www.ofi.at
www.pelletstesting.com

Österreichisches Forschungsinstitut
für Chemie und Technik

Torrefaction

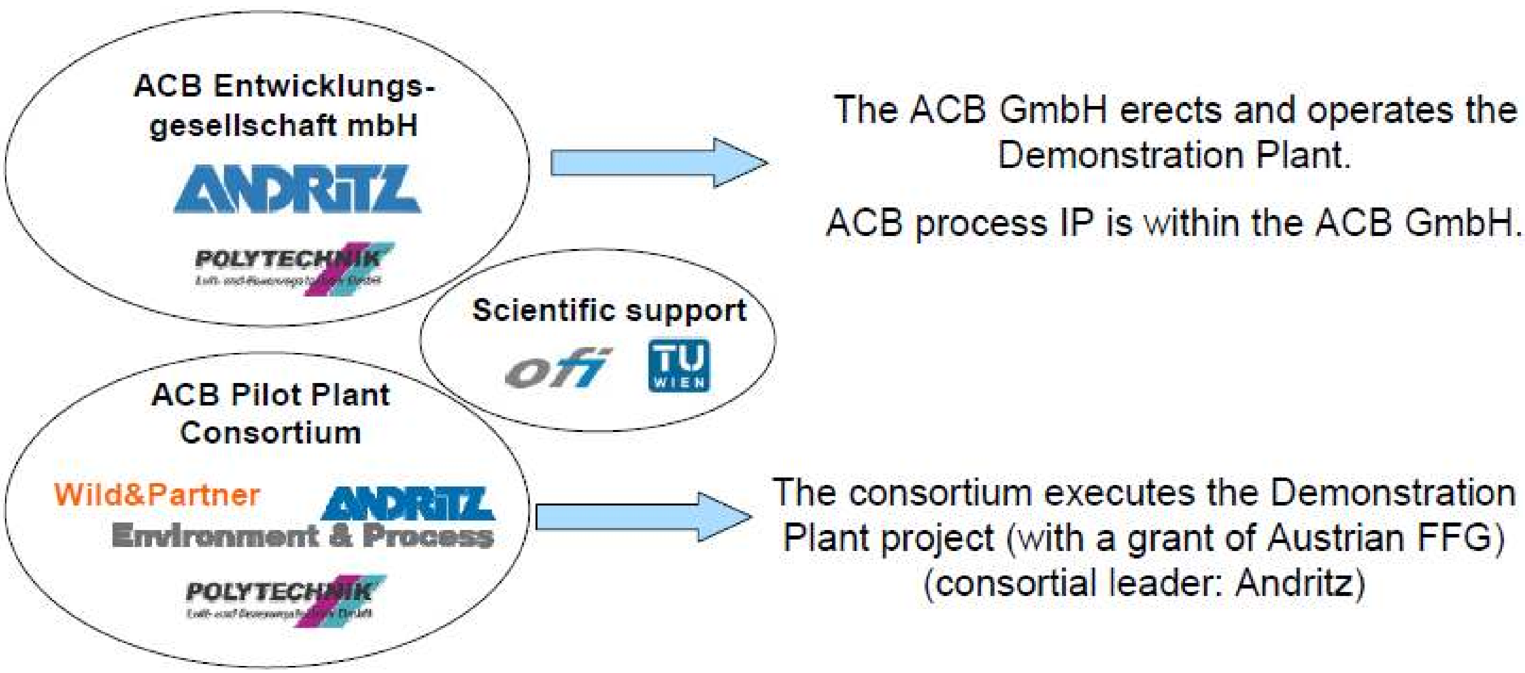
fundamentals and basic principles of torrefaction

BIOENERGIE

Martin Englisch

torrefaction process development Austria

- Research project (2008-2009)
  - Evaluation of reaction principles
  - Evaluation of possible technology and reactor designs
  - Economical feasibility
- Semi industrial pilot plant (2010-2012)



Testing of different reactor designs

Evaluation of principles and reactor types, e.g.:

- Drum reactor
- Continuous paddle reactor
- Stirred batch reactor

www.ofi.at
www.pelletstesting.com

Requirements for successful industrial process

1. Understand chemistry of the process
2. Define properties of marketable product
3. Solve technical problems handling reaction products of process
4. Optimize product and process to customers requirements

1.	2.	3.	4.
1901 - 2011	2005 - 2011	2011 - ??	
Fundamentals published by ECN, First plant Pechiney, France, 80ties Summary processes see R. Walton	Summary processes see R. Walton, 2010		

What is torrefaction?

