Conversion of Biomass Particles

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Energy Technology (CTW)

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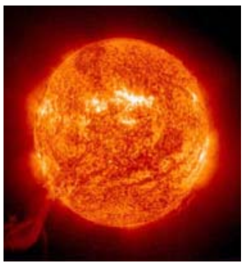
Contents of the lecture "Conversion of Biomass Particles"

- Introduction on Sustainable Energy
- Energy from biomass
- Combustion of Biomass Particles
- Pyrolysis of Biomass Particles
- Biorefinery



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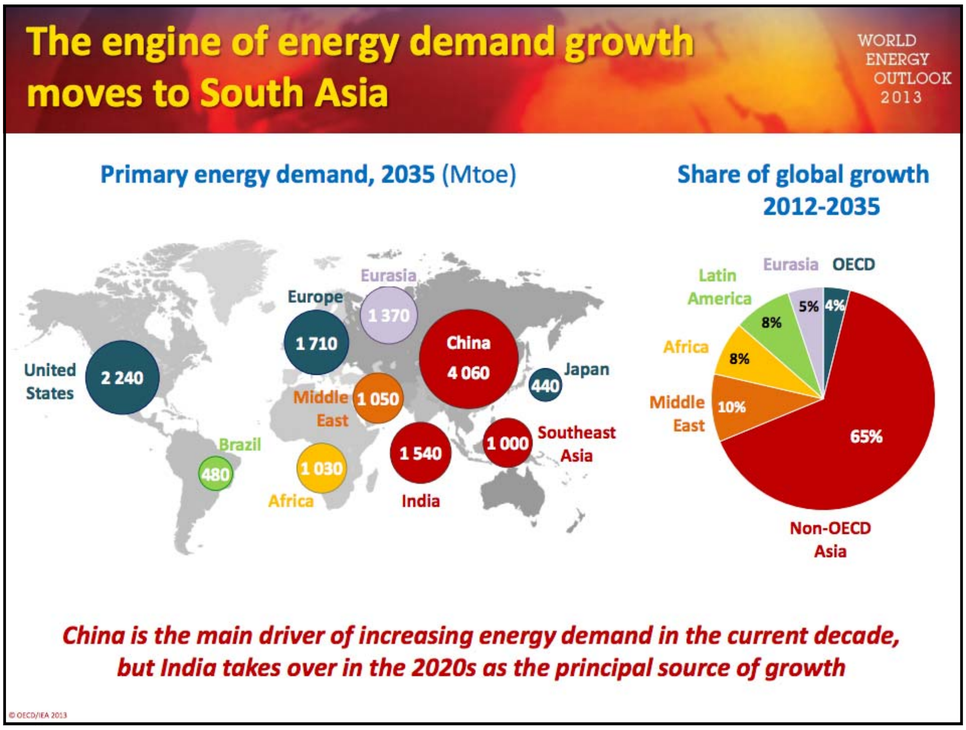
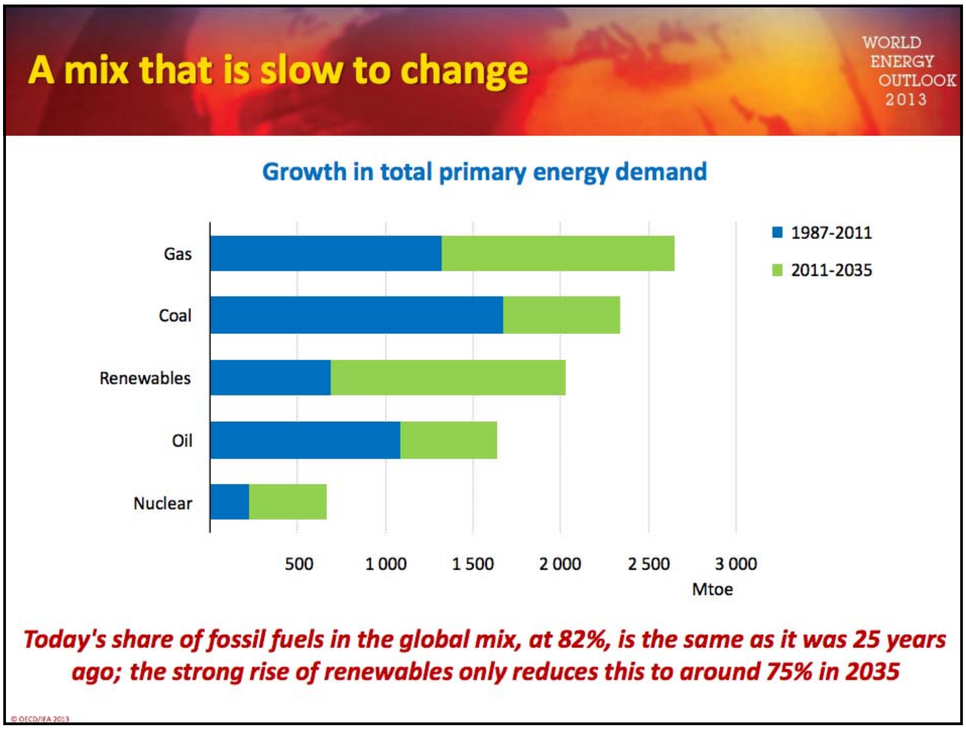
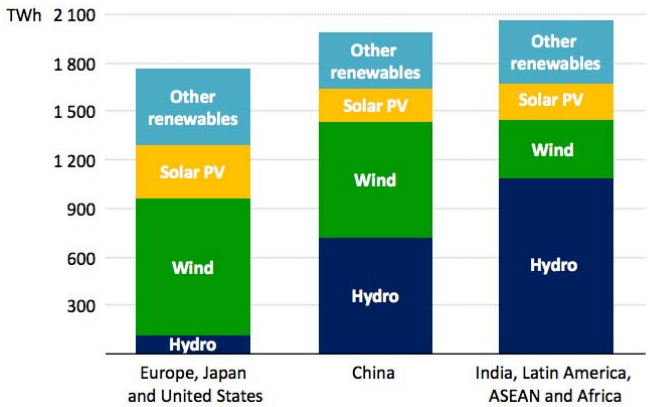

