Energy in technical and biological systems
WS 2017-2018

Lecture 7

Gasification of wood

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Car powered with a wood gas (~ 1940 to 1950)

Mercedes-Benz
Typ 170 VG
22 PS (hp)
max. 80 km/h

Fuel consumption:
15 kg Wood per 100 km

Petrol consumption
??? litres per 100 km

Car powered with a wood gas (~ 1940 to 1950)

Lower Heating Value (LHV) of Wood (air-dry):	15.2 MJ/kg = 4.3 kWh/kg
Lower Heating Value (LHV) Petrol:	43.5 MJ/kg = 12.0 kWh/kg
Density of petrol:	ρ = 726 kg/m³

Car powered with a wood gas (~ 1940 to 1950)

Lower Heating Value (LHV) of Wood (air-dry): 15.2 MJ/kg = 4.3 kWh/kg

Lower Heating Value (LHV) Petrol: 43.5 MJ/kg = 12.0 kWh/kg

Density of petrol: ρ = 726 kg/m³

$$15\frac{\text{kg}}{100\,\text{km}} \times 4.3\frac{\text{kWh}}{\text{kg}} = 64.5\frac{\text{kWh}}{100\,\text{km}}$$

$$64.5\frac{\text{kWh}}{100\,\text{km}} / 12.0\frac{\text{kWh}}{\text{kg}} = 5.37\frac{\text{kg}}{100\,\text{km}} = \frac{5.37}{0.726}\frac{\text{liters}}{100\,\text{km}} = 7.5\frac{\text{liters}}{100\,\text{km}}$$

Car powered with a wood gas (~ 1940 to 1950)

Mercedes-Benz
Typ 170 VG
22 PS (hp)
max. 80 km/h

Fuel consumption:
15 kg Wood per 100 km

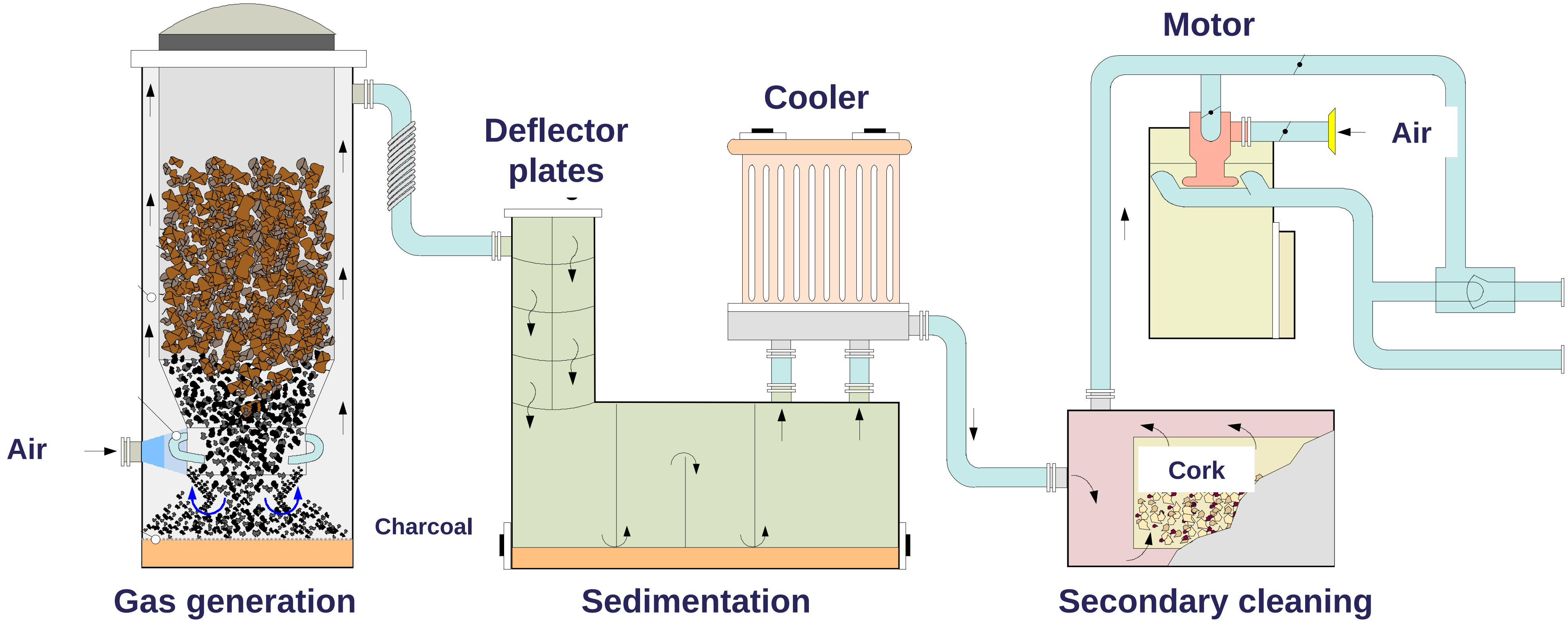
Petrol consumption
7,4 litres per 100 km