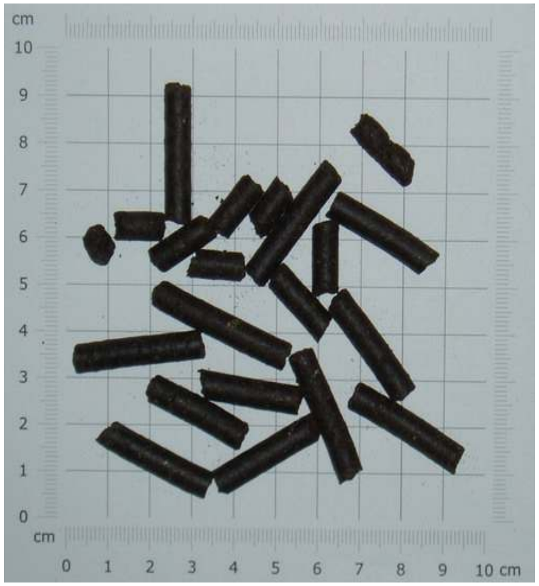
Torrefaction (in German: Rösten)

- Some definitions found:
  - ...dry, fatfree heating of plants (foodstuff) up to 300℃ - extension for biofuels: in the absence of oxygen
  - ...can be described as a mild form of pyrolysis at temperatures typically ranging between 200-320 ℃
  - ... is a thermal upgrading of solid biofuels
  - ... is a controlled carbonisation of biomass

Street sign, Bordeaux, France

- ➢ All definitions leave a wide range for interpretation
- ➢ Currently no specification for torrified biomass exists

From raw material to product



Raw material (Miscanthus)

GCV (db): 17.500 J/g

BD: 150 kg/m³

Torrified material

GCV(db): 23.300 J/g

BD: 200 kg/m³

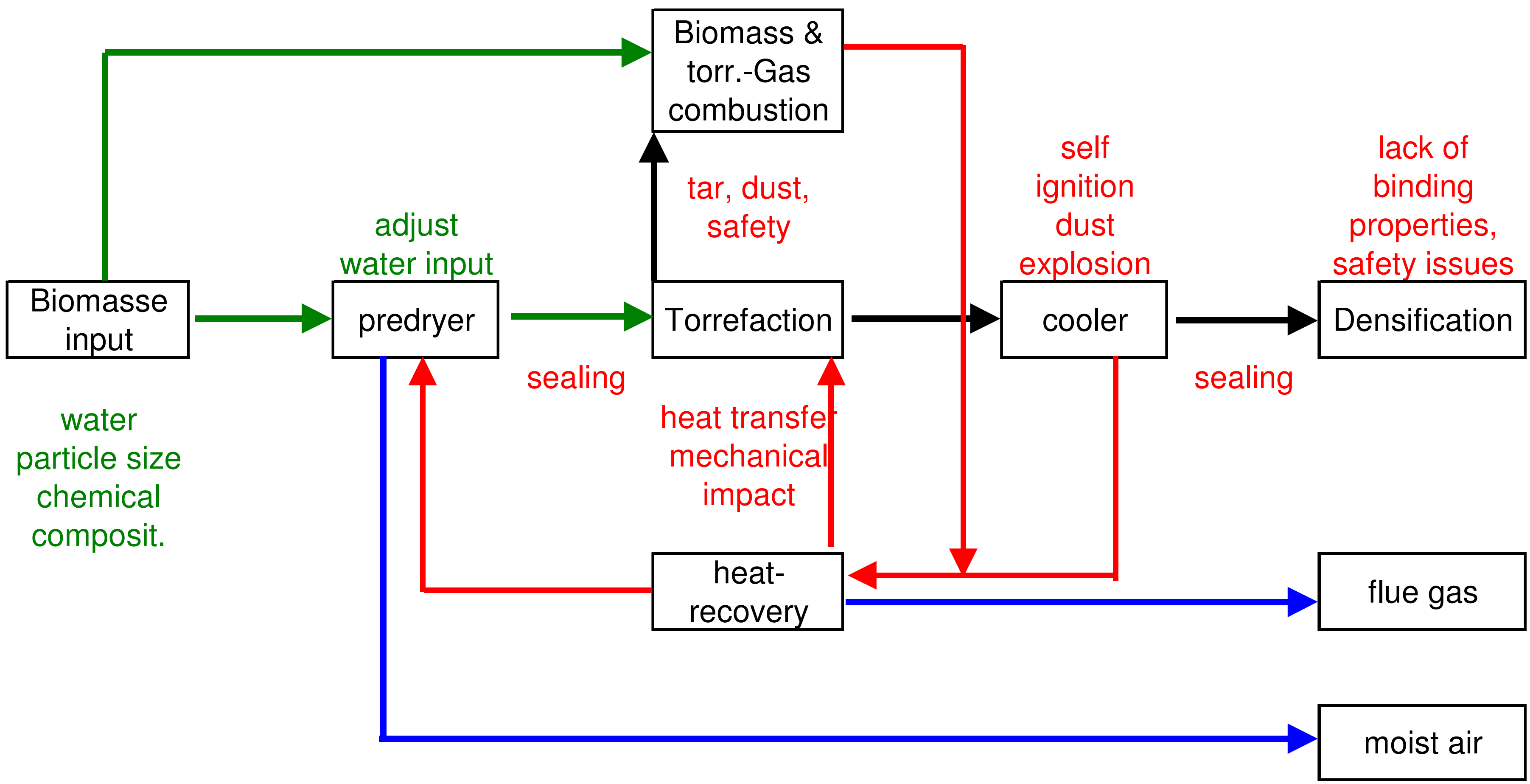
Torrified pellets

GCV (db): 23.300 J/g

BD: ~ 650 kg/m³

Source: EBES AG & ofi

Torrefaction causes succesive challenges



In general, similar problems occur as known from gasification and additional ones!

