All over the world different kind of low-grade biomass and biomass containing waste streams are available:

Low-grade biomass:

- **Wood (branches; bark; stumps; sawdust)**
- **Agricultural residues (bagasse; kernels; nut scales)**
- **grass (road side grass; banagrass)**

Biomass containing waste streams:

- **Demolition wood**
- **Solid Recovered Fuel**

Not easy to use this material as raw material in their original shape (appearance; low bulk density; high moisture content; hydroscope; biologically active)

Wood

Bagasse

Banagrass

Demolition wood

Solid recovered Fuel

Pre-treatment is needed to use these kind of biomass as raw material in a controlled way. An appropriate pre-treatment is reducing, drying and next torrefaction.

Torrefaction: reduced, dried biomass is **heated up in the absence of oxygen** to a temperature of about 290 °C.

This heating causes thermal degradation and by that **production of gas** (mainly consisting of H_2O, CO_2, CO and organics) **and solid material** (bio-coal).

This **gas** is used as fuel **to produce energy** (heat) for supporting the torrefaction process.

The **solid material** is called bio-coal and **is the product** of this pre-treatment (torrefaction process).

Pre-treated (torrefied) biomass will show:

- About 30 % Increase of energy density
- Homogeneous composition after grinding / pelletizing
- Fragile and brittle behavior (torrefied wood need 70 % less energy to pulverize)
- Favorable storage conditions (biological inactive; hydrophobic)

Pre-treated (torrefied) biomass can be used among other things in a controlled way for:

- Energy production (electricity; heat)
- Syn-gas production (gasification)
- Steel production (replacement of cokes)
- Carbon production (carbon black; active coal)

Torrefaction: Converting biomass into bio-coal

- Wood (branches; bark)
- Agricultural residues
- Grass (various types)
- Demolition wood
- Solid Recovered Fuel

Torrefaction process

Bio-coal

- Energy production
- Syn-gas production
- Steel production
- Carbon production

- Increase the energy density
- Make it homogeneous
- Make it easy to pulverize
- Make it easy to store

Biomass composition before and after torrefaction

	Content biomass deciduous	Content biomass coniferous	Content biomass herbaceous	Kind of polymer	Degradation temperature (in absence of oxygen)	Degradation products (in absence of oxygen)
Hemi-cellulose	18 % - 25 %	25 % - 35 %	15 % - 25 %	Short chain saccharide	220 °C – 280 °C	Gas: condensables and non-condensables
Cellulose	40 % - 44 %	40 % - 44 %	30 % – 50 %	Long chain glucose	240 °C – 350 °C	Anhydrous cellulose and levoglucosan
Lignin	15 % - 35 %	20 % - 32 %	20 % - 40 %	Cross-linked macro molecular polyphenol	280 °C – 500 °C	Phenols and phenolic fragments

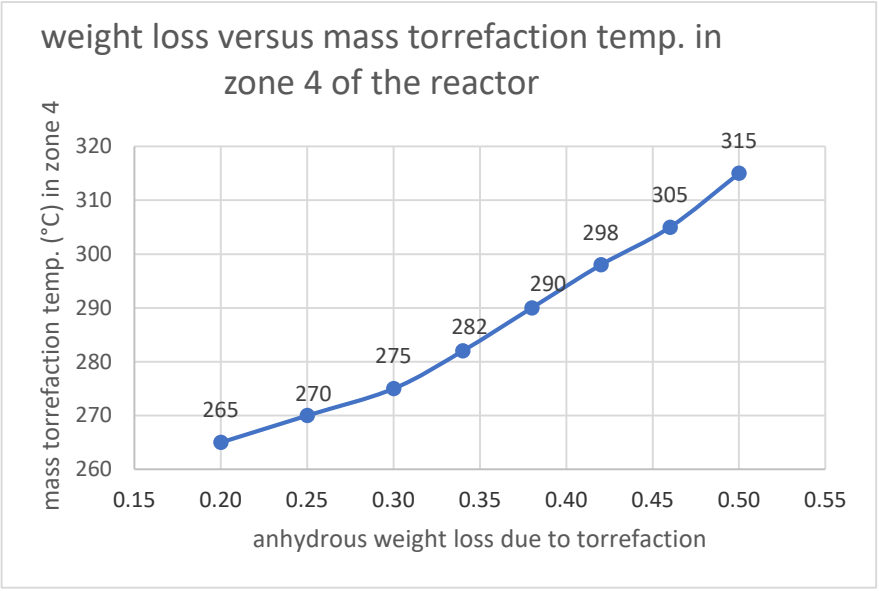
Biomass composition before and after torrefaction (about 280 °C), based on analysis results (N = 5), period 2015