The engine of energy demand growth moves to South Asia
WORLD ENERGY OUTLOOK 2013
Primary energy demand, 2035 (Mtoe)
United States 2 240
Europe 1 710
Eurasia 1 370
China 4 060
Japan 440
Middle East 1 050
Southeast Asia 1 000
India 1 540
Brazil 480
Africa 1 030
Share of global growth 2012-2035
Eurasia 5%
OECD 4%
Latin America 8%
Africa 8%
Middle East 10%
Non-OECD Asia 65%
China is the main driver of increasing energy demand in the current decade, but India takes over in the 2020s as the principal source of growth
© OECD/IEA 2013


A mix that is slow to change
WORLD ENERGY OUTLOOK 2013
Growth in total primary energy demand
Gas
Coal
Renewables
Oil
Nuclear
1987-2011
2011-2035
500
1 000
1 500
2 000
2 500
3 000
Mtoe
Today's share of fossil fuels in the global mix, at 82%, is the same as it was 25 years ago; the strong rise of renewables only reduces this to around 75% in 2035
© OECD/IEA 2013

Renewables power up around the world

WORLD ENERGY OUTLOOK 2013

Growth in electricity generation from renewable sources, 2011-2035

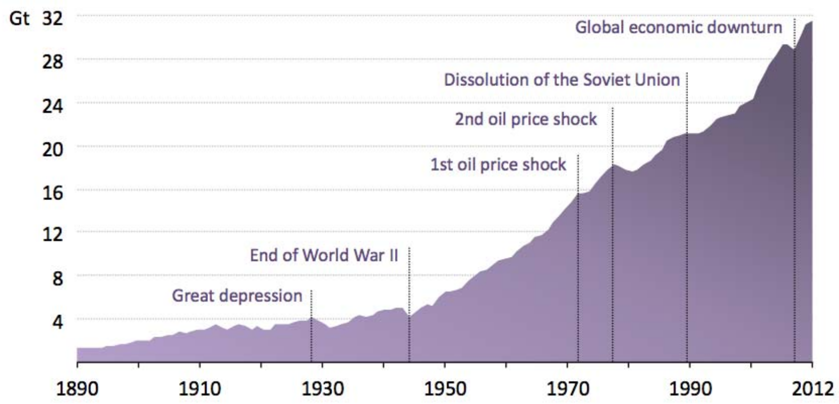


The expansion of non-hydro renewables depends on subsidies that more than double to 2035; additions of wind & solar have implications for power market design & costs

…but the world is still moving in the wrong direction

WORLD ENERGY OUTLOOK Special Report

Global energy-related CO_2 emissions



CO_2 emissions trends point to a long-term temperature increase of up to 5.3 °C

80 Million barrels oil per day!

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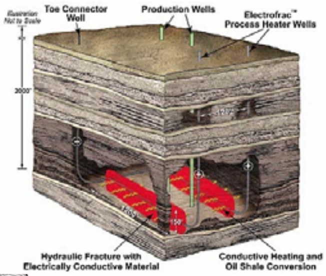
Energy scenario's

- Present consumption of 80 Mbarrels/day
- In 2030: 120 Mbarrels/day
- Half of present production sites will be exhausted in 2030
- So we need another 80 Mbarrels/day



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Drivers for sustainable energy

- Energy resource scarcity in the long term
- Costs (oil 150 $ / barrel, 7-2008)
- Environmental and Climate change
  - Mankind's CO_2 emissions
- Security of supply
  - Matter of politics, Self-sufficiency
- Decentral electricity production
- Alternatives!