Elemental composition

Composition wood
(EN 14961-1)

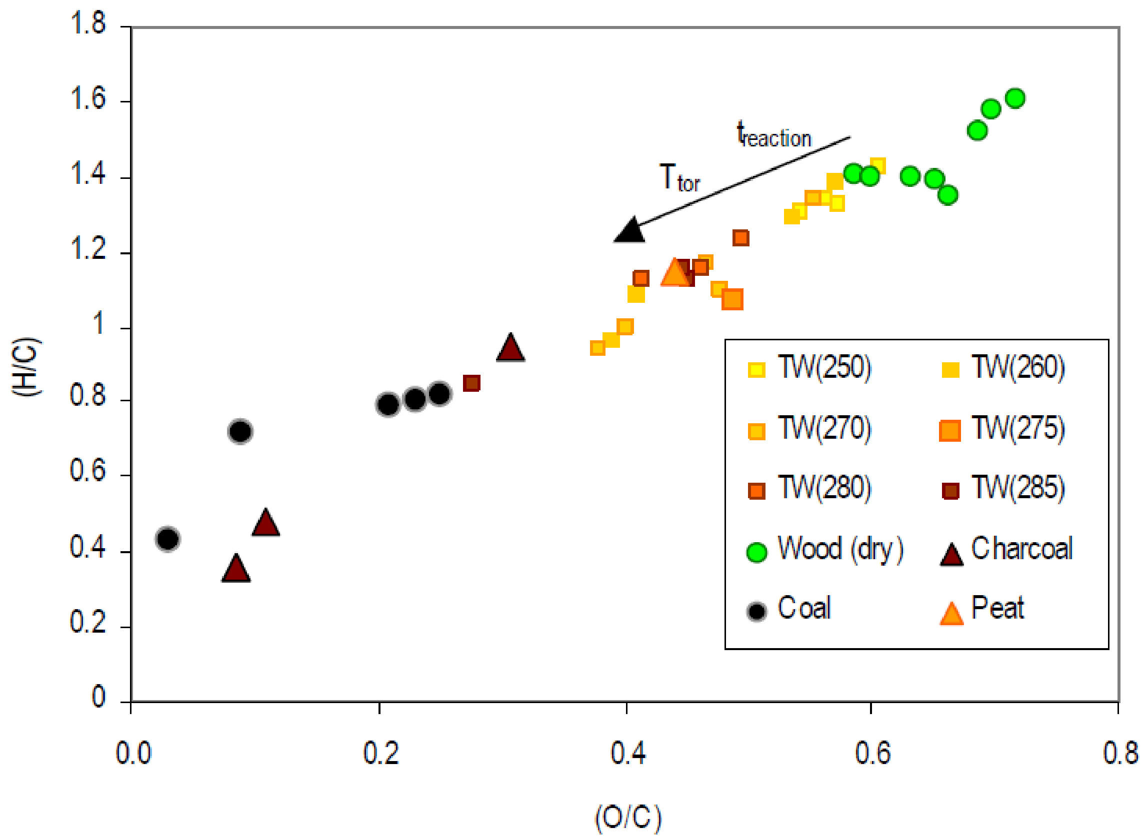
Torrefaction:

47-54% Carbon ↑

5,6-7% Hydrogen ↓

40-45% Oxygen ↓

< 2% minerals, nitrogen, others –



Direct correlation of elemental composition and gcv / ncv e.g.:

(1) gcv (kJ/g) = 0.3491 C + 1.1783 H - 0.1034 O - 0.0211 A + 0.1005 S - 0.0151 N

(2) ncv (kJ/g) = 0.2746 C + 5.79

Sources: figure ECN, (1): Channiwala 1992 , (2) EN 15296

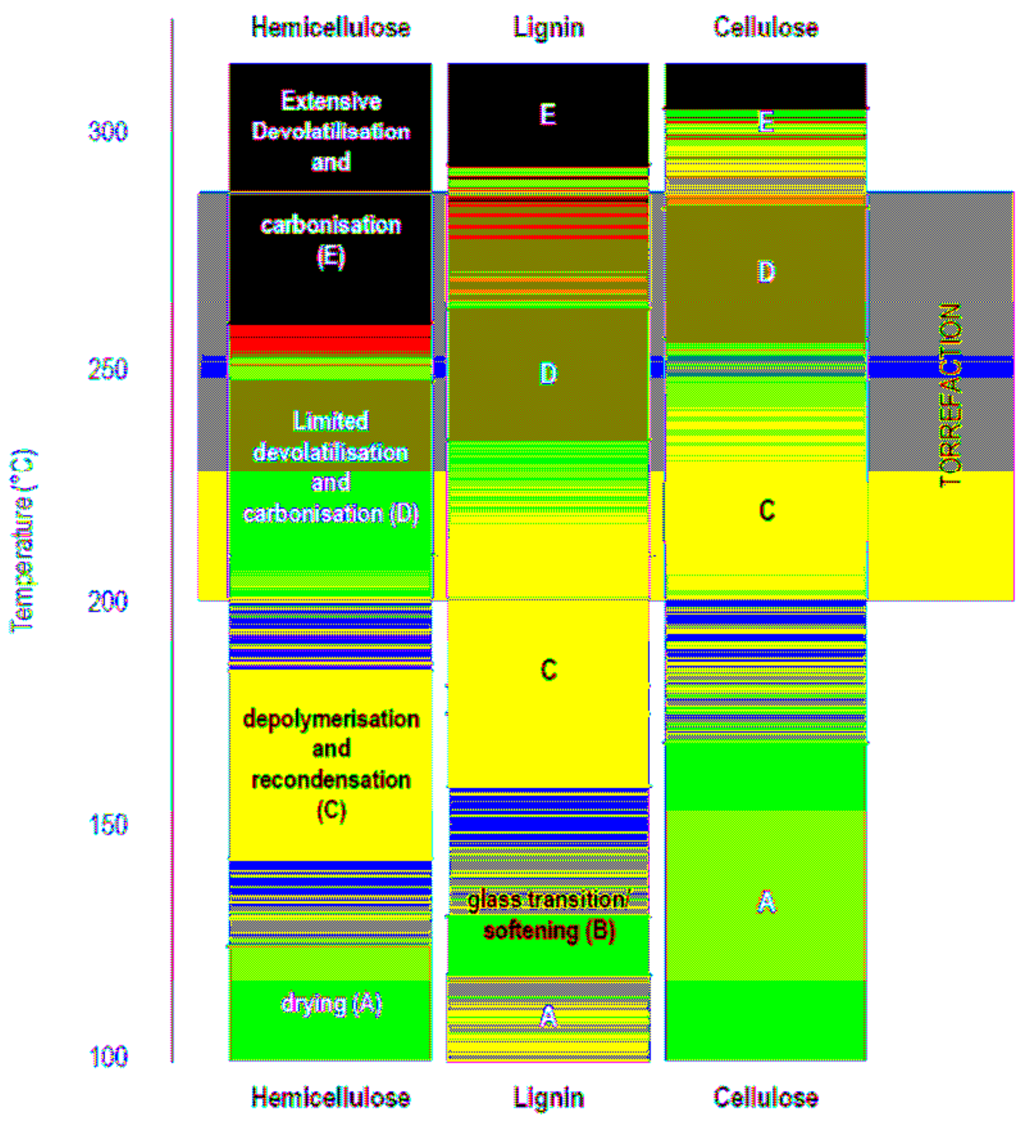
How to describe torrefaction?

Soft pyrolysis or partial carbonization means:

- Evaporation of substances
  physical e.g. waxes
- Devolatilization
  chemical reactions

