Gas Engies

2023

Gas Engines

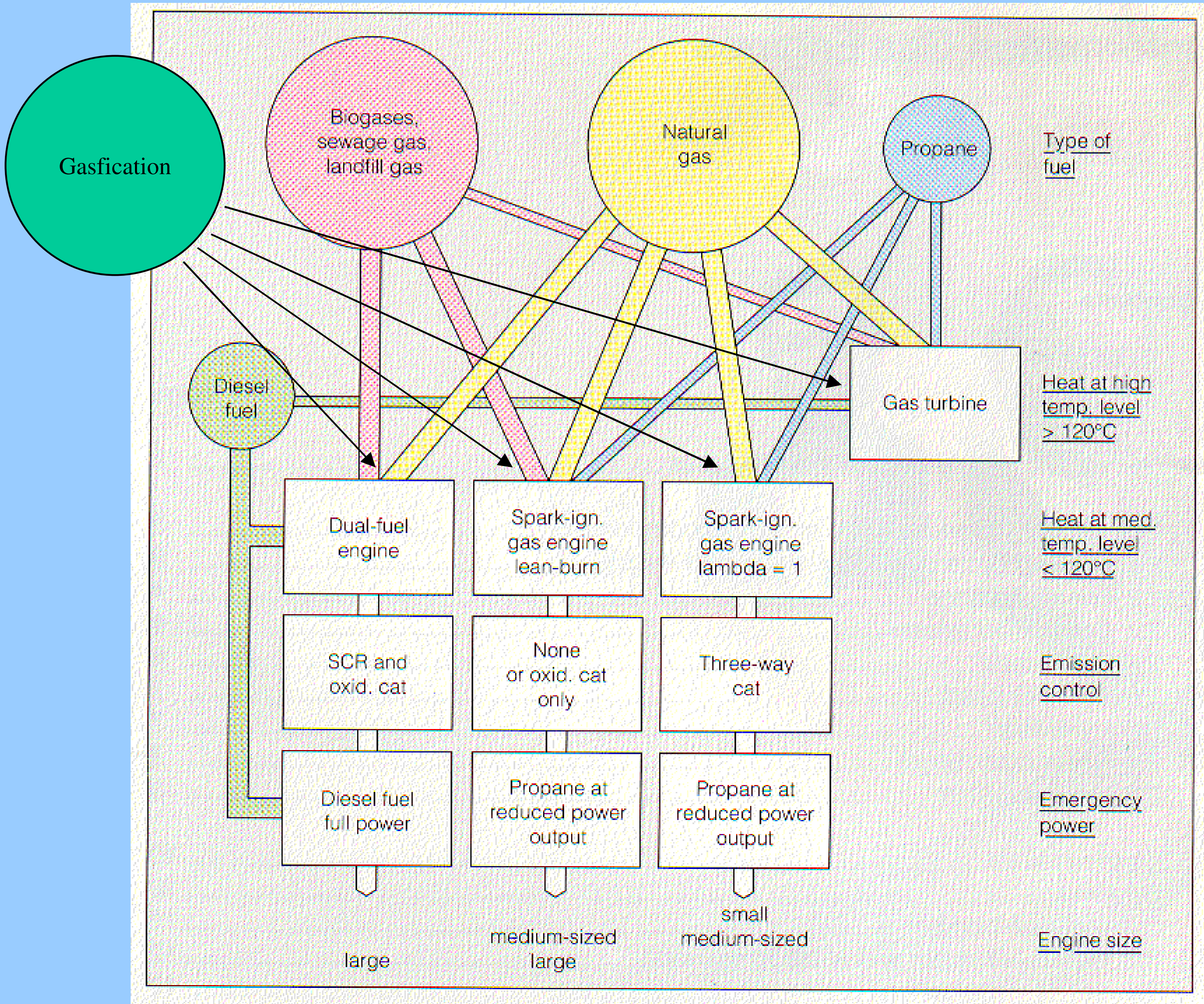