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Sustainable energy sources

- Solar PV
- Solar heat
- Wind
- Biomass
- Geothermal
- …

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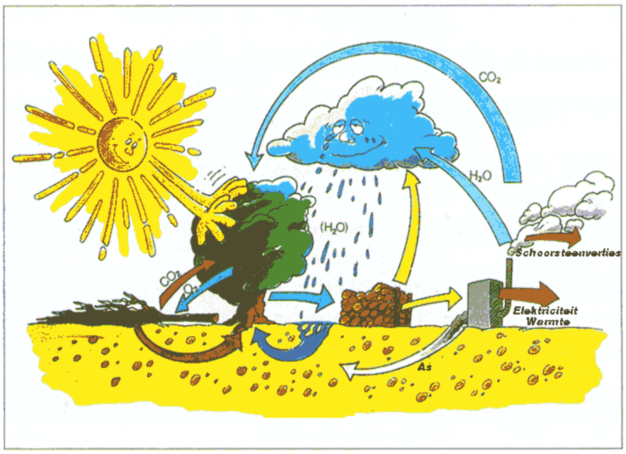
Biomass: closed CO_2 cycle



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Biomass characteristics

- **Renewable**
- **Large quantities available**
- **Can be stored & transported**
- **Contains C, H (& O)**

  production of conventional (oxygenated) hydrocarbon chemicals & fuels
- **Sustainable (under strict conditions)**

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Sustainability Criteria
minister Cramer

- Reduction greenhouse gases
- No competition with food chain
- Biodiversity
- Environmental impact (soil, water,air)
- Local prosperity
- Local welfare

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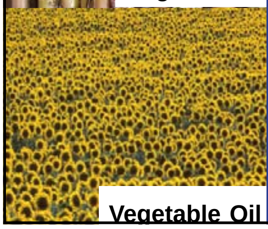
Biofuels - generations

~~1st generation~~
~~"edible"~~


Sugar Cane


Vegetable Oil

2nd generation
"non-edible"

Waste / Residue


Sawdust


Rice Husk

Energy crops


Grass


Algae

Biomass to products

Heat
Electricity
Fuels
Chemicals
Materials

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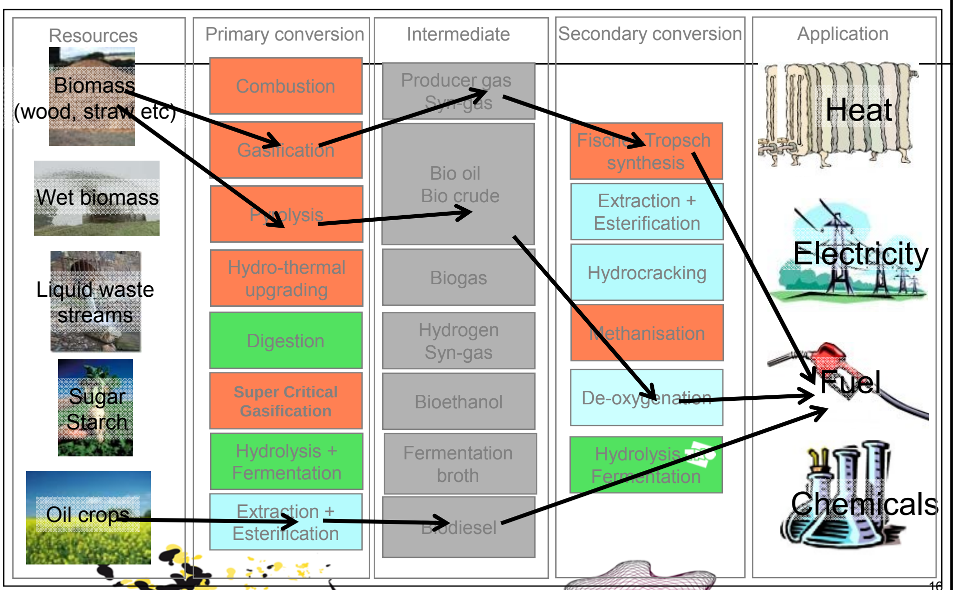

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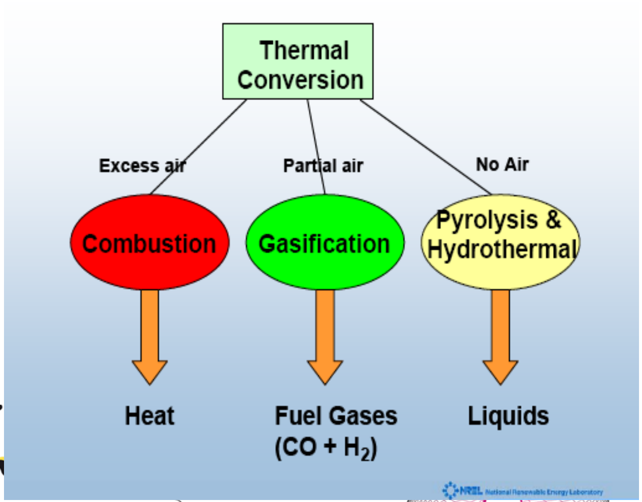
Thermal conversion of biomass