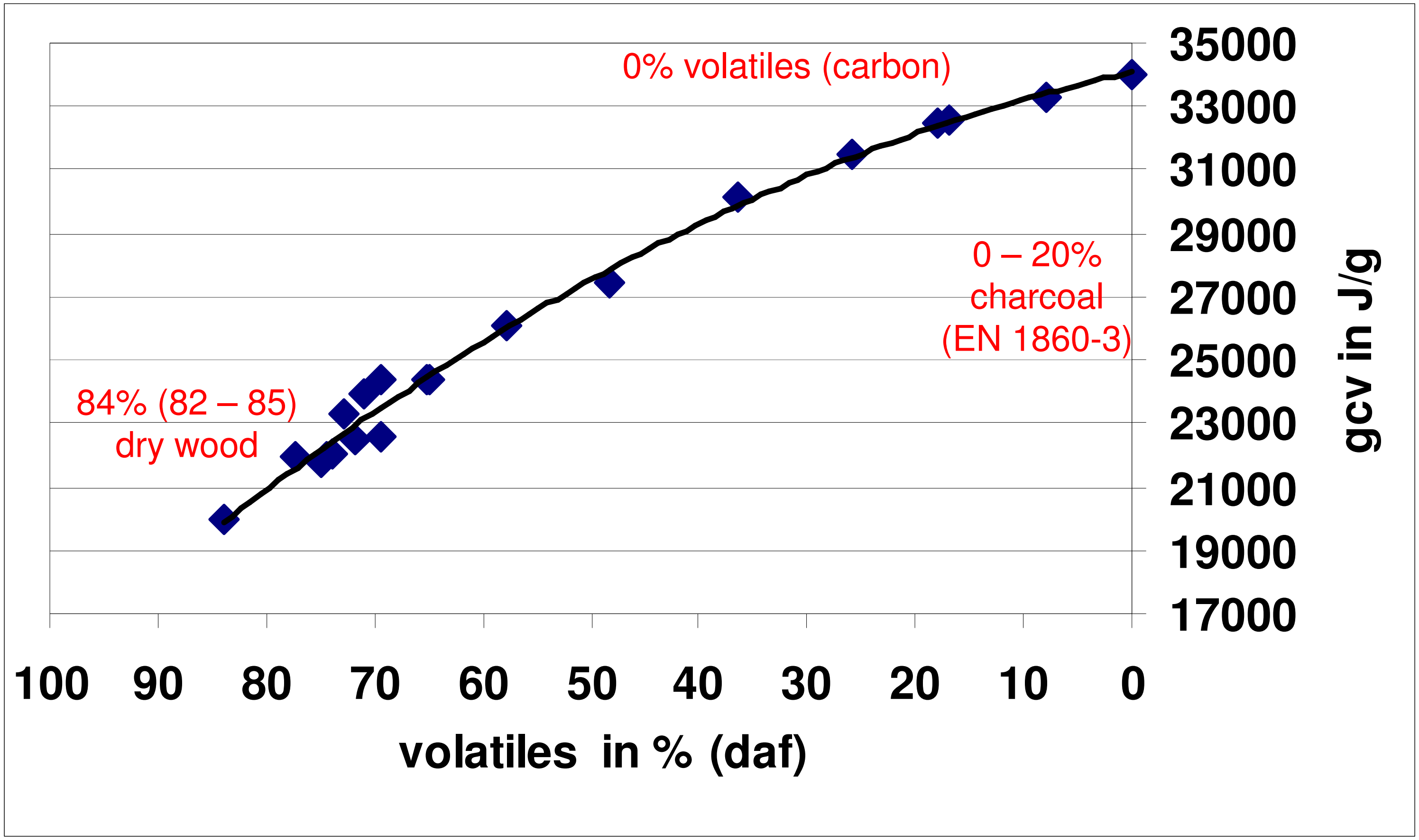
Function of T and time, loss of

- Condensables:
  H_2O, acids, alcohols, furans, ketones, lipids, terpenes, phenols, fatty acids, waxes, tanins, benzene, toluene,…
- Gases:
  H_2, CO, CO_2, CH_4, C_xH_y



Source: ECN

Carbonization reaction



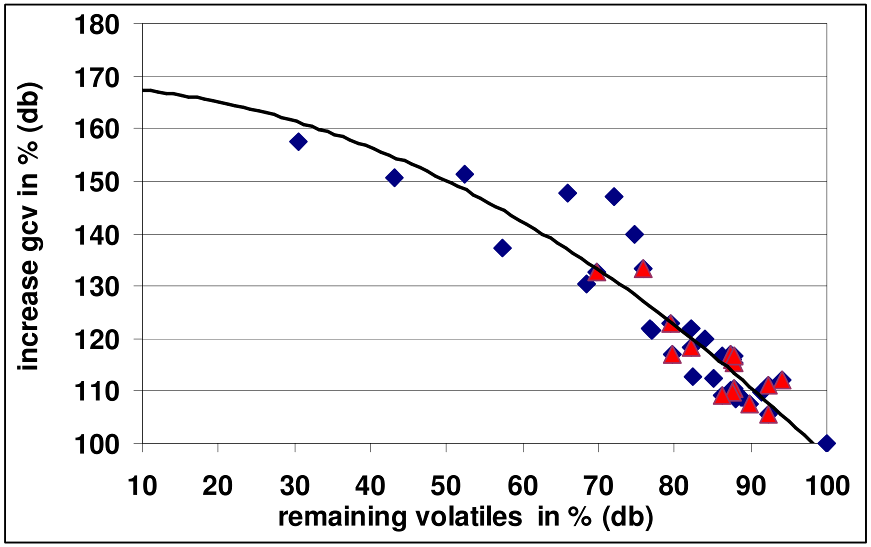
- All points derived from experiments
- Shown here: results for wood, similar results for miscanthus and other biomass
- Depending on reaction conditions (T, t)

How to describe quality and properties ?

