic Aromatic Hydrocarbons (PAH) - Mutagenecity tests (Salmonella strains) with slow and fast bio-oils: Slow toxic - Eutrophication test: Low fertilising effect. - Ecotoxicologic effect: Acute toxicity of slow pyrolysis oil on Daphnia - Corrosive, moderate sensitizer
Biochar	Presence of heavy metals which are toxic
Gases	
CO_2, CxHy	- Green House Gases contribution
CO, H_2S, NOx	- Toxic gas emission
HCl, HF, SO_2	- Acidic rain
Ash	- Serious health hazard, because the nano-particles are easily inhaled and can cause lung damage.

Applications of thermo-chemical processes



Applications of thermo-chemical processes

Primary product	Secondary processing	Secondary product	Tertiary processing	Tertiary product
	Activation	**Activated carbon** (Air separation and purification/Vehicle exhaust emission/ solvent recovery/ catalyst support)		
Biochar (Soil amendment /Adsorbent/ black powder)	Combustion	**Heat/power**		
	Compaction	**Briquette** (Heat fuel)	Combustion	**Heat/power**
	Mixing	**Slurry** (Fuels)	Gasification	

Stage 1 **Stage 2** **Stage 3**

Applications of thermo-chemical processes

Primary product	Secondary processing	Secondary product
Bio-oil	Combustion	Heat/Steam
	Engine/Turbine	Electricity
	Stabilization	Stabilized oil
	Upgrading	**Hydrocarbons** **Chemicals** (Fertilizer/Surfractant/ Plasticizers/Octane enhancer/Chemical precursors/Polymers)
	Extraction	Chemicals
	Gasification	Gas

Stage 1 Stage 2 Stage 3

Applications of thermo-chemical processes

Primary product	Secondary processing	Secondary product	Tertiary processing	Tertiary product
Gas (Syngas/Hydrogen/ alkanes/ other hydrocarbons/ steam)	**Fischer-Tropsch**	**Liquid Fuel**	**Combustion**	**Electricity**
	Combustion	**Heat/steam**		
	Engine/turbine	**Electricity**		
	Fuel cell	**Electricity**		
Ash (Cement bricks/Road fill/Solidification of sludges/Soil amendment)				

Stage 1 **Stage 2** **Stage 3**

Commercial plants

1980s-1990s

Development of special reactors

- -Entrained down-flow
- -Ablative reactor
- -Fluid bed
- -Circulating fluid bed
- -Vacuum moving bed
- -Auger systems
- -Rotating cone reactor

1990s-2010

Pilot plants

- -Union Fenosa, Spain 160 kg/hr
- -Enel, Italy 650 kg/hr
- -Wellman, UK
- -Pyrovac, Canada
- -Dynamotive, Canada 200 t/day
- -Fortum, Finland
- -BTG, Netherland
- -Ensyn, USA
- -Egemin, Belgium, 200 kg/hr
- -CRES, Greece

2010…

Commissioning of full scale pilot

- -bioliq, KIT germany, 500 kg/hr (2009)
- - Dynamotive 200 t/day (2010)
- - IFP, France (2017)
- -Envergent , US (2012)
- -Ensyn (2010)

???