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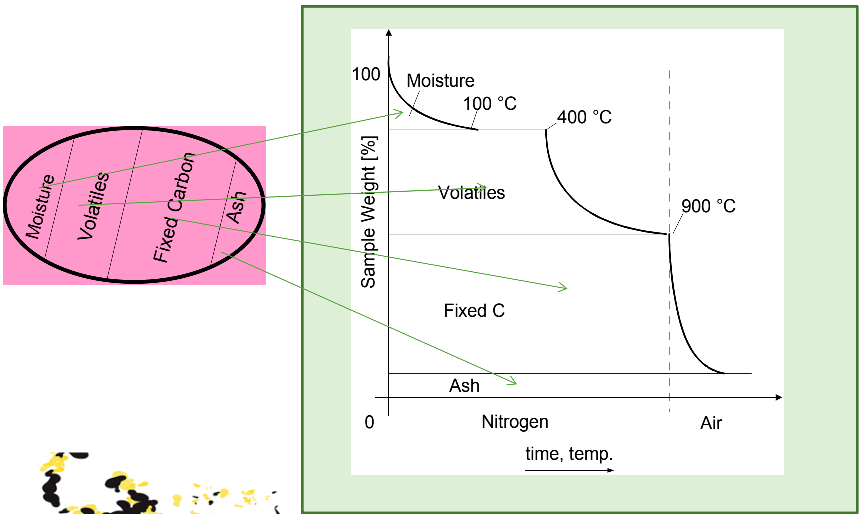
Thermal Conversion of Biomass Particles



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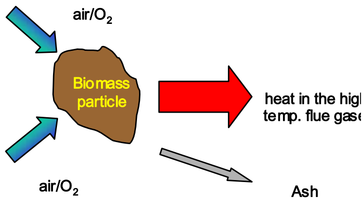
Combustion

$CH_{1.4}O_{0.6} + 1.05\ O_2 \rightarrow CO_2 + 0.7\ H_2O \quad \Delta H = -17.5\ MJ/kg$

- Process
  Complete oxidation of the organic material in an air or oxygen environment at high temperatures
- Conditions
  - T > 850 °C
- Products
  Heat
  CO_2, H_2O and ash



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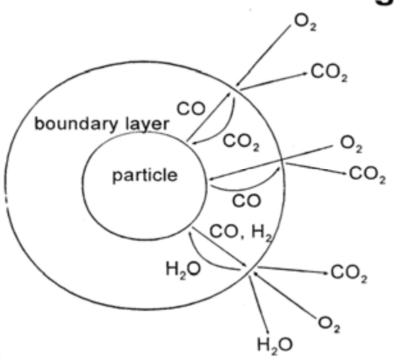
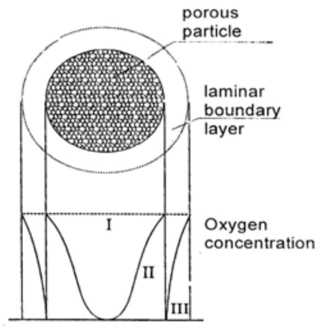
Heterogenous Reaction





reaction dependent on:

- transport through boundary layer
- transport into porous particle
- reaction at solid surface
- availability of surface

overlapping consecutive mechanisms
- boundary layer diffusion
- pore diffusion
- chemical reaction

→ all mechanisms temperature dependent
→ slowest mechanism governs combustion velocity
T<800 °C chemical reaction, T > 1000 °C diffusion

Single Particle Model (mass balances)

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left[D_e(\varepsilon_S)r^2\frac{\partial C_A}{\partial r}\right] - R_A = 0.$$

$$\frac{\partial C_S}{\partial t} = -R_S \qquad R_S = k_s C_A^m A_g(\varepsilon_S)$$

$$r = 0,\quad \frac{\partial C_A}{\partial r} = 0 \text{ and } \frac{\partial C_S}{\partial r} = 0. \qquad r = r_s,\quad D_e\frac{\partial C_A}{\partial r} = k_d(C_{A,\infty} - C_{A,s})$$

Single Particle Model (dimensionless)

$$\frac{1}{\xi^2}\frac{\partial}{\partial \xi}\left[D(S)\xi^2\frac{\partial C}{\partial \xi}\right] - \phi_0^2 C^m A(S) = 0$$

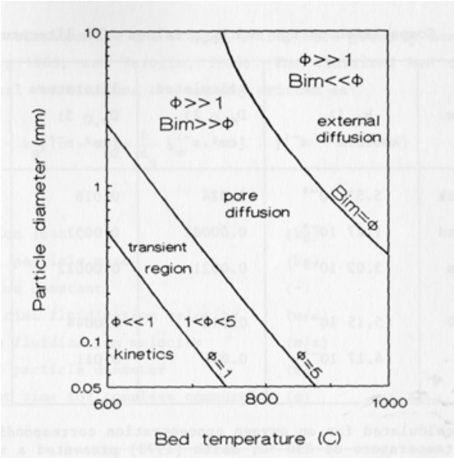
$$\frac{\partial S}{\partial \Theta} = -C^m A(S)$$

$$\xi = \xi_s,\quad D\frac{\partial C}{\partial \xi} = Bi_m(1 - C_s)$$

$$\phi_0 = R\sqrt{\frac{ak_s A_{g,0} C_{A,\infty}^{m-1}}{D_{e,0}}}$$

$$Bi_m = R\frac{k_d}{D_{e,0}}.$$

Single Particle Model (mechanisms)



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Single Particle Model (energy balance)

$$\frac{\partial}{\partial t}[\rho_S(1-\varepsilon_S)c_p T] = \frac{1}{r^2}\frac{\partial}{\partial r}\left[\lambda_e(\varepsilon_S) r^2 \frac{\partial T}{\partial r}\right] - \frac{\partial C_S}{\partial t}(-\Delta H)$$

$$r = r_s, \quad \lambda_e \frac{\partial T}{\partial r} = h(T_s - T_\infty) + \varepsilon_r \sigma (T_s^4 - T_\infty^4)$$