	Composition biomass dry mixed wood (avg.; std.)	Composition torrefied biomass (avg.; std.)
Hemi-cellulose	**19 %** (+/- 0,7%)	**7 %** (+/- 2,8)
Cellulose	**39 %** (+/- 2,2%)	**37 %** (+/- 3,0)
Lignin	**28 %** (+/- 1,6%)	**44 %** (+/- 4,4)

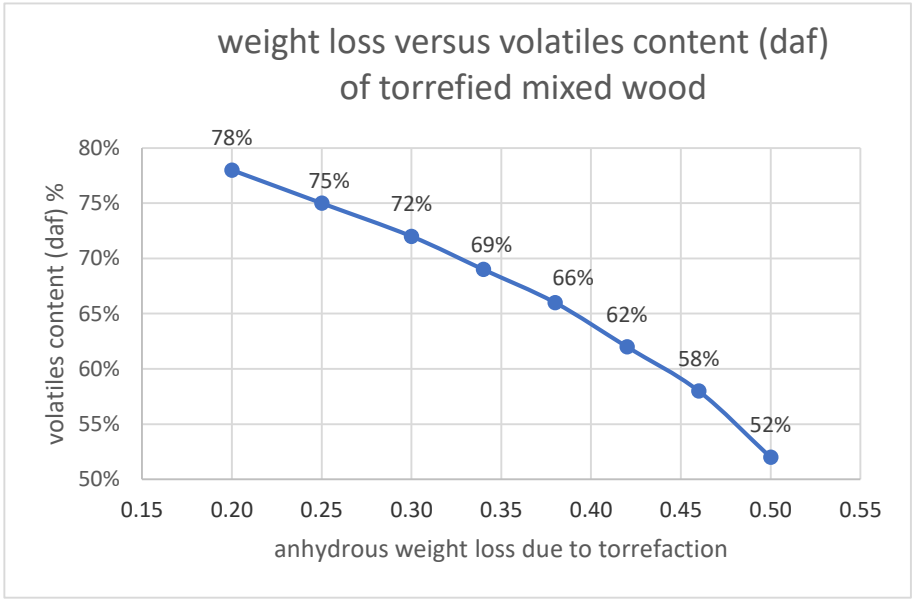
Proximate and ultimate analysis results (Torr-Coal Group period 2011 – 2019) before and after torrefaction of mixed wood.

		mixed	torrefied wood	
		wood chips	powder	pellets
Moisture	% (a.r.)	40 - 45	< 2	4 - 6
Ash	% (d.b.)	1,0 - 2,0	2,0 - 3,0	
Volatiles	% (daf)	80 - 85	see graph 2*	
GCV (daf)	MJ/kg	20,0 - 20,6	see graph 3*	
Hydrogen	% (daf)	5,9 - 6,3	5,0 - 5,8 *	
Carbon	% (daf)	48 - 52	see graph 4*	
Nitrogen	% (daf)	0,3 - 0,7	0,3 - 0,7	
Sulfur	% (daf)	0,02 - 0,12	0,02 - 0,12	
Oxygen	% (daf)	38 - 44	25 - 35 *	
Chlorine	% (dry)	< 0,01	< 0,01	
Bulk density	kg/m³	270	270	650
Mechanical durability %				> 97