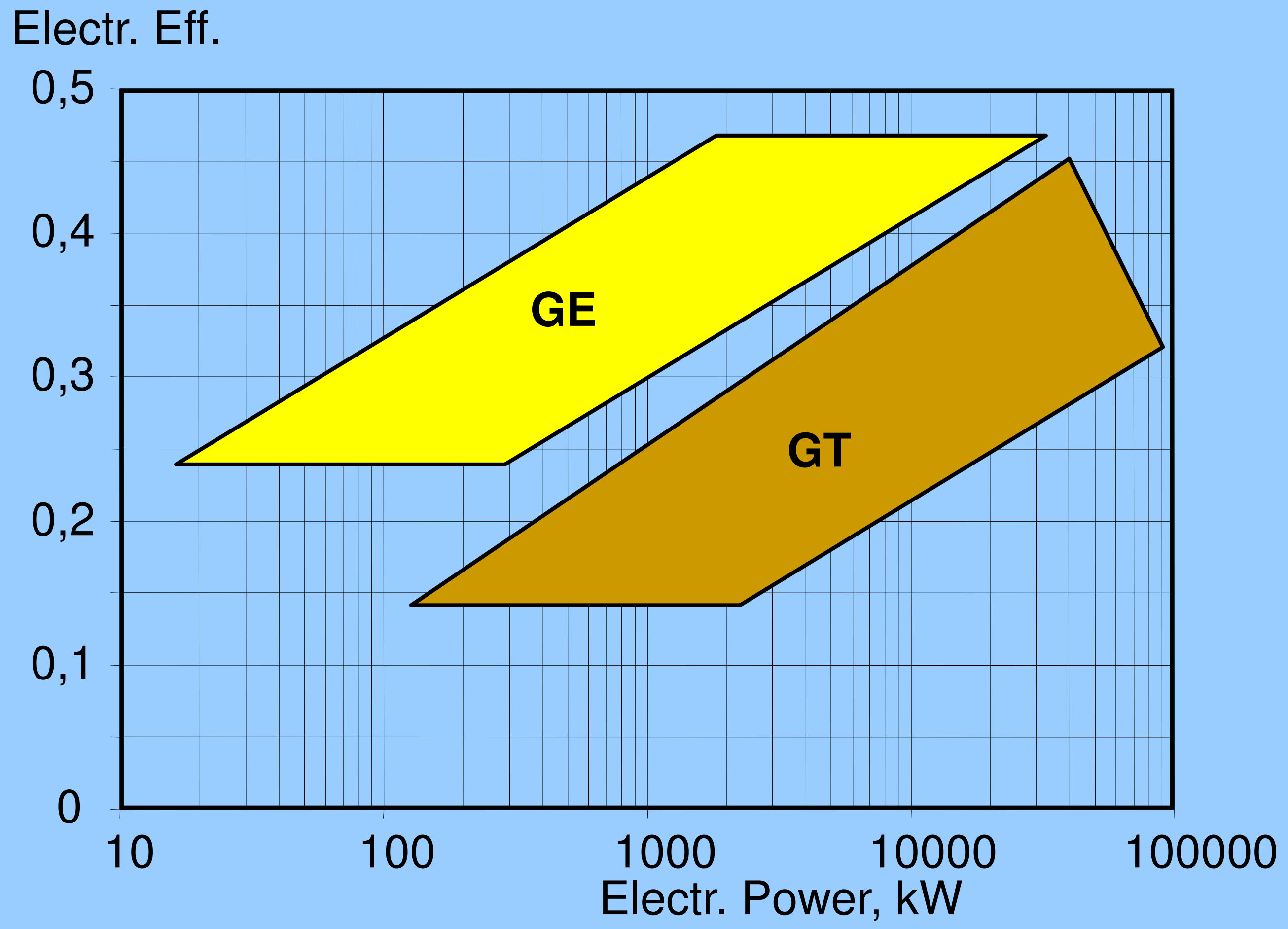