Commercialization

Biorefeneries
+
New applications other than biofuels
+
Economic evaluation

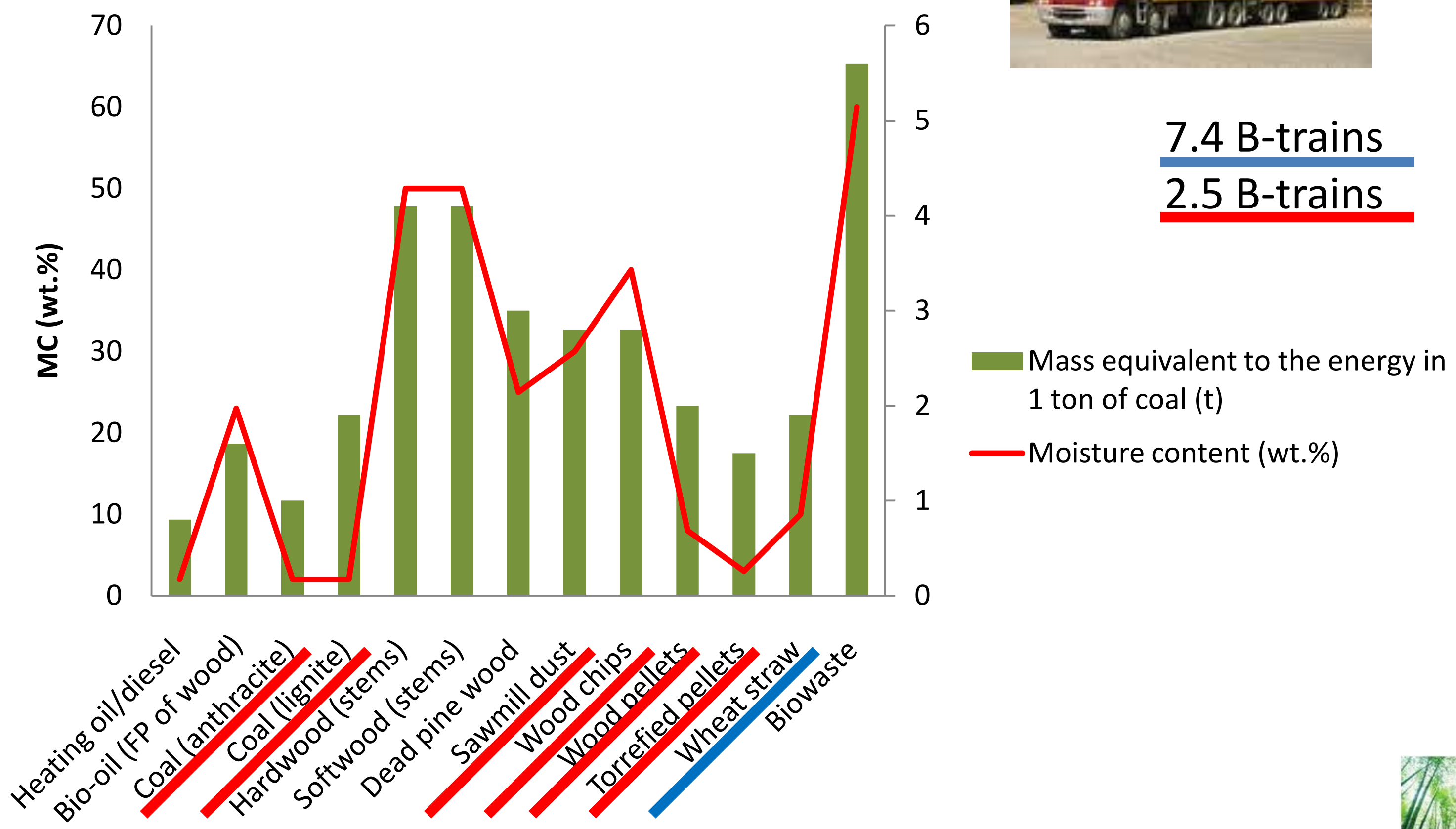
Keys-Challenges

- **Thermo-chemical processes more adapted** than bio-conversion to convert **wood** biomasses:
  - Wood contains a high lignin content which is not easily accessible for biological degradation
  - Ethanol production involves multiple steps (pretreatment, enzymatic or acid hydrolysis, fermentation and distillation.
  - 120 L aromatics/m^3 = 180 L ethanol/m^3

- Large choice of thermo-chemical processes for specific applications:
  - -Gasification for synthetic fuel and electricity production
  - -Liquefaction for chemicals and fuel production
  - -Slow/vacuum for biochar and activated carbon production
  - -Fast pyrolysis for fuel production
  - -Both, **Chemical refining, derivative products**

- **Transportation:** increase the energy density to decrease the cost of transportation

Transportation



7.4 B-trains

2.5 B-trains

BC Bioenergy Network, 2010

Maximum load (t) **Cost (500 km)**

$0.003/t-km

$0.03/t-km

$0.10/t-km

Densification of wood:
- PELLETIZATION (Small portable pellet unit)
- TORREFACTION (Small portable pyrolysis unit)

BC Bioenergy Network, 2010

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- **Potential of CO_2 sequestration**

CO_2 sequestration

17,475,000 tons in 2008

~ 1,939,090 t CO_2 sequestered

364,157,200 t CO_2 emissions for SA in 2003

Pyrolysis

Bio-oil + Gas — Combustion

Biochar — Soil amendment

Fast pyrolysis and slow pyrolysis, 10 wt.% and 27 wt.% of CO_2 sequestered, respectively

20 wt.% of raw forest wastes - 0.3 wt.% of reduction of CO_2 emissions

Keys-Challenges

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- **Transportation:** increase the energy density to decrease the cost of transportation

- **Potential of CO_2 sequestration**

- Intensification of non-friendly environmental woody culture leading to the **soil impoverishment**

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Thank you for your attention

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