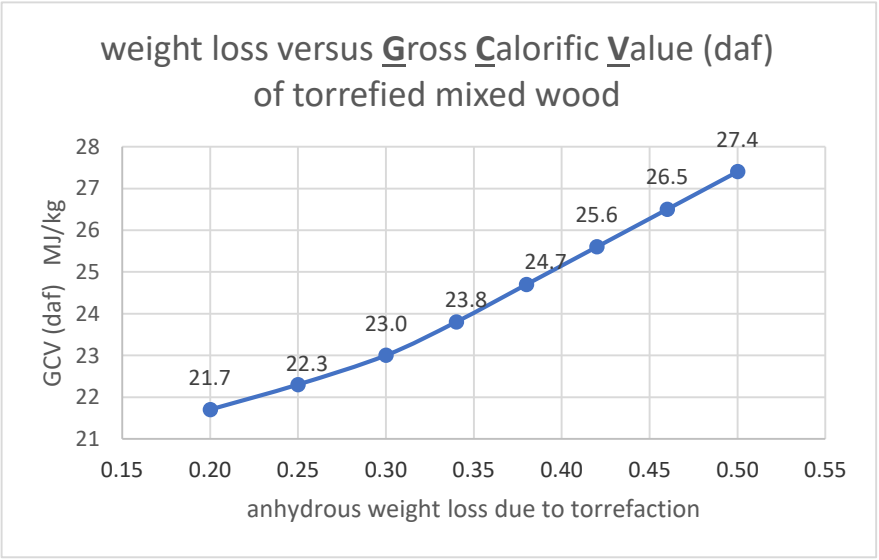
* is determined by degree of torrefaction (torrefaction temperature)