➔ Particle overshoot temperature

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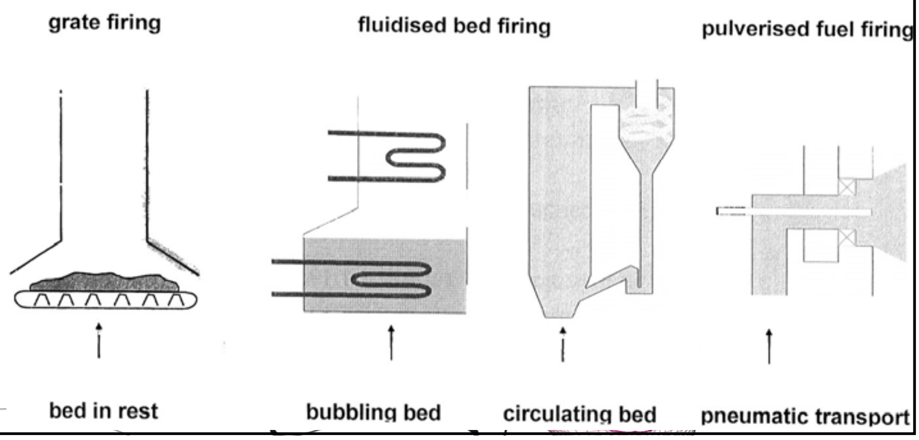
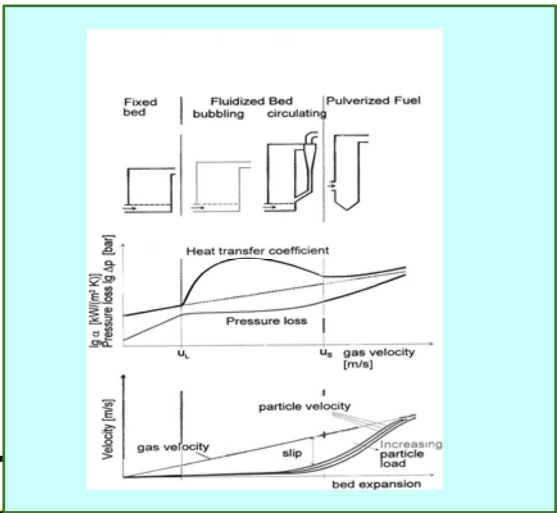
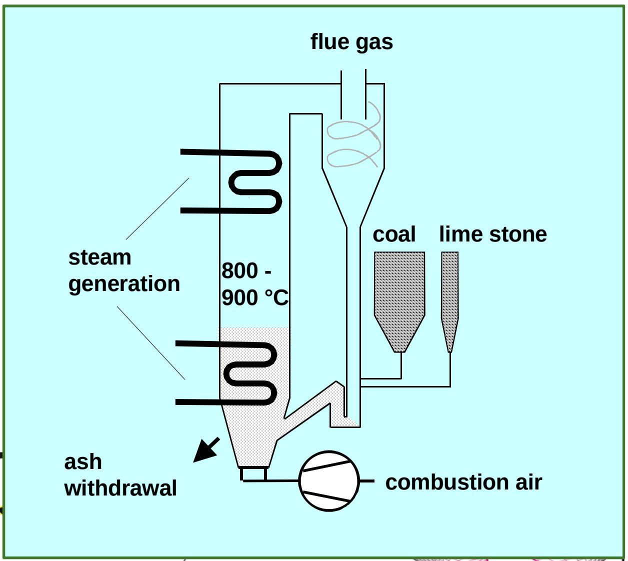
Combustion systems



Characteristics of Combustion Systems



Fluidized Bed Combustion (FBC)



Comparison of Fluidised Bed and Pulverised Fuel Firing

	fluidised bed bubbling	fluidised bed circulating	pulverised fuel firing
air velocity [m/s]	1 - 3	4 - 8	25 - 50
flue gas velocity [m/s]	< 1 - 4	4 - 8	8 - 12
flue gas temperature [°C]	750 - 900	750 - 900	1150 - 1450
average grain [µm]	2000 - 4000	1000 - 2000	30 - 100
fuel/inert material [%]	0,5 - 1 (5)	0,5 - 2	40 - 100
air ratio	1,2	1,2	1,2 - 1,5
cross sectional heat release rate [MW/m²]	1 - 2	4 - 6	4,5 - 6,5
firing efficiency [%]	90 - 96	95 - 99	95 - 99