Historical review

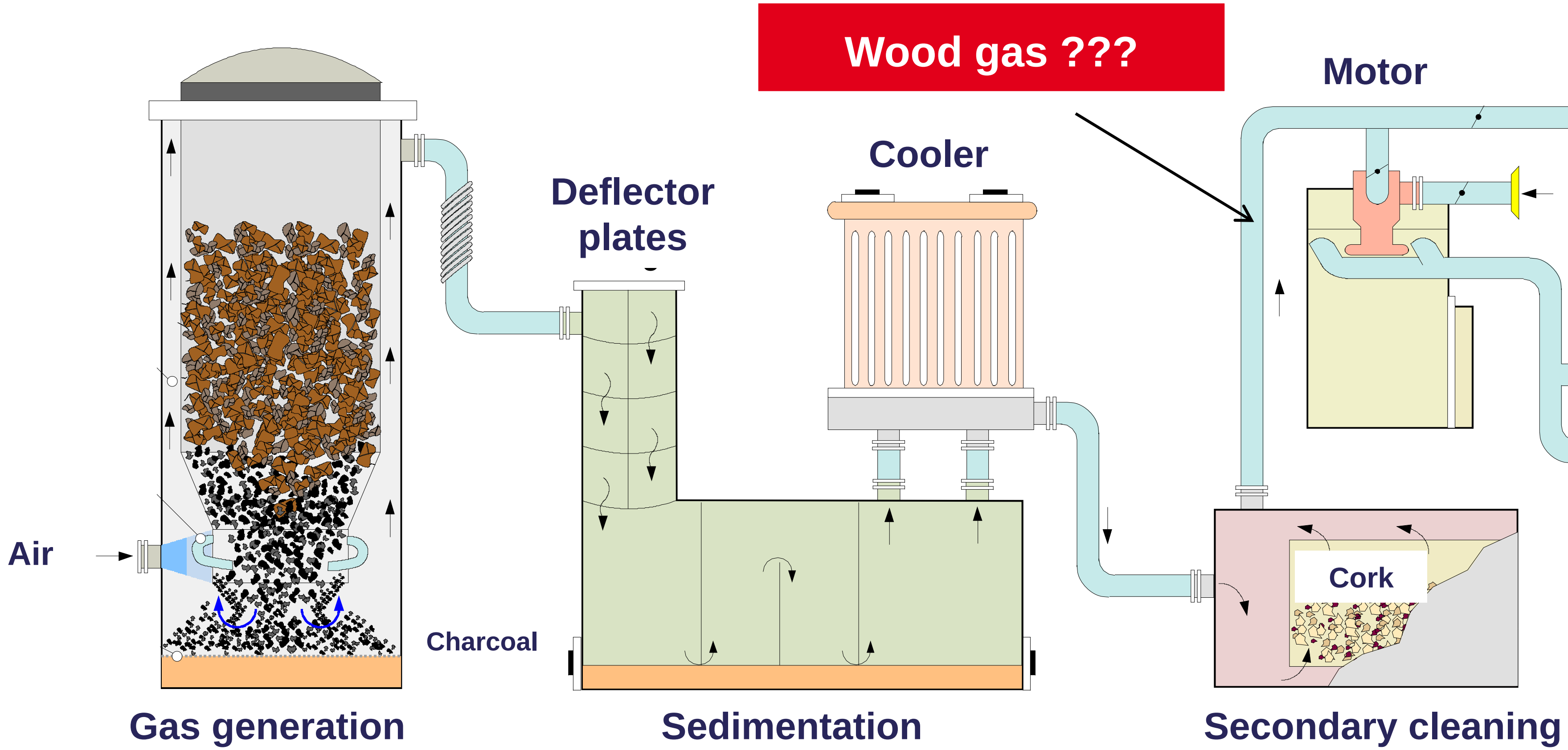
1791	**Philipp Lebon uses wood gas as lighting system at Le Havre lighthouse.**
1921	**Georg Imbert drives from Straßburg to Paris with a wood gas powered car.**
1938	**In France, 8,000 wood gas powered cars are in operation. 1,500 filling stations are available.**
1938 - 45	**More than 500,000 wood gas powered cars are en route in Europe.**
1948	**Imbert-Köln shuts down its production of wood gas powered cars.**
1970	**As a consequence of the first oil crisis, some 20 wood gasifiers with motor and power generator are in operation.**
since 1990	**Increasing interest in wood gasification due to new conditions concerning reimbursement of energy from renewables.**

Car powered with a wood gas (2009)

Wood Gasifier Typ Imbert (1942)



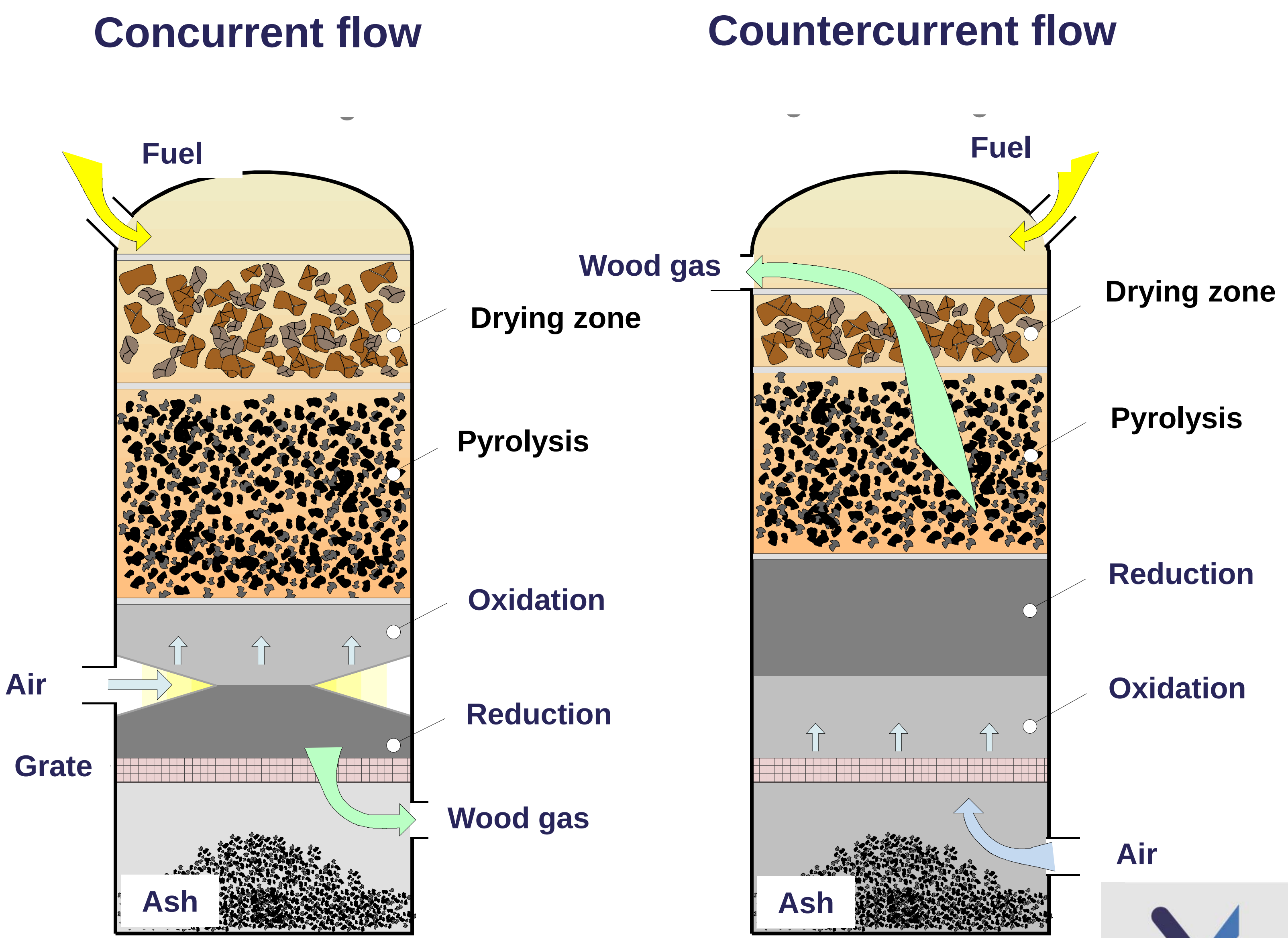
Wood Gasifier Typ Imbert (1942)