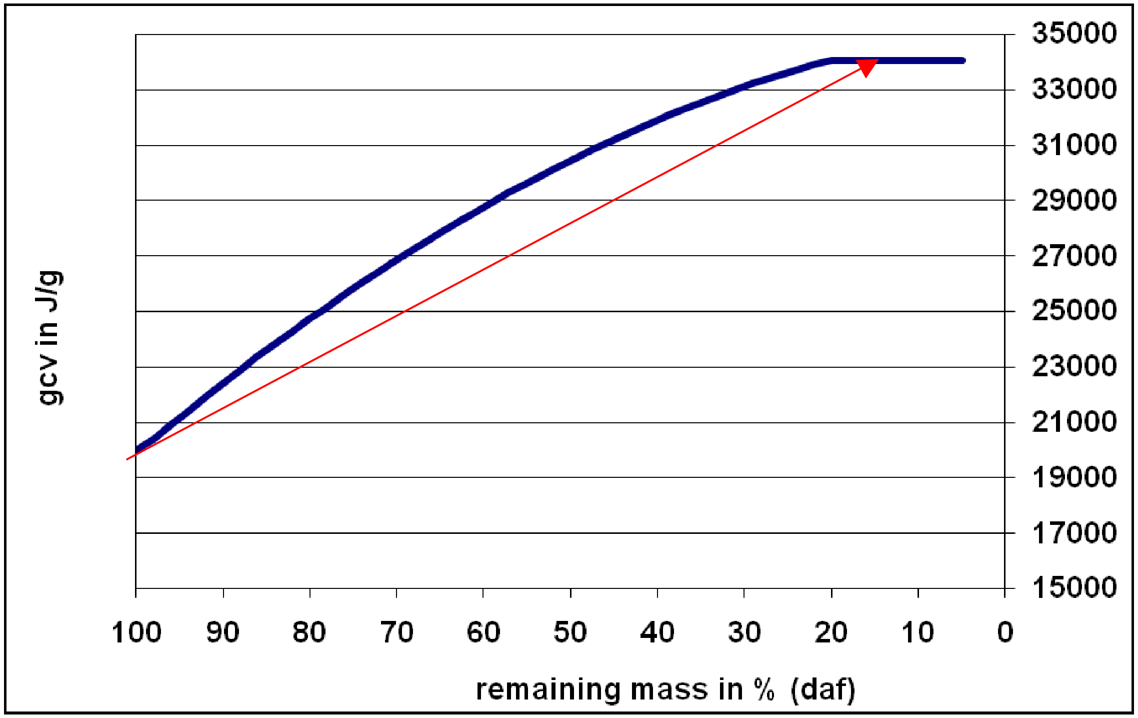
- Volatiles according EN 15148 :
  - wood: 80-85%
  - (soft) torrefied wood (ncv 21000-23000 J/g): 70-80%
  - other biomass 73-85% (typical hard coal: 25-40%)
  - ➢ Volatiles are not specific to describe change in physical properties e.g. embrittlement or hydrophobicity
  - ➢ Normalization is necessary e.g.:

- Degree of torrefaction [in %]
  - Describes how far carbonisation proceeded, independent of raw material
  - 0%: original biomass, independent of type
  - 100%: charcoal

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



unique torrefaction reaction characteristics



- Starting with wood containing 84% volatiles, remaining charcoal should be 16% mass of raw material
- Experiments showed, that around 20% remain
- explanation: coking reactions occur

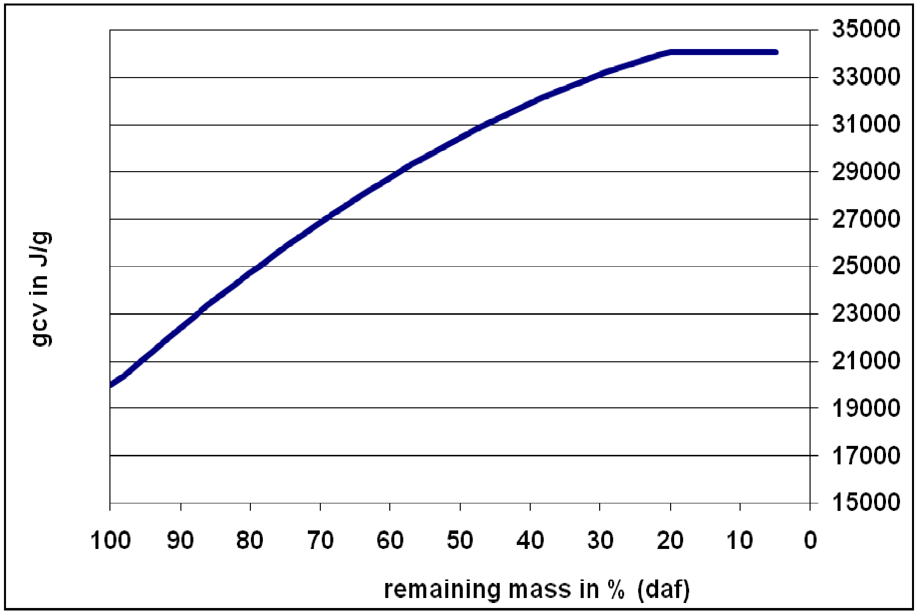
unique torrefaction reaction characteristics

- Increase in heating value is not linear
- torrefaction is a complex mixture of endothermic and exothermic reactions
- For low torrefaction degrees:

  $\Delta H = H_{products} - H_{raw\ material}$

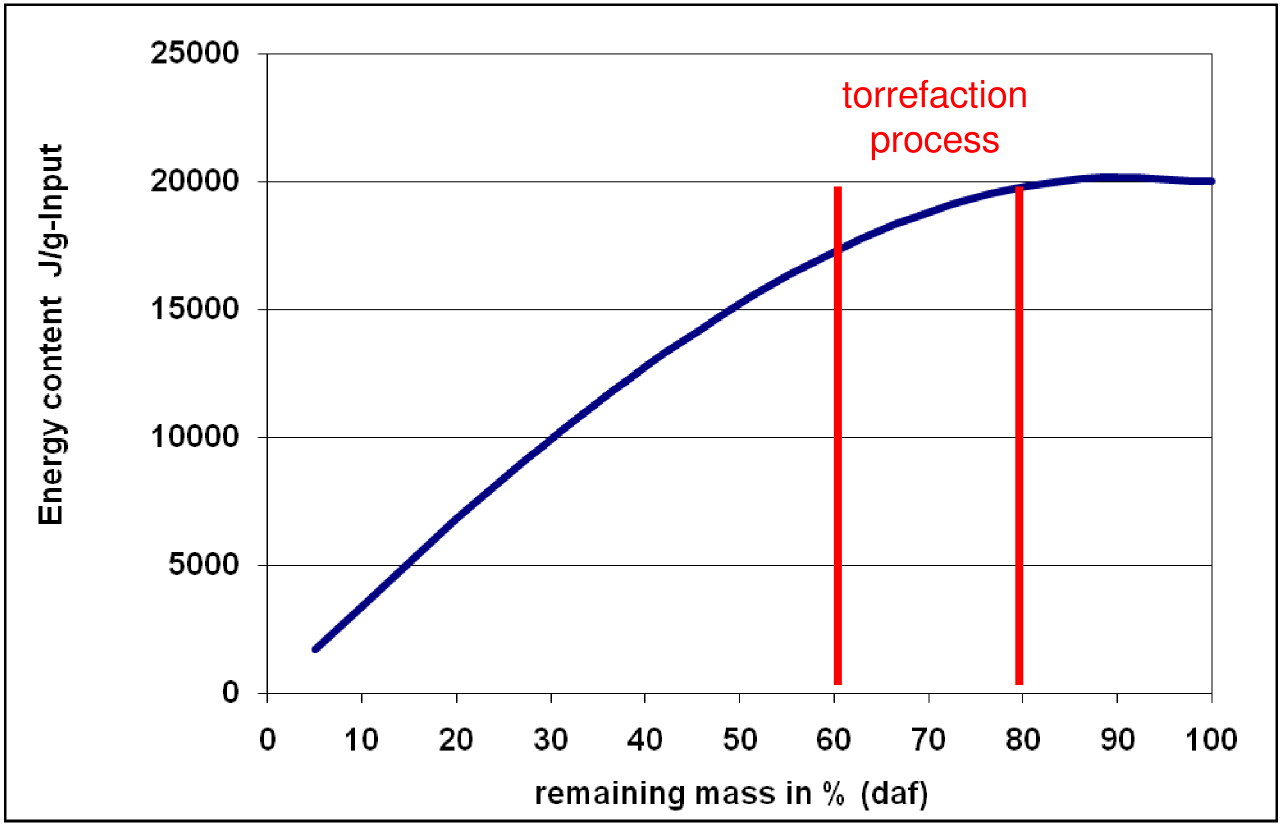
  is positive (endothermic)

- In model calculations, torrefied biomass can contain more that 100% of energy content of raw material ! (not including gases)
- own calculations in good relation with [1]



[1]: Dudgeon R., (2009) An Aspen Plus Model of Biomass Torrefaction

Reaction characteristics



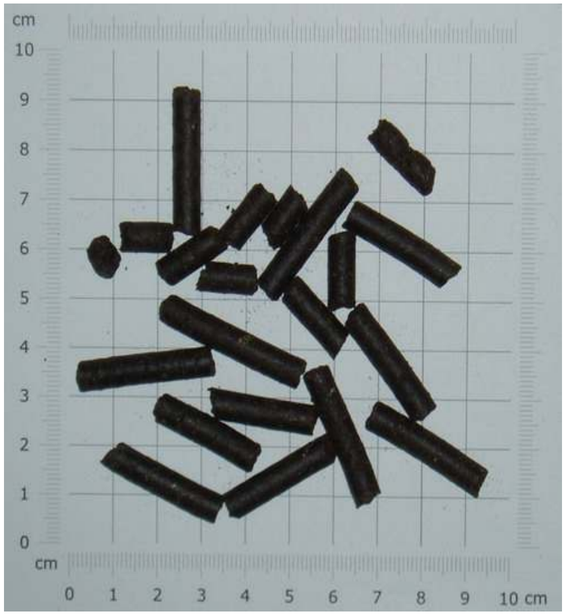
- Up to 30 % weight loss, more than 90% of energy remains in the product
- Calculation shows, that 100% is possible although the torr gas contains a heating value $\Rightarrow$ torrefaction requires process heat
- Process can be customized depending on required properties: grindability, possibility of compacting, resistance to water etc.