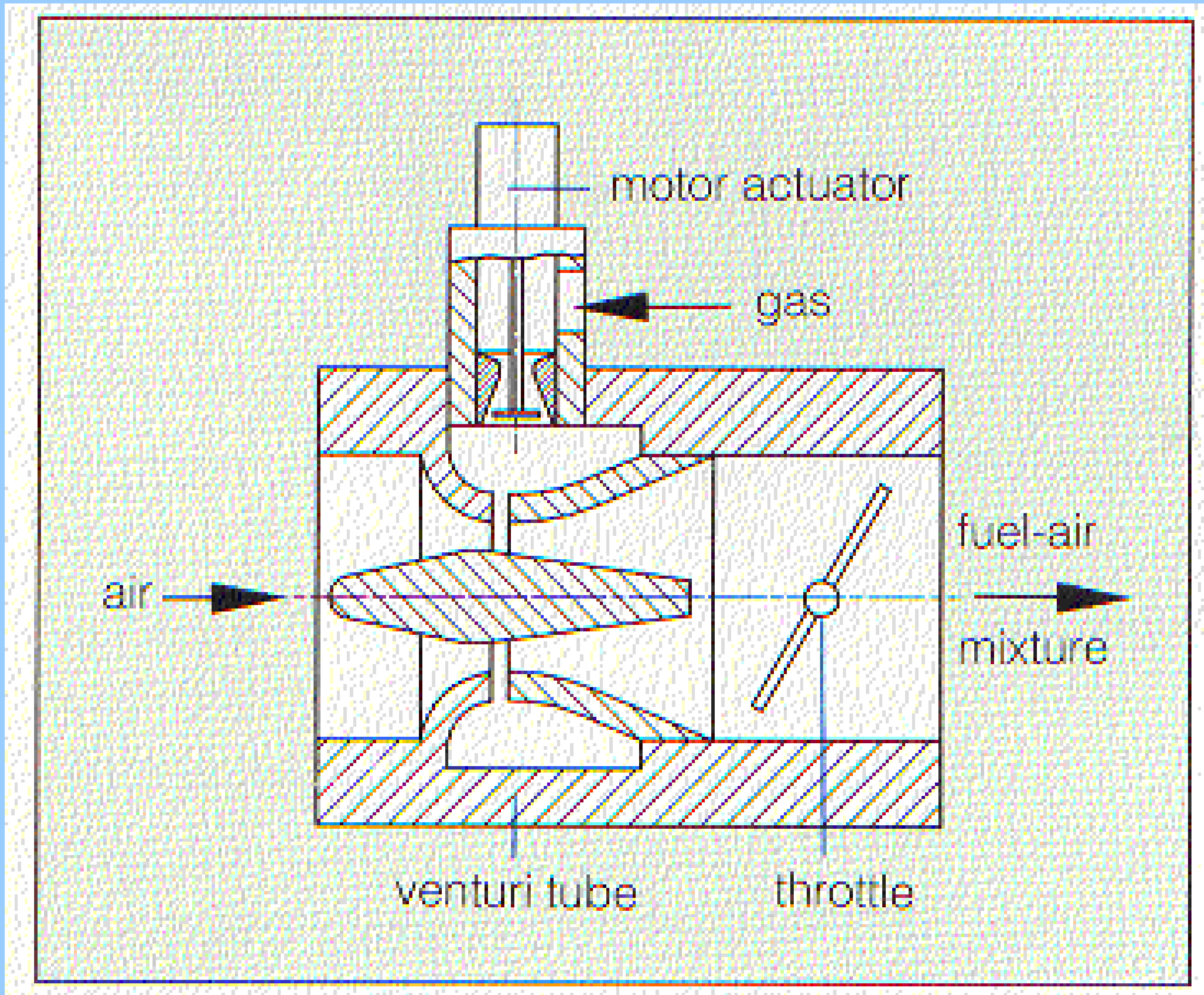
Fig. 1 Chart – Gas engine options

Source: DEUTZ

Gas Engines / Gas Turbine

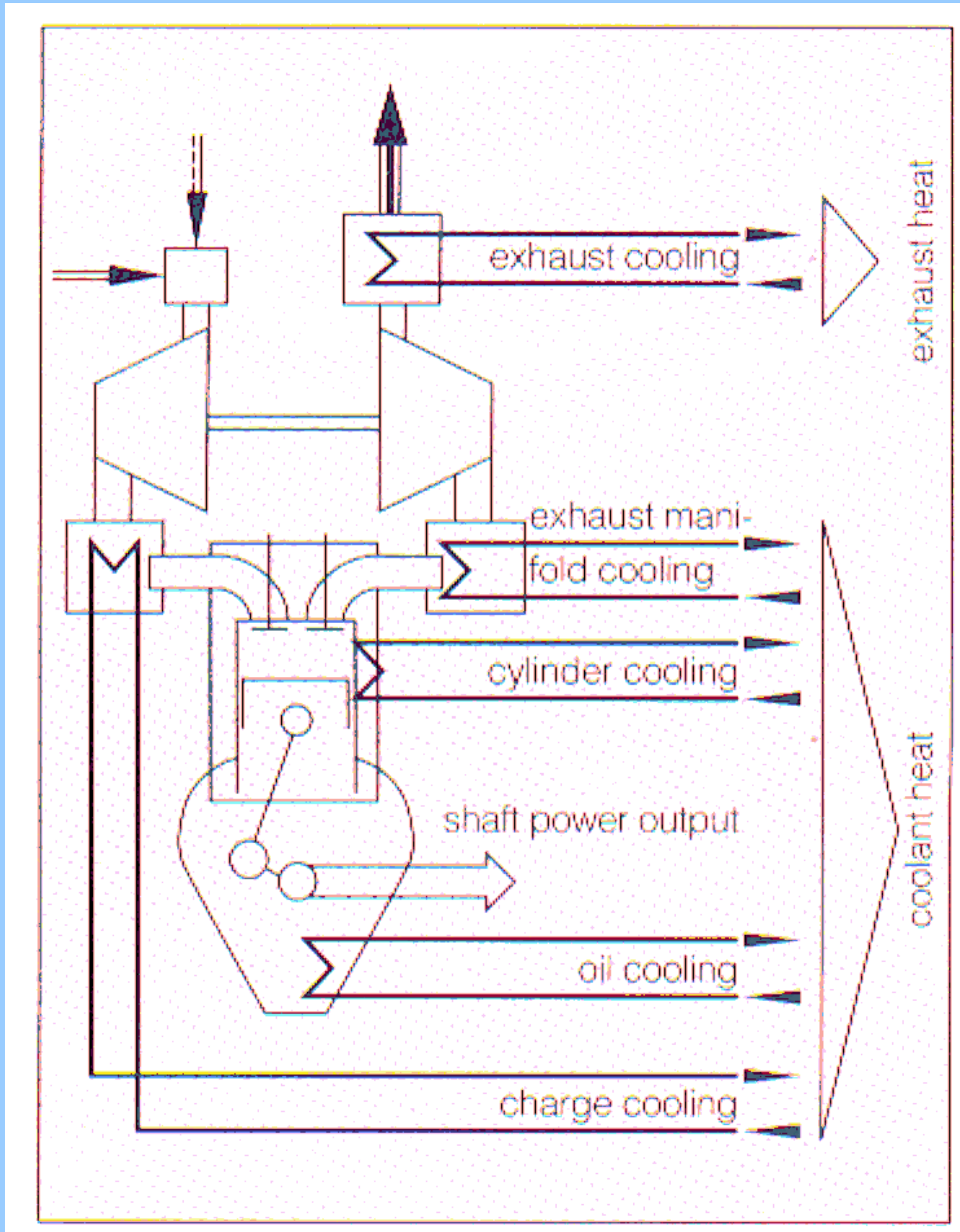


Fuel (gas) – Air mixer



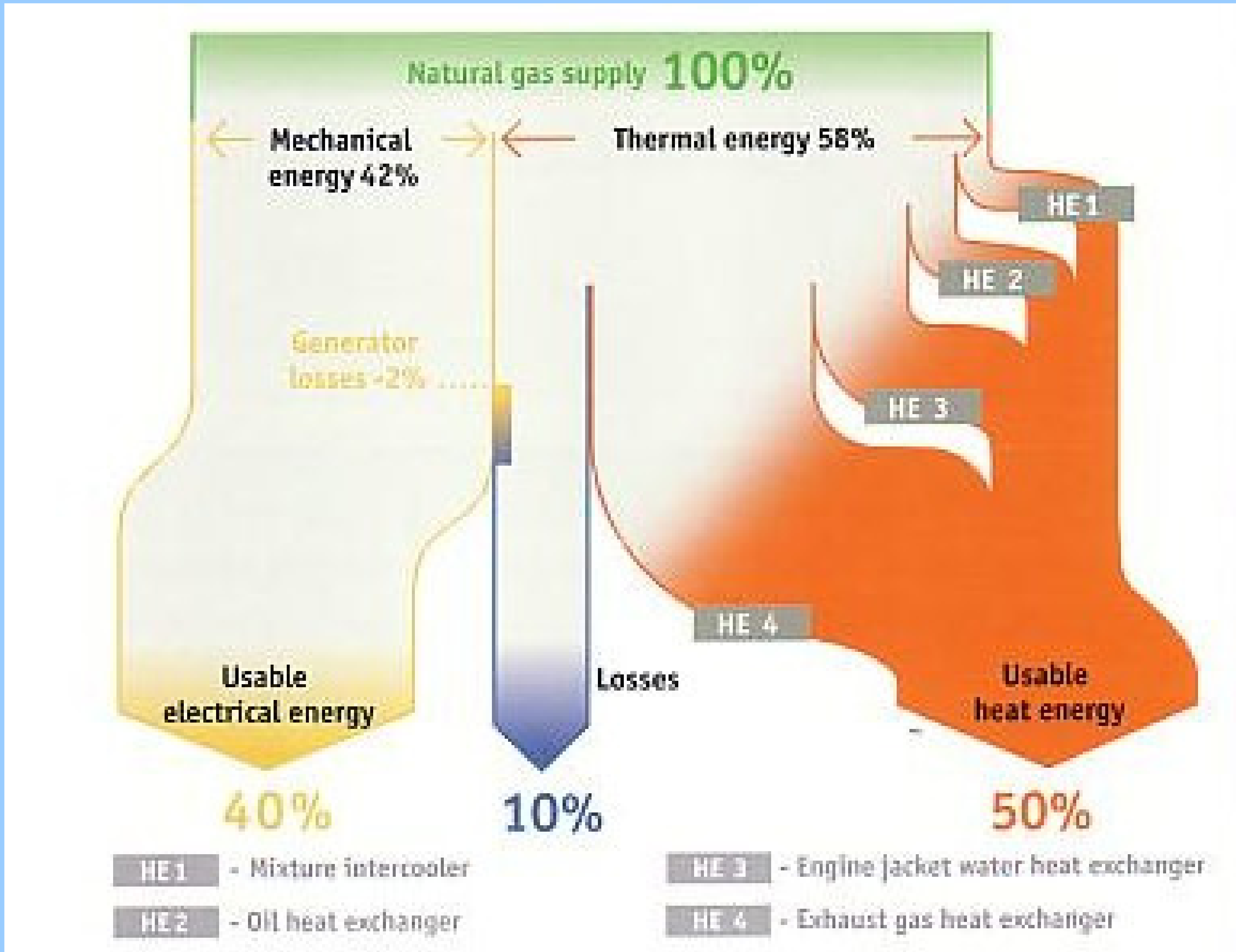
Source: DEUTZ

Heat Flows of Gas Engines



Forrás:DEUTZ

Heat Balance-1