Carbon	**47 - 50 w%**
Oxygen	**40 - 45 w%**
Hydrogen	**5 - 7 w%**

Tar is modified pitch produced primarily from the wood and roots of pine by destructive distillation under pyrolysis.

The process of gasification



The reaction mechanism

Pyrolysis

(normalized equations)

$$(CH_mO_n)_{solid} \rightarrow (1-n)C + nCO + \frac{m}{2}H_2$$

$$(CH_mO_n)_{solid} \rightarrow (1-n-\frac{m}{8})C + nCO + \frac{m}{4}H_2 + \frac{m}{8}CH_4$$

$$\{\, 3(C_6H_{10}O_5)_{solid} \rightarrow 7C + 2CO + C_6H_8O8 + H_2O + 2CO_2 + CH_4 + H_2 \,\}$$

Oxidation

$$C + O_2 \rightarrow CO_2$$

$$C_xH_y + \left(x + \tfrac{1}{4}y\right) O_2 \rightarrow xCO_2 + \tfrac{1}{2}yH_2O$$

Boudouard reaction

$$C + CO_2 \rightarrow 2\,CO$$

Watergas shift reaction (WGS)

$$C + H_2O \rightarrow CO + H_2$$

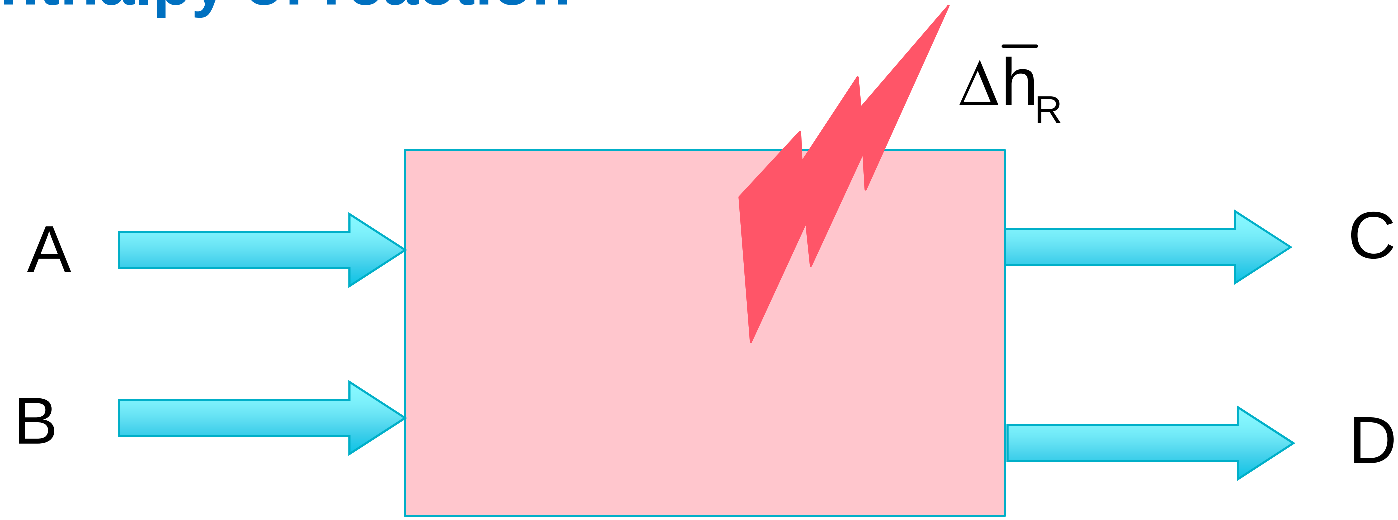
$$C_xH_y + xH_2O \rightarrow xCO + \left(x + \tfrac{1}{2}y\right) H_2$$

Methane reaction

$$C + 2\,H_2 \rightarrow CH_4$$

Reduction

Enthalpy of reaction



Chemical equation

$$\nu_A\, A + \nu_B\, B \rightarrow \nu_C\, C + \nu_D\, D$$

Enthalpy of reaction

Products

Reactants

$$\Delta \bar{h}_R = \sum \nu_{i,P} \cdot \bar{h}_{F,i,P} - \sum \nu_{i,R} \cdot \bar{h}_{F,i,R} \qquad \left[\frac{J}{mol}\right]$$