www.ofi.at
www.pelletstesting.com

Examples energy and mass yields for carbonisation

Example

- 1 m³ wood chips
- w 50, 300 kg/m³, v=84%
- 150 kg (ds), ca. 3 kg ash
- gcv 3,0 GJ (= 20 MJ/kg)
- ncv 2,87 GJ (=19,1 MJ/kg)



Torrefied wood TG=23, v=63%

- 93 kg (ds), incl. 3 kg ash
- as pellets (w 10, 650 kg/m³):
  102 kg, 0,16m³
- gcv 2,56 GJ (= 27,5 MJ/kg)

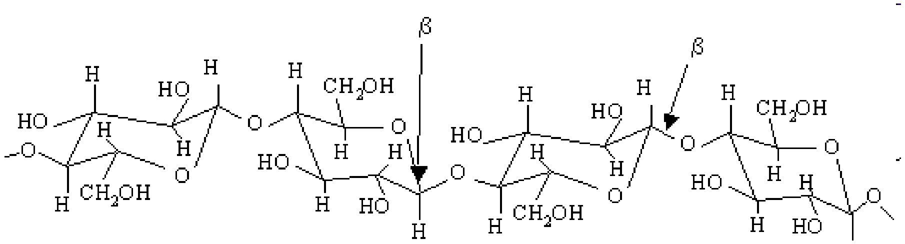
Charcoal

- 45 kg, incl. ca. 3 kg ash
- mass ca. 30 % if v=10%
- gcv 1,48 GJ (= 32,6 MJ/kg)

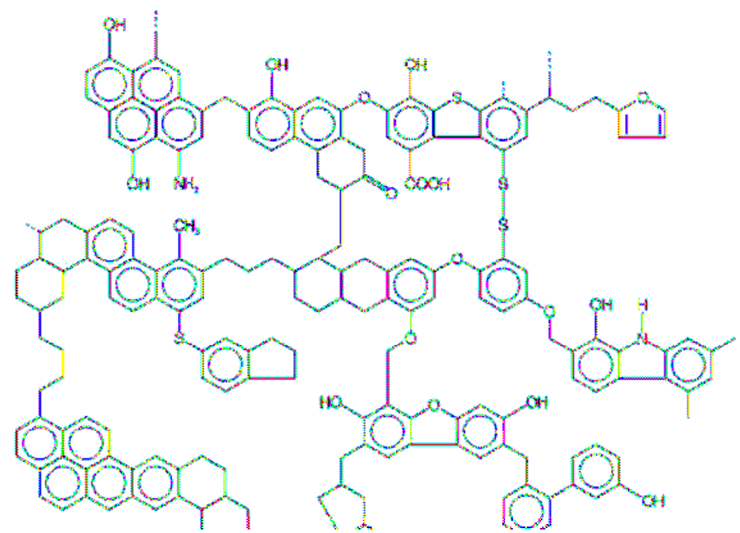
Properties of torrefied biomass

Improved properties compared with biomass due to same chemical reactions

- Increased heating value (ncv)
  - ➢ 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



Example structure cellulose



Example structure coal

Byproducts

Every devolatilization/pyrolysis leads to reaction products (torrefaction gases)

- While permanent gases (H_2, CO, CO_2, CH_4, C_xH_y) are suitable fuels
- Condensables may cause challenges, especially tars and dust



Properties of torrefied biomass

Disadvantages

- Dust and dirtyness
- Safety issues
  - Self ignition and spontaneous combustion occurs at 150-170℃
  - Explosion hazards increase compared with biomass (high surface area, heating value, etc..)
- Compacting is more difficult

Problems to be solved

- Process control issues
  - Exclusion of oxygen
    - Safety issues (fires, explosions)
    - Homogeneity of product
    - Loss of efficiency
  - Optimal heat transfer
  - Torr gas handling
    - Gas contains water, tar and dust – difficult to handle
      - Advantage for shaft reactors (ECN, Thermya)
  - Finding a suitable compacting technology
  - Upscaling, requirements to raw material pretreatment (e.g. particle size)
  - Safety and health issues with respect to product and emissions (currently widely unknown)

- Maybe these and other problems lead to the delay with most ongoing projects!

State of the art

- Comment of R. Walton, summer 2010:
  - “In the World today, there are actually no more than 7 or 8 machines making torrefied wood”
  - “All of these only exist at a laboratory or pilot plant scale, the largest one produces enough material annually to run a power station for about 3 minutes”
- We are at the beginning!
- Some plants will solve problems “next week”

www.ofi.at
www.pelletstesting.com

Thank you for your attention!

ofi – Österreichisches Forschungsinstitut für Chemie und Technik
Franz-Grill Str. 5, Arsenal Objekt 213
A-1030 Wien
Tel.: +43-1-7981601-490
Fax: +43-1-7981601-8
martin.englisch@ofi.at