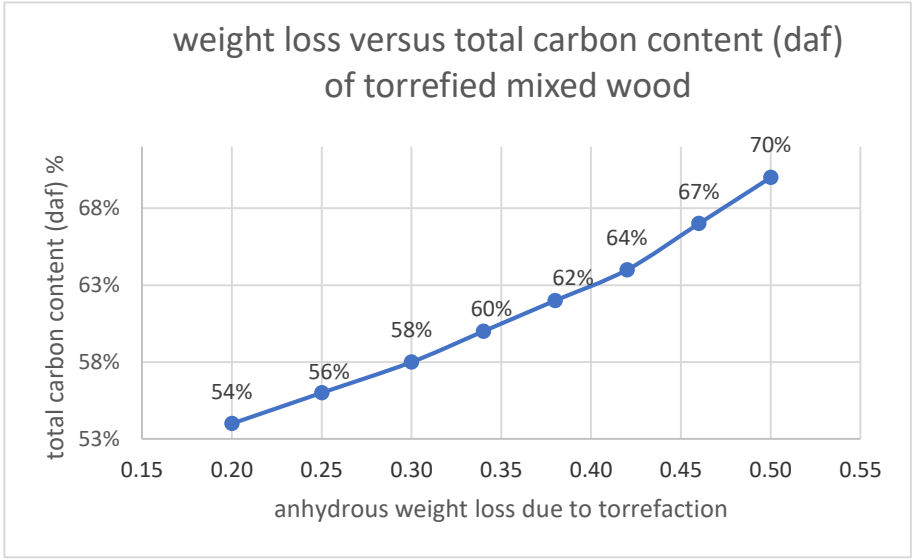
Graph 1



Graph 2



Graph 3



Graph 4

Torr-Coal Production Centre

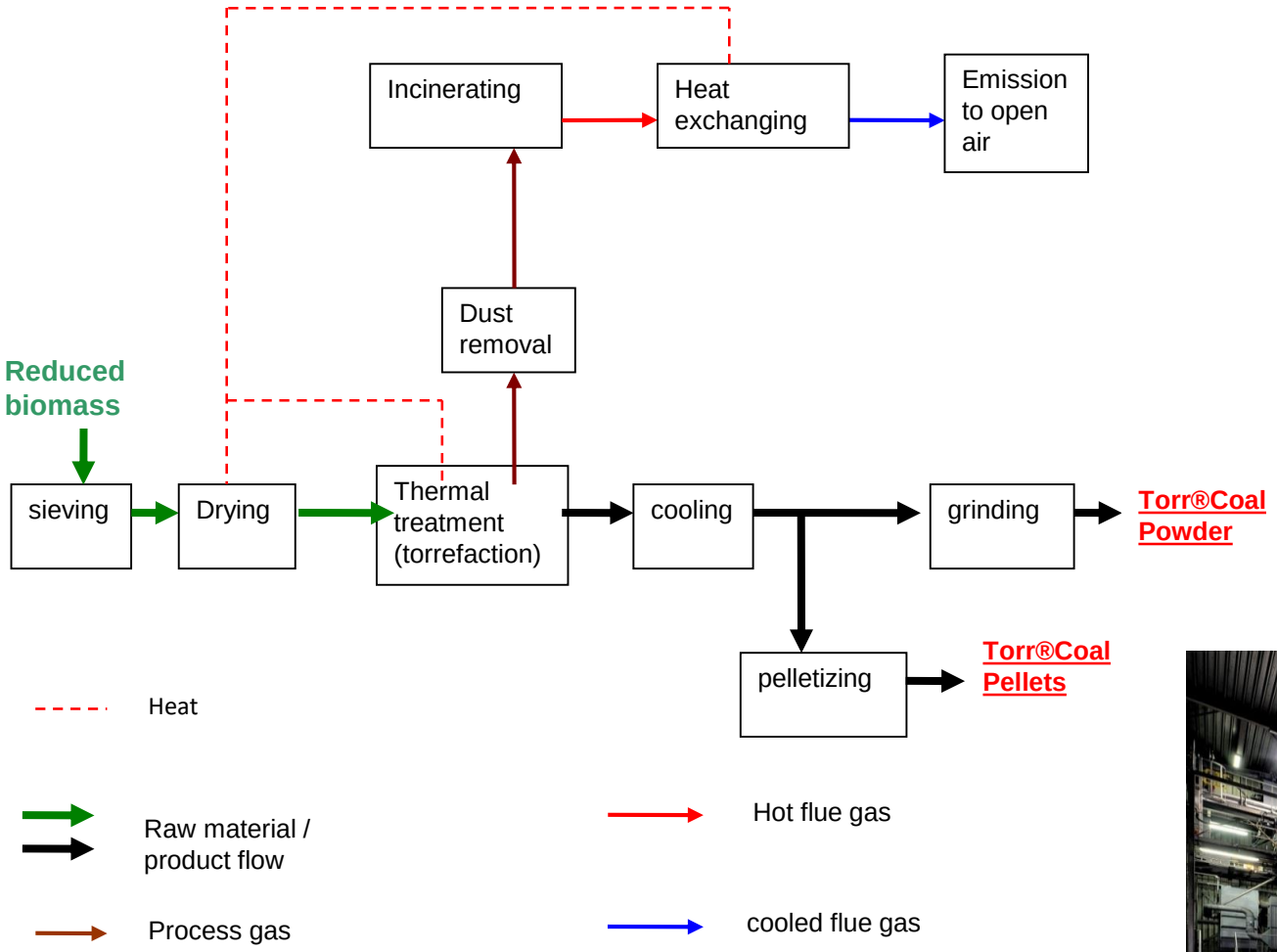
Industrial scale plant:

- Start engineering Jan. 2007
- Start building June 2009
- Operational Oct. 2010

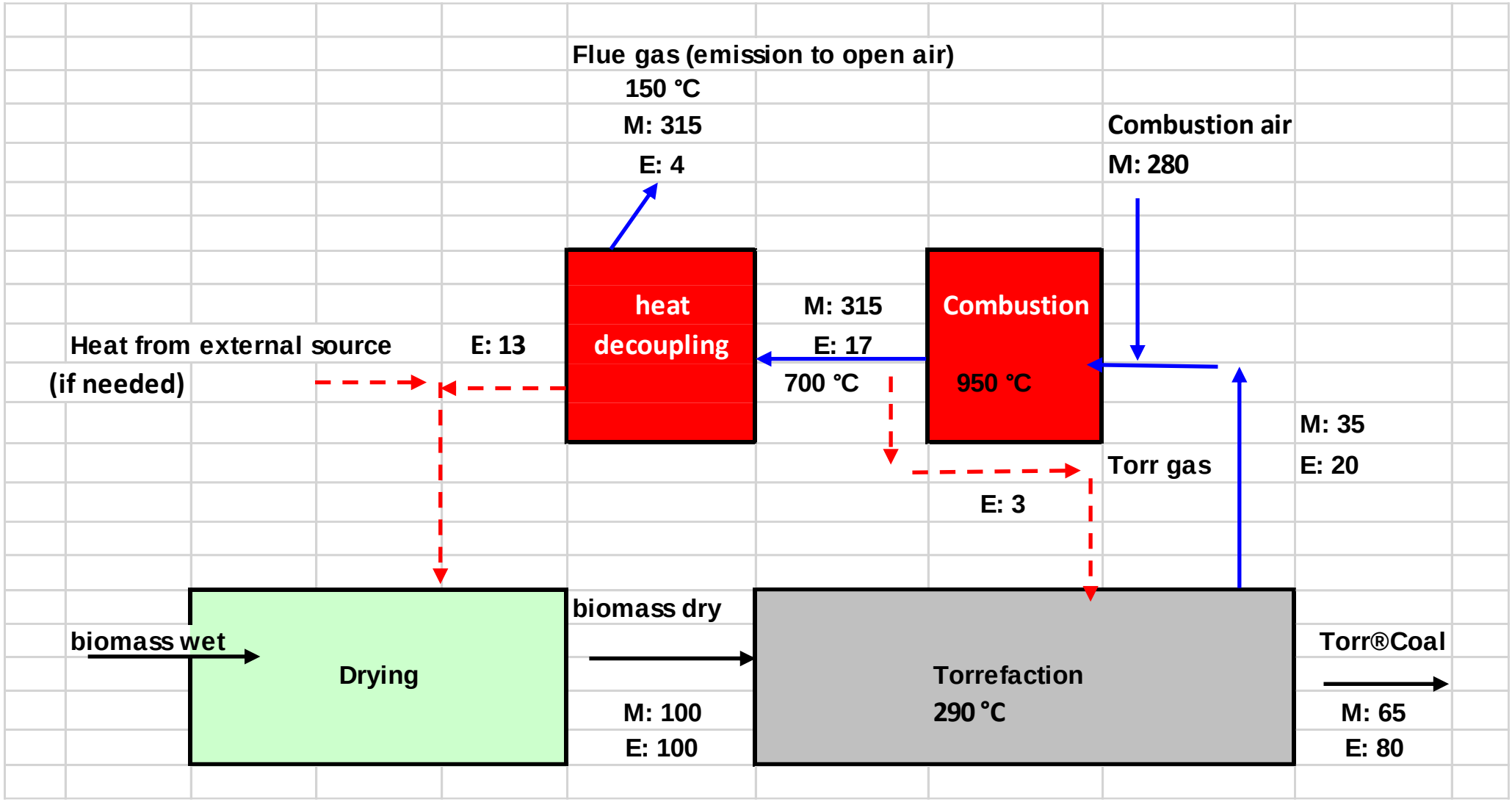
- Input: 110.000 ton/y woody biomass (moisture content +/- 45%)
- Output: 40.000 ton/y bio-coal

- Powder (since Nov. 2010) and pellet production (since Oct. 2013)

Production process Torr®Coal



Mass_Energy balance Production process Torr®Coal



Any questions?

Torr-Coal Group

Nusterweg 69, 6136 KT Sittard, The Netherlands

Jo Sluijsmans
j.sluijsmans@torrcoal.nl

+31 - 46 - 4775174

www.torrcoal.com