Source: Jenbacher

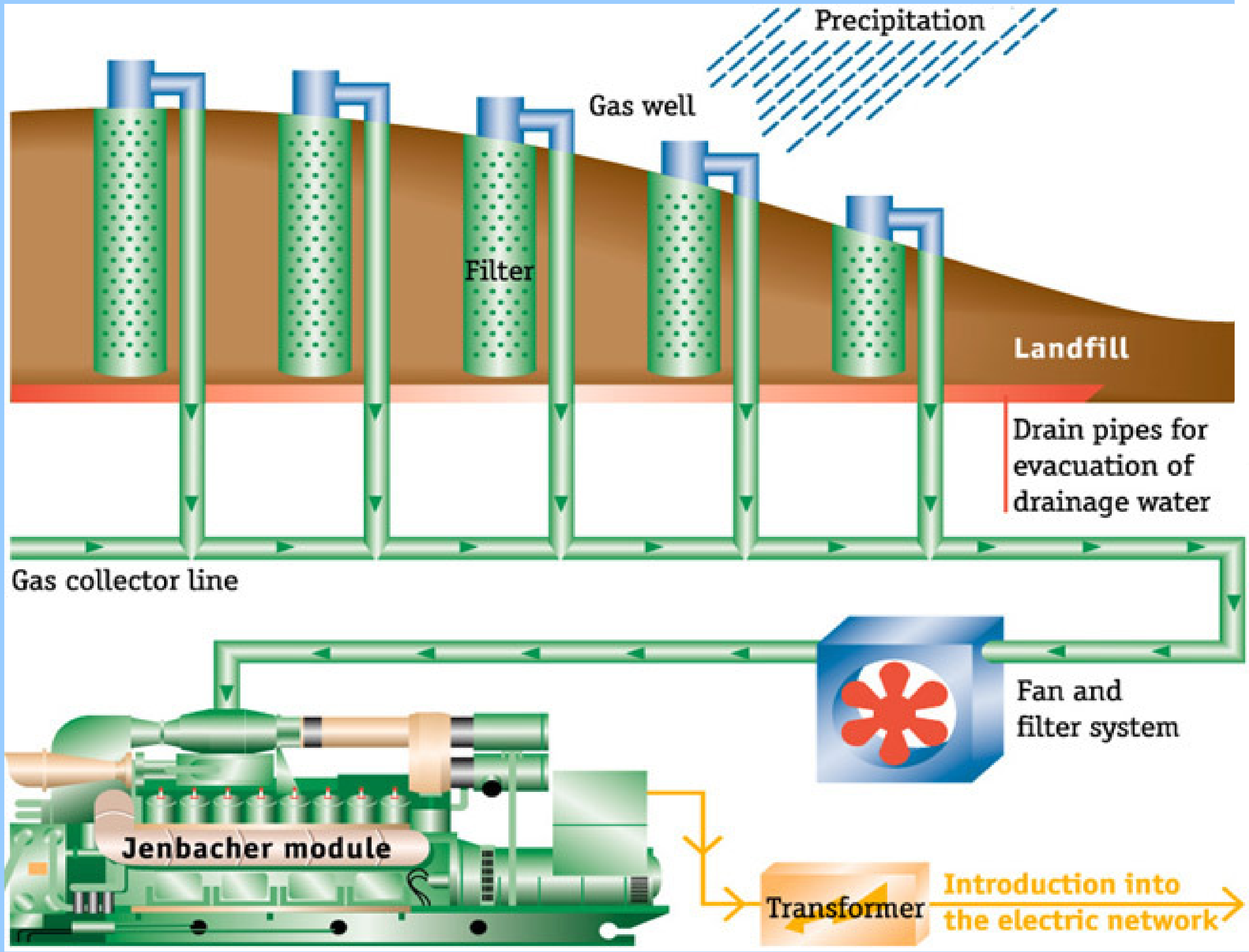
Fuels

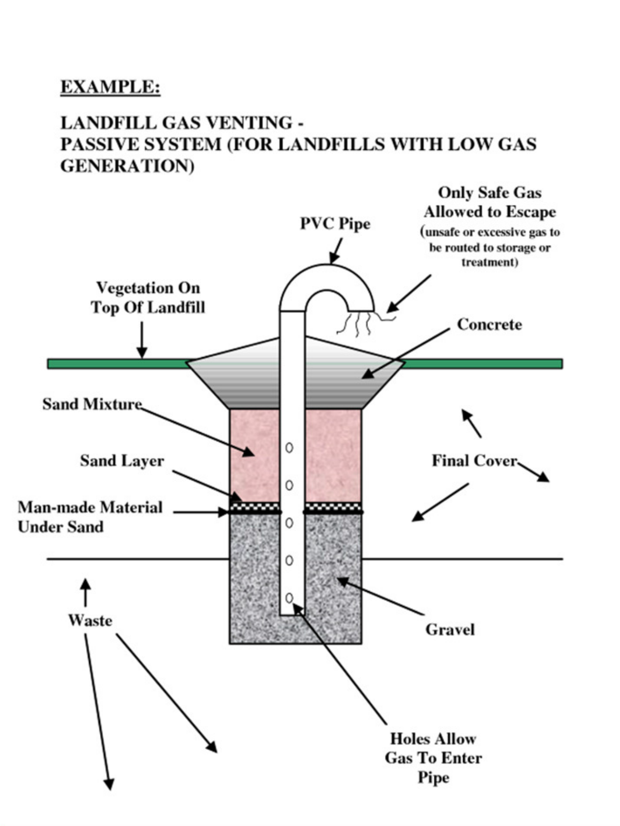
- Fossil:
  - NG (CNG or LNG)
  - LPG (Liquefied Petroleum Gas)
- Renewabel gases:
  - PtG (P2G, electrolysis to produce hydrogen)
  - power-to-methane: power-to-hydrogen system+ carbon dioxide to produce methane using Sabatier reaction or biological methanation,
  - Biogas is produced by anaerobic digestion (Prof. Lezsovits), Landfill Gas, Sewage Gas,
  - Pyrolysis (Prof. Lezsovits),
  - Gasification (Prof. Lezsovits).

Different biogases:

\	*Biogas*	*Landfill Gas I*	*Landfill Gas II*	*Sewage Gas*
CH_4	**58,70%**	**35,80%**	**50,60%**	**61,20%**
CO_2	**39,70%**	**32,90%**	**37,10%**	**38,50%**
O_2	**1,60%**	**1,80%**	**2,60%**	**-**
Other:	**-**	**$H_2O + N_2$**	**N_2**	**N_2**
-	**-**	**29,50%**	**9,70%**	**0,20%**
H_2S	**25 ppm**	**-**	**-**	**1350 ppm**

Landfill Gas





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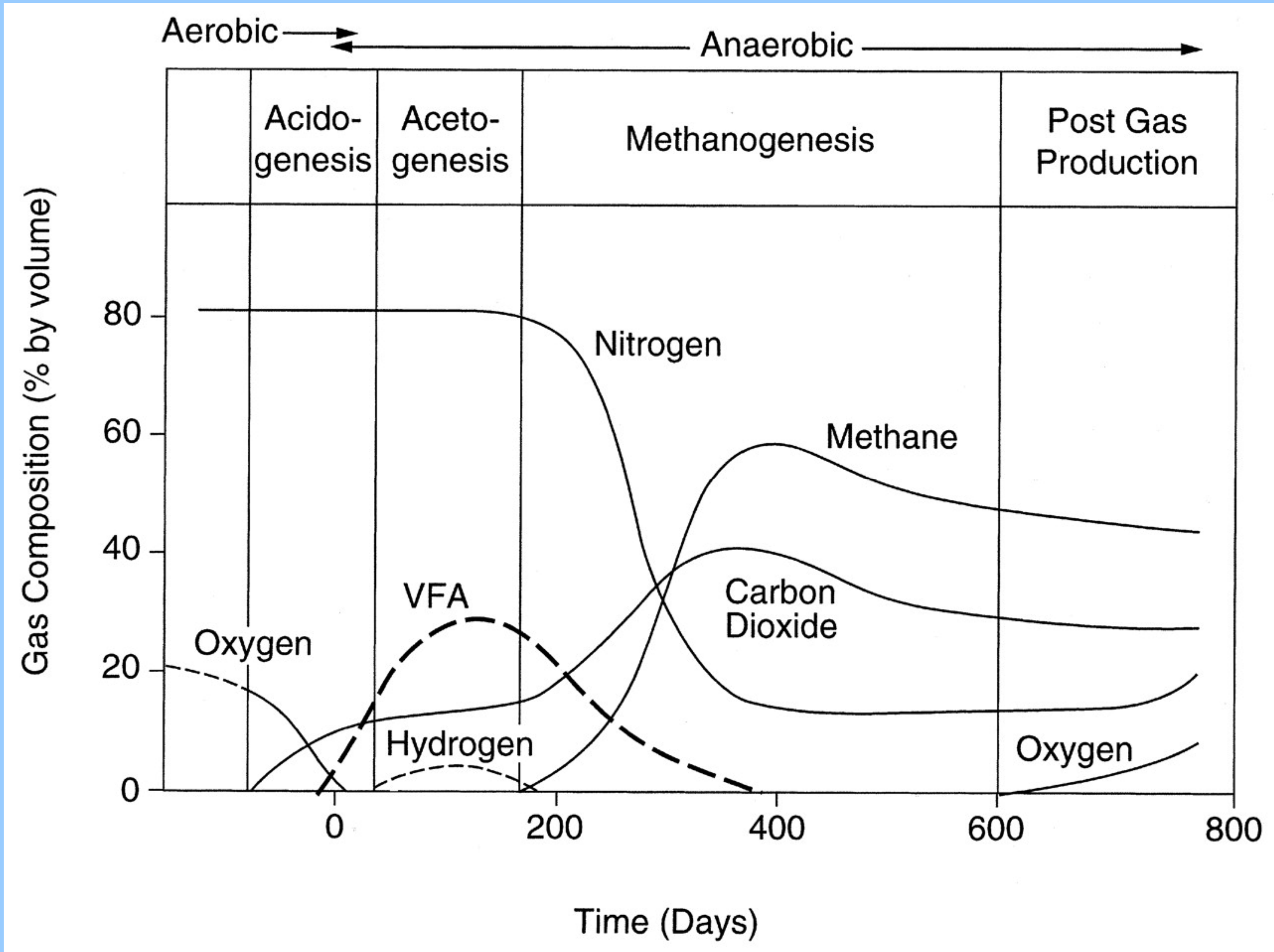
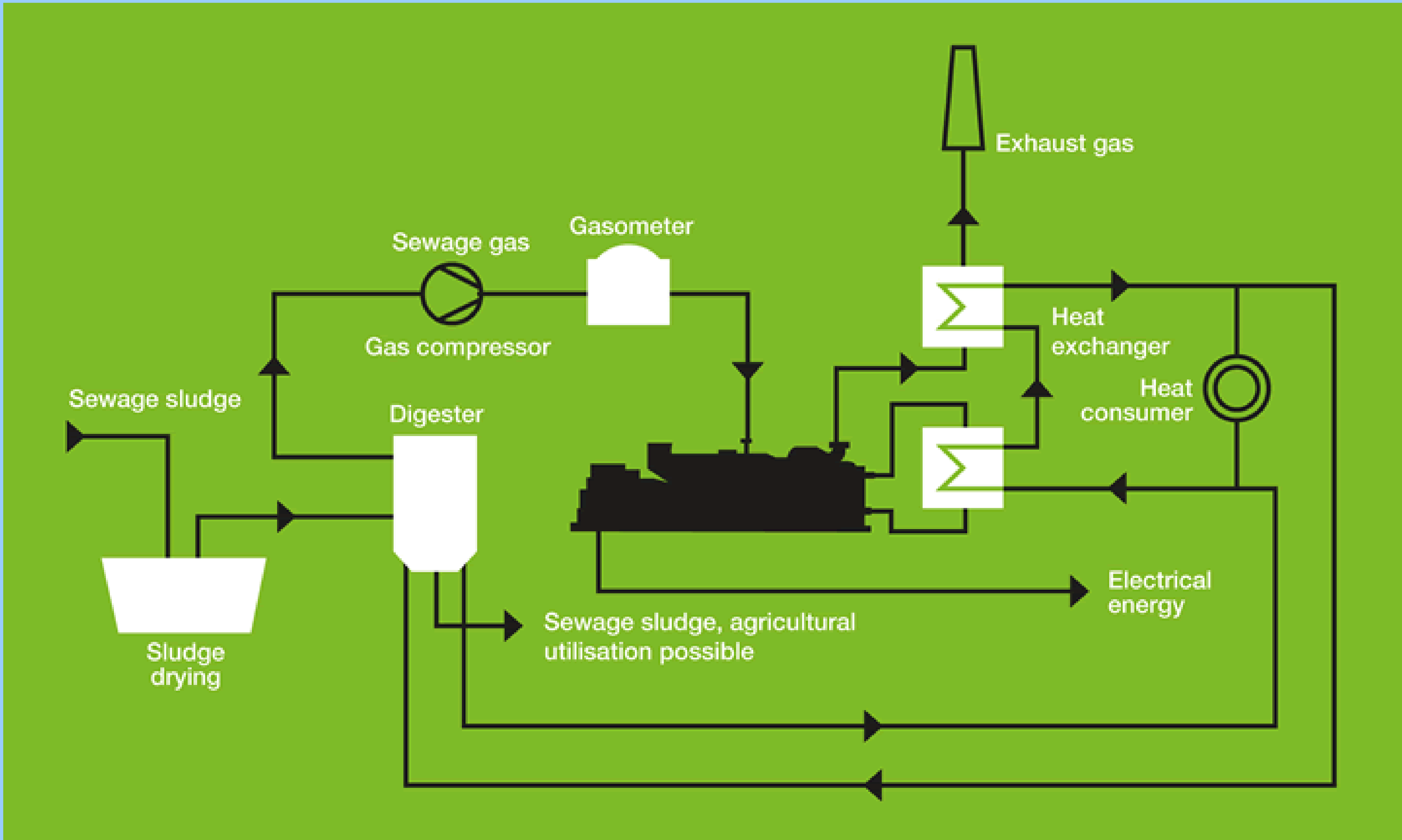
Landfill Gas



DAVID A. C. MANNING:Carbonates and oxalates in sediments and landfill: monitors of death and decay in natural and artificial systems

Sewage Gas



www.clarke-energy.com

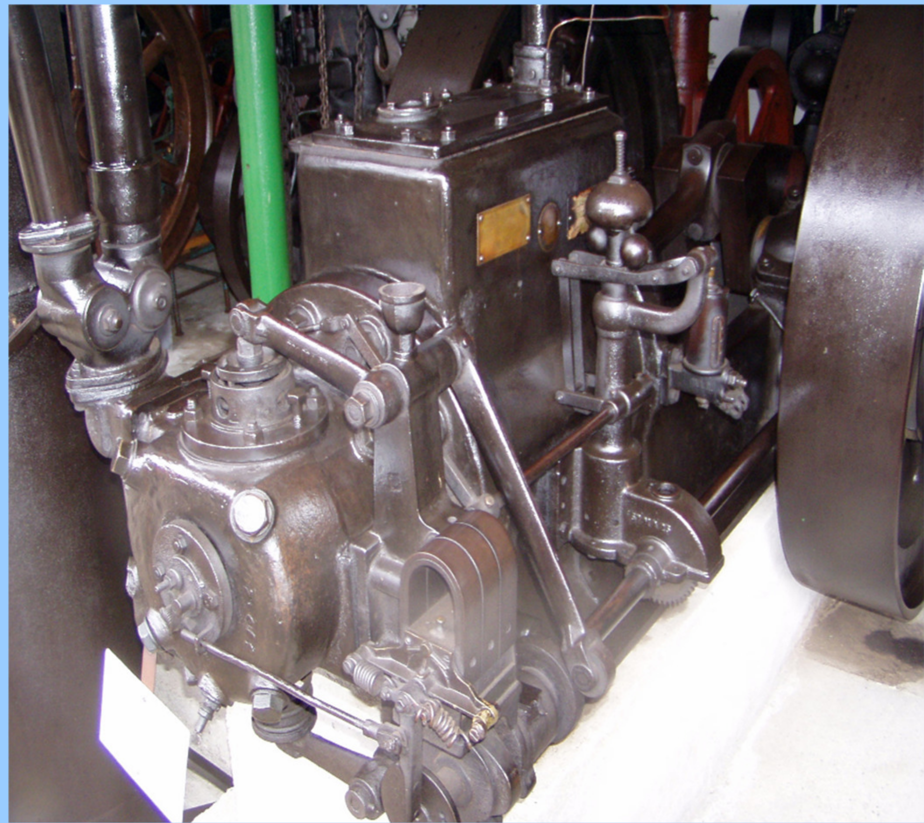
Gasification

- The *pyrolysis* process occurs at around 200-300°C. Volatiles are released and char is produced,
- The *gasification* process occurs as the char reacts

$$C + H_2O \rightarrow H_2 + CO$$
$$CO + H_2O \leftrightarrow CO_2 + H_2$$

(water gas shift reaction)

Gasifier



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