Stoichiometric coefficients

Enthalpy of formation (see respective tables)

Enthalpy of formation

$\left[\frac{J}{mol}\right]$

Reduction

$$C + CO_2 \rightarrow 2\,CO$$

$$C + H_2O \rightarrow CO + H_2$$

$$C + 2\,H_2 \rightarrow CH_4$$

Tabelle 10.6. Molmasse M, Gaskonstante R sowie molare Bildungsenthalpie $\mathfrak{H}^0$ und molare absolute Entropie $\mathfrak{S}^0$ im Standardzustand[1] ($T_0 = 298{,}15$ K, $p_0 = 1$ atm)

Stoff	M kg/kmol	R J/kg K	$\mathfrak{H}^0$ kJ/mol $\overline{h}_F$	$\mathfrak{S}^0$ J/mol K	Formart im Standard-zustand
He	4,0026	2077,2	0	126,04	g
Ne	20,183	411,9	0	146,22	g
Ar	39,948	208,13	0	154,73	g
Kr	83,80	99,22	0	163,97	g
Xe	131,30	63,32	0	169,57	g
H_2	2,0159	4124,4	0	130,57	g
O_2	31,9988	259,83	0	205,03	g
H_2O	18,0153	461,51	−285,83	69,91	fl
			−241,82	188,72	g
F_2	37,9968	218,82	0	202,7	g
Cl_2	70,906	117,26	0	222,96	g
HCl	36,461	228,03	−93,31	186,80	g
S	32,064	259,30	0	31,8	f., rhomb.
SO_2	64,0628	129,78	−296,83	248,1	g
H_2S	34,0799	243,96	−20,6	205,7	g
N_2	28,0134	296,80	0	191,5	g
Luft	28,964	287,06	—	198,5	g
NH_3	17,0306	488,20	−46,11	192,3	g
NO_2	46,0055	180,72	33,2	240,0	g
N_2O	44,0128	188,91	82,05	219,7	g
C	12,0112	692,21	0	5,740	f., Graphit
			1,895	2,377	f., Diamant
CO	28,0106	296,83	−110,52	197,56	g
CO_2	44,0100	188,92	−393,51	213,6	g
CH_4	16,0430	518,25	−74,81	186,15	g
CH_3OH	32,0424	259,48	−238,7	128	fl
CCl_4	153,823	54,05	−135,4	216,4	fl
$CHCl_3$	119,378	69,65	−134,5	202	fl
CF_2Cl_2	120,914	68,76	−477	300,7	g
$CFCl_3$	137,369	60,53	−301,3	255,4	fl
C_2H_2	26,0382	319,31	226,7	200,8	g
C_2H_4	28,0542	296,37	52,26	219,5	g
C_2H_6	30,0701	276,50	−84,68	229,5	g
C_2H_5OH	46,0695	180,47	−277,7	160,7	fl
C_3H_8	44,097	188,55	−103,9	269,9	g
n-C_4H_{10}	58,124	143,04	−124,7	310,0	g
n-C_5H_{12}	72,151	115,23	−173,1	262,7	fl
n-C_6H_{14}	86,179	96,48	−198,8	296,0	fl
C_6H_6	78,115	106,44	−49,0	173,2	fl
n-C_7H_{16}	100,206	82,97	−224,4	328,0	fl
n-C_8H_{18}	114,233	72,78	−250,0	361,2	fl

H.D. Baehr
Thermodynamik

Endothermic and exothermic reactions

Boudouard reaction

Standard reference state

$$C + CO_2 \rightarrow 2\,CO \qquad \Delta\bar{h}_R^0 = 2 \cdot \left(-110.52\,\frac{kJ}{mol}\right) - \left(-393.51\,\frac{kJ}{mol}\right) = 172.47\,\frac{kJ}{mol}$$

endothermic

Heat demand !!!

Watergas shift reaction (WGS)

$$C + H_2O \rightarrow CO + H_2 \qquad \Delta\bar{h}_R^0 = -110.52\,\frac{kJ}{mol} - \left(-241.83\,\frac{kJ}{mol}\right) = 131.31\,\frac{kJ}{mol}$$

endothermic

Methane reaction

$$C + 2\,H_2 \rightarrow CH_4 \qquad \Delta\bar{h}_R^0 = -74.81\,\frac{kJ}{mol}$$

exothermic

Kinetics of equilibrium reactions

Equilibrium reaction

$$\nu_A\,A + \nu_B\,B \underset{k_2}{\overset{k_1}{\rightleftarrows}} \nu_C\,C + \nu_D\,D$$

Rate constant

$$k_1, k_2$$

Reaction rate

$$r_A = k_1 \cdot c_A^{\nu_A} \cdot c_B^{\nu_B} - k_2 \cdot c_C^{\nu_C} \cdot c_D^{\nu_D} = 0$$

$c \triangleq$ concentration

The reaction rate equals zero at equilibrium conditions. $r_A = 0$

Equilibrium constant

$$K = \frac{k_1}{k_2} = \frac{c_C^{\nu_C} \cdot c_D^{\nu_D}}{c_A^{\nu_A} \cdot c_B^{\nu_B}} = f(T)$$