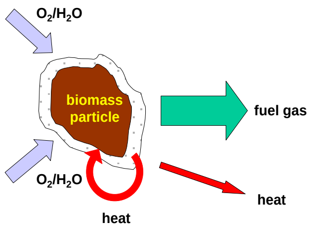
Gasification

$CH_{1.4}O_{0.6} + 0.2\ O_2 \rightarrow CO + 0.7\ H_2$

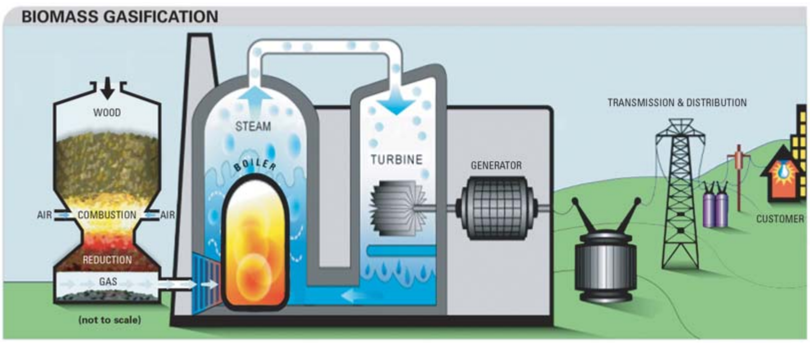
- Process
  Thermal degradation of the organic material
  and partial oxidation of the decomposition products

- Conditions
  - T = 700 – 950 °C, T > 1350 °C
  - P = 1 – 70 bar

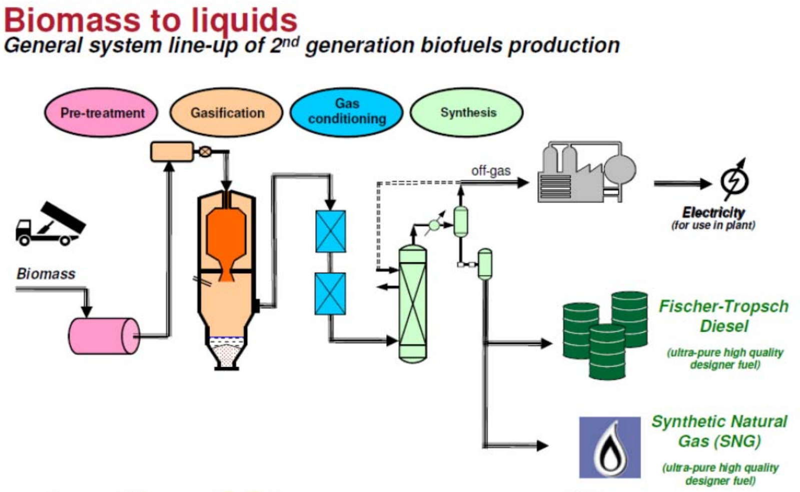
- Products
  Fuel gas (CO, CO_2, H_2, C_nH_m, H_2O, tars)
  Synthesis gas (CO, H_2, H_2O, CO_2,)
  Ash and heat



Gasification



Gasification



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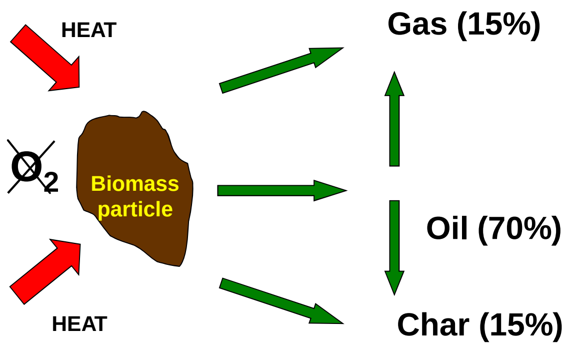
Flash pyrolysis



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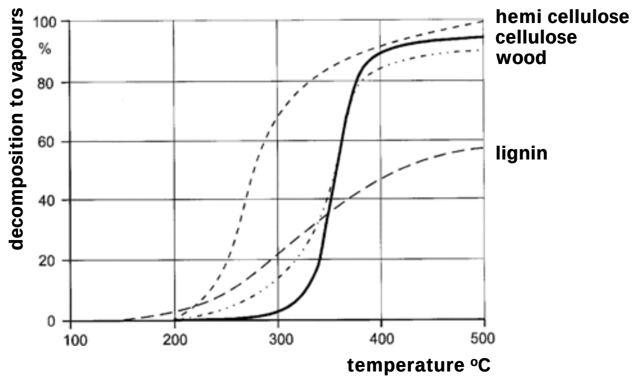
Decomposition of biomass



Elementary processes in pyrolysis

- heat transfer to the biomass particle
- intra particle heat transfer
- primary cracking of the biomass
- intra particle mass transfer of products
- external particle mass transfer
- secondary vapour cracking in the reactor

Rate determining step

Biot number: $Bi = h\,2r_p/\lambda_p$ (external/internal heat transfer resistance)

- Bi << 1 external heat transfer limitation
- Bi >> 1 internal heat transfer limitation

Pyle number: $Py = \lambda_p/k_b\,c_p\,\rho_p\,r_p^2$ (internal heat transfer/reaction kinetics)

- Py << 1 internal heat transfer limitation
- Py >> 1 kinetics controlling factor

Ext. Pyle number: $Py' = h/k_b\,c_p\,\rho_p\,r_p$ (external heat transfer/reaction kinetics)

- Py << 1 external heat transfer limitation
- Py >> 1 kinetics controlling factor

With:
h = external heat transfer coefficient
λ_p = thermal conductivity of particle
k_b = kinetic constant
c_p = specific heat of particle
r_p = particle radius
λ_g = thermal conductivity of gas
ρ_p = particle density

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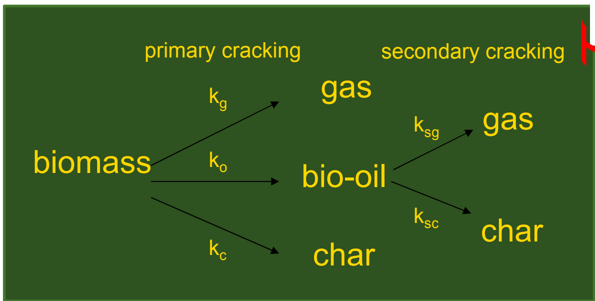
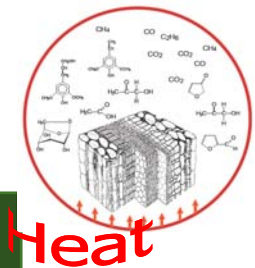
Reaction mechanisms in pyrolysis

Pyrolysis:
- dissociation of biomass
- many parallel and sequent reactions
- many products
- complex to describe





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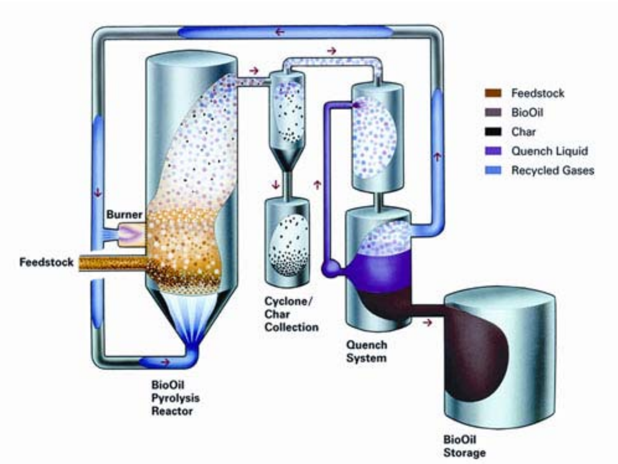
Flash pyrolysis of biomass



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Wood pyrolysis on lab scale - movie

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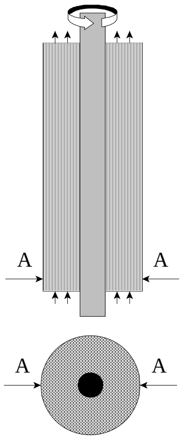
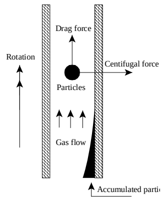
RPS filter integrated in cyclone





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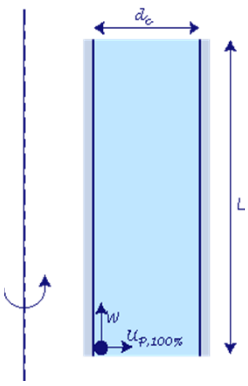
Particle separation



W_p = W_{gas} for small particles = f (flow, D_c)

u_p = f (d_p, Ω, ρ_p η_g, r)

100 % separation if:

$$\frac{L}{W_{gas}} > \frac{d_c}{u_{p100\%}}$$

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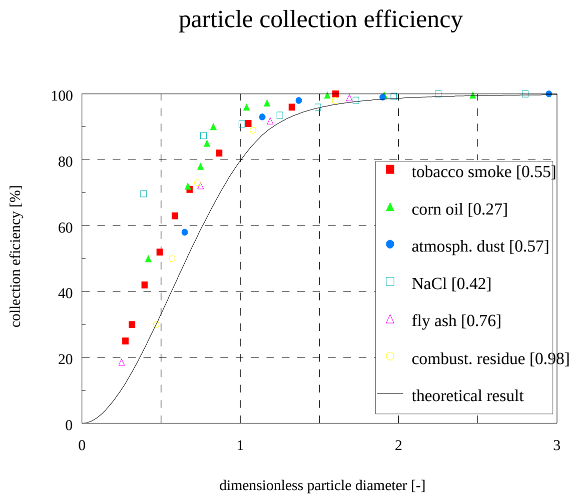

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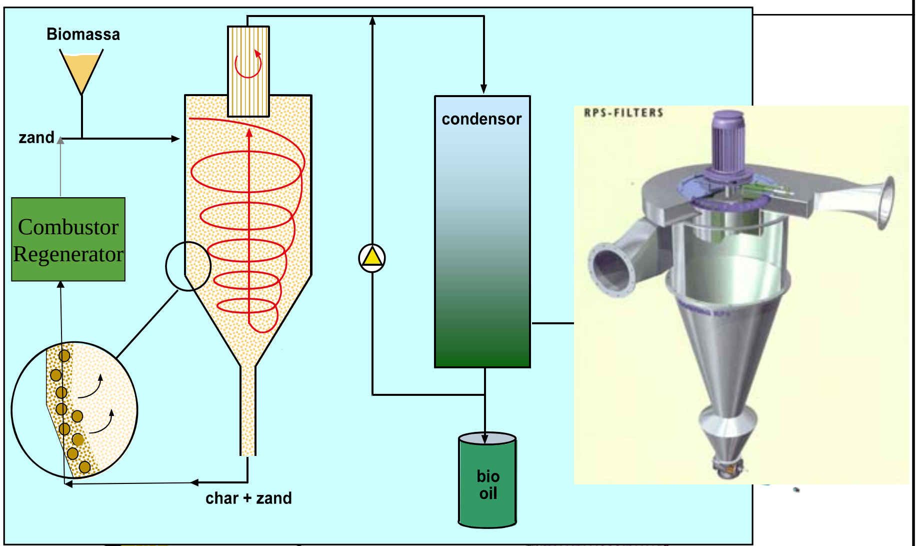
PyRos reactor