van´t Hoff principle

$$\frac{d(\ln K)}{dT} = \frac{\Delta \bar{h}_R^0}{R \cdot T^2}$$

$R \triangleq$ General gas constant

Temperature dependency of equilibrium constant

$$K = K_\infty \cdot e^{-\frac{\Delta \bar{h}_R^0}{R \cdot T}}$$

Temperature dependency of equilibrium constant

$$K = K_{\infty} \cdot e^{-\frac{\Delta \bar{h}_R^0}{R \cdot T}}$$

Boudouard reaction

$$C + CO_2 \rightarrow 2\,CO$$ **endothermic**

Watergas shift reaction

$$C + H_2O \rightarrow CO + H_2$$ **endothermic**

Methane reaction

$$C + 2\,H_2 \rightarrow CH_4$$ **exothermic**

Temperature dependency of equilibrium constant

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Boudouard reaction

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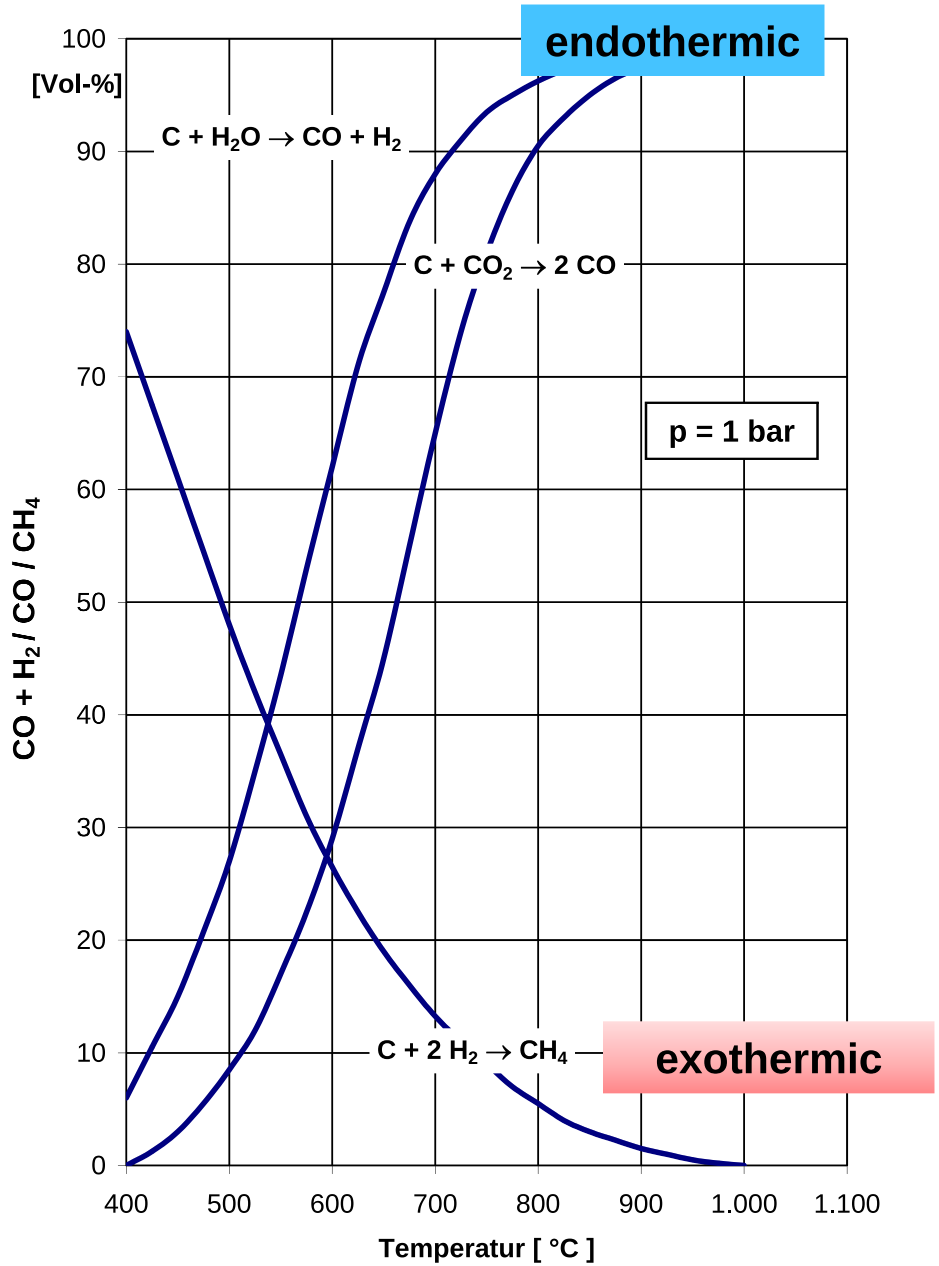


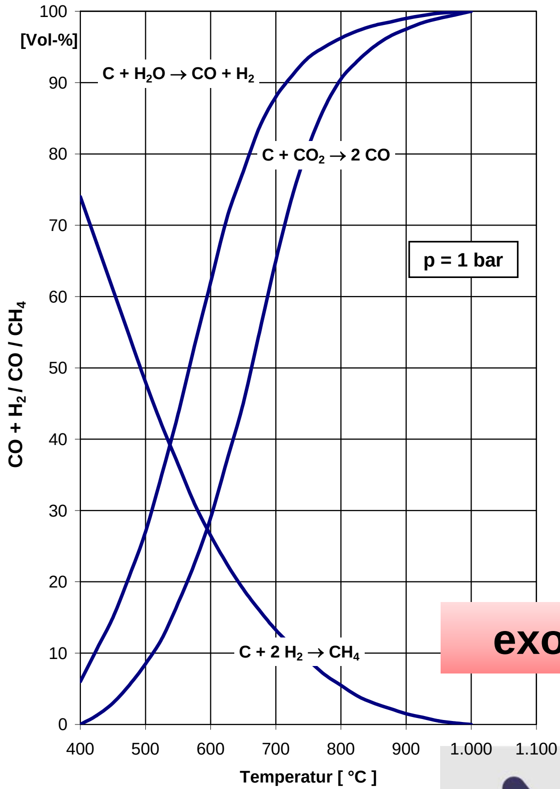
Main difficulty: How to get rid of the tar ?

Required conditions for safe operation of a gas motor:

Concentration of dust: < 50 mg/Nm³ (most preferably < 5 mg/Nm³)

Concentration of tar: < 100 mg/Nm³ (most preferably < 50 mg/Nm³)

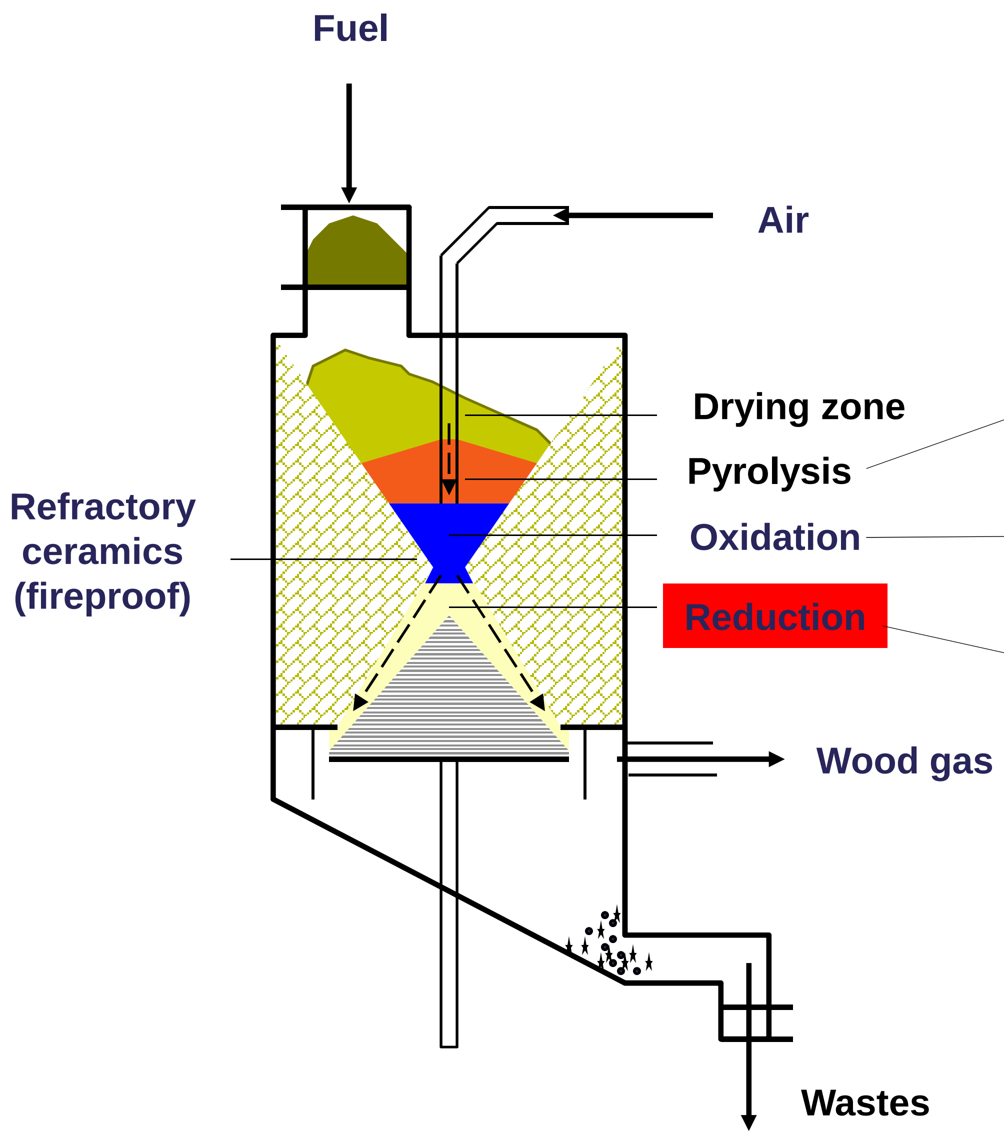
Tar **is modified pitch produced primarily from the wood and roots of pine by destructive distillation under pyrolysis.**



$$C + 2\,H_2 \rightarrow CH_4$$

exothermic

Principle of HTV - High Temperature Gasification Plant for used timber at Espenhain



$$(CH_mO_n)_{solid} \rightarrow (1-n)C + nCO + \frac{m}{2}H_2$$

$$C + O_2 \rightarrow CO_2$$

exothermic

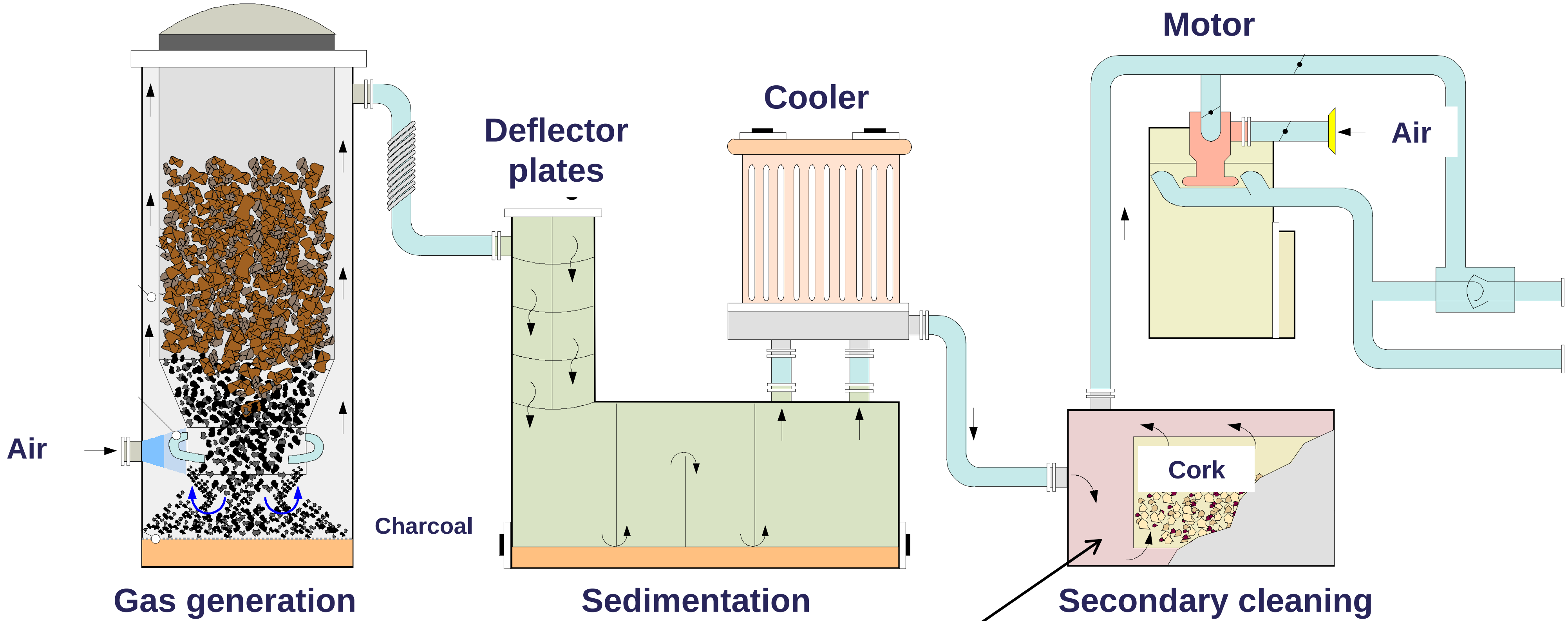
$$C + CO_2 \rightarrow 2\,CO$$

$$C + H_2O \rightarrow CO + H_2$$

$> 1{,}500°C$

Source: Hochschule für Technik, Wirtschaft und Kultur Leipzig (FH)
Fachbereich Maschinen- und Energietechnik / Prof. Dr.-Ing. Michael Kubessa

Wood Gasifier Typ Imbert (1942)



To get rid of the tar !!

HTV - High Temperature Gasification Plant Espenhain

Edge length
min 20 x 20 mm
max 160 x 160 mm

Fuel, i.e. wood

Reactor

Wastes

Source: Hochschule für Technik, Wirtschaft und Kultur Leipzig (FH)
Fachbereich Maschinen- und Energietechnik / Prof. Dr.-Ing. Michael Kubessa

HTV - High Temperature Gasification Plant Espenhain

Source: Hochschule für Technik, Wirtschaft und Kultur Leipzig (FH)
Fachbereich Maschinen- und Energietechnik / Prof. Dr.-Ing. Michael Kubessa

Conclusion

Direct thermal conversion, i.e. burning of wood can be considered as state-of-the-art technology. Former difficulties concerning both stable operation and odour nuisances are eliminated.

Quality of wooden chips !!!

Gasification is technically feasible, however, it cannot be considered as a mature and robust technology.

Why?

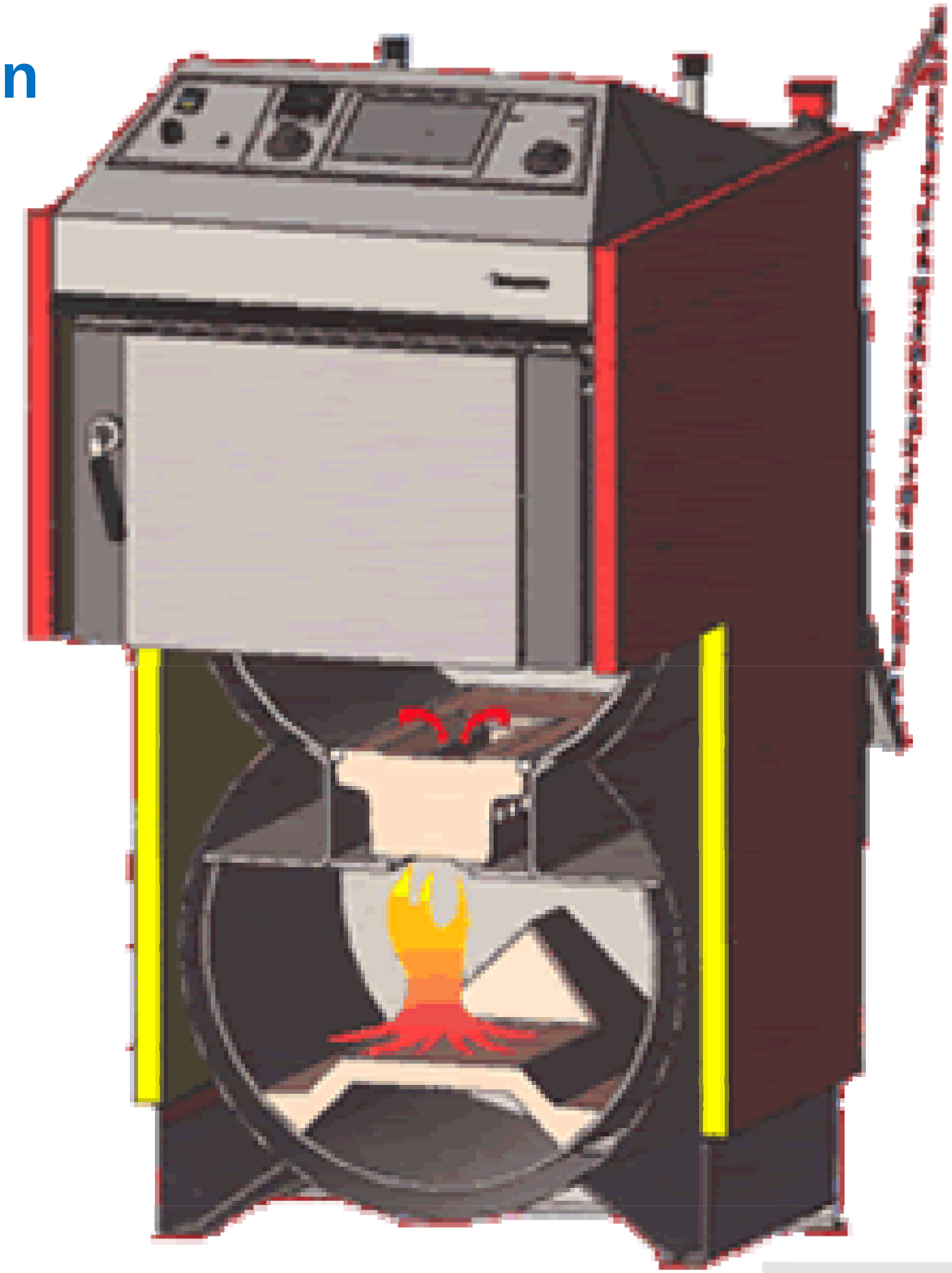
See Lecture „Gasification“

How to get rid of the tar !!

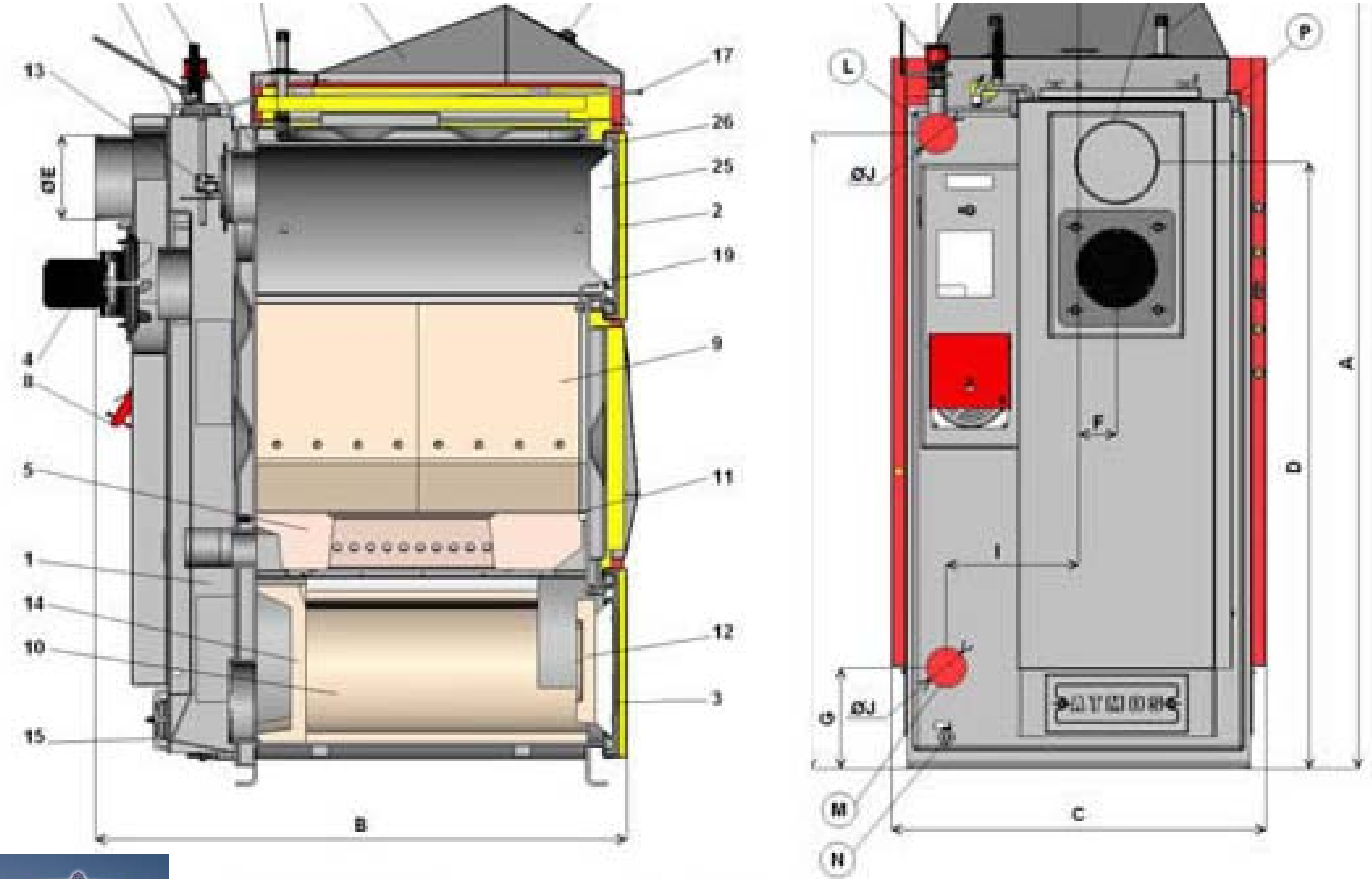
Co-incineration in existing coal-fired power plant can be considered as a proven technology with best electrical efficiencies.

Gasifier as domestic heating system

Structure and operation



Schematic drawing



List of components

1.	Boiler drum	14.	Fireproof and heat-resisting fitting - GS - rear face of round space
2.	Filling door	15	Cleaning cover
3.	Ash pan door	16	Orifice plate
4.	Fan - pressure, exhaust (S)	17	Firing safety valve pull rod
5.	Fireproof and heat-resisting fitting - nozzle	18	Thermometer
6.	Control panel	19	Furnace orifice plate
7.	Safety thermostat	20	Switch
8.	Regulating safety valve	22	Power regulator - Honeywell FR124
9.	Fireproof and heat-resisting fitting - furnace side - GS	23	Cooling loop
10.	Fireproof and heat-resisting fitting - GS - round space L+P	24	Fan thermostat
11.	Sealing - nozzles	25	V. Door panel - Sibrall
12.	Fireproof and heat-resisting fitting - half-moon	26	Door sealing - cord 18 x 18
13.	Firing safety valve	27	Waste gas thermostat