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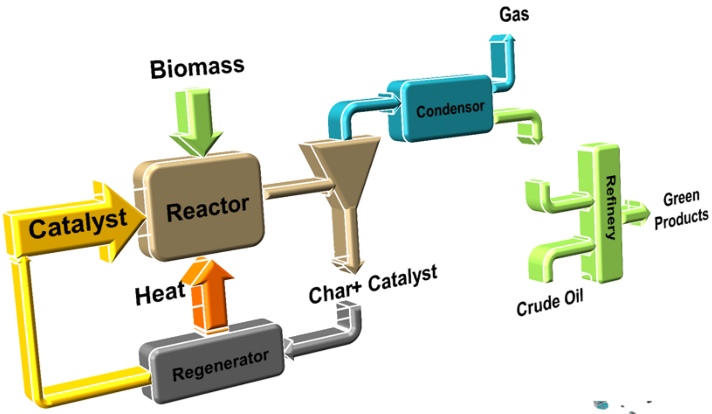
Pyrolysis Oil Quality Improvement by Catalysis



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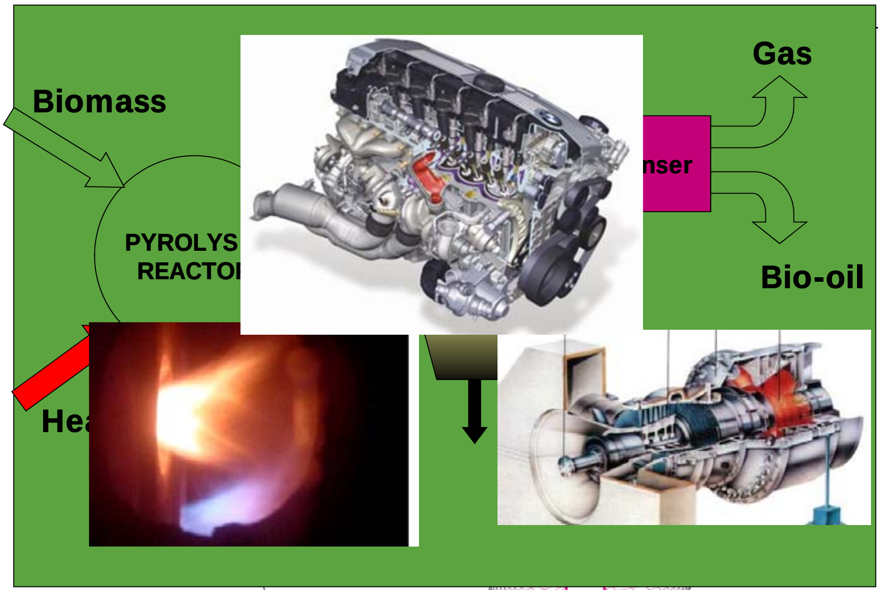
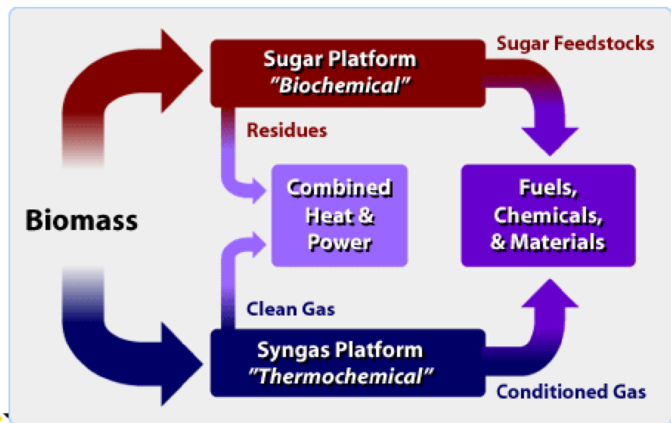
PyRos pilot-plant 30 kg/h biomass feed

Near-future applications for pyrolysis oil

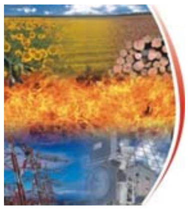


Biorefinery Concept



Biobased economy

In 2030 biobased raw materials can supply at least 30% of the need for raw materials and energy in the Netherlands!



More specific:

- ► 60% of transport fuels
- ► 25% of chemicals and materials
- ► 17% of space heating
- ► 25% of the electricity demand.

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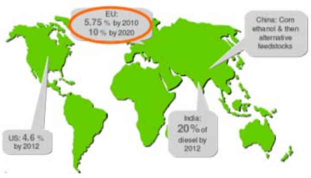
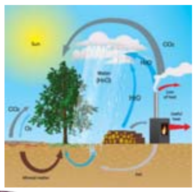
Potentials of Biomass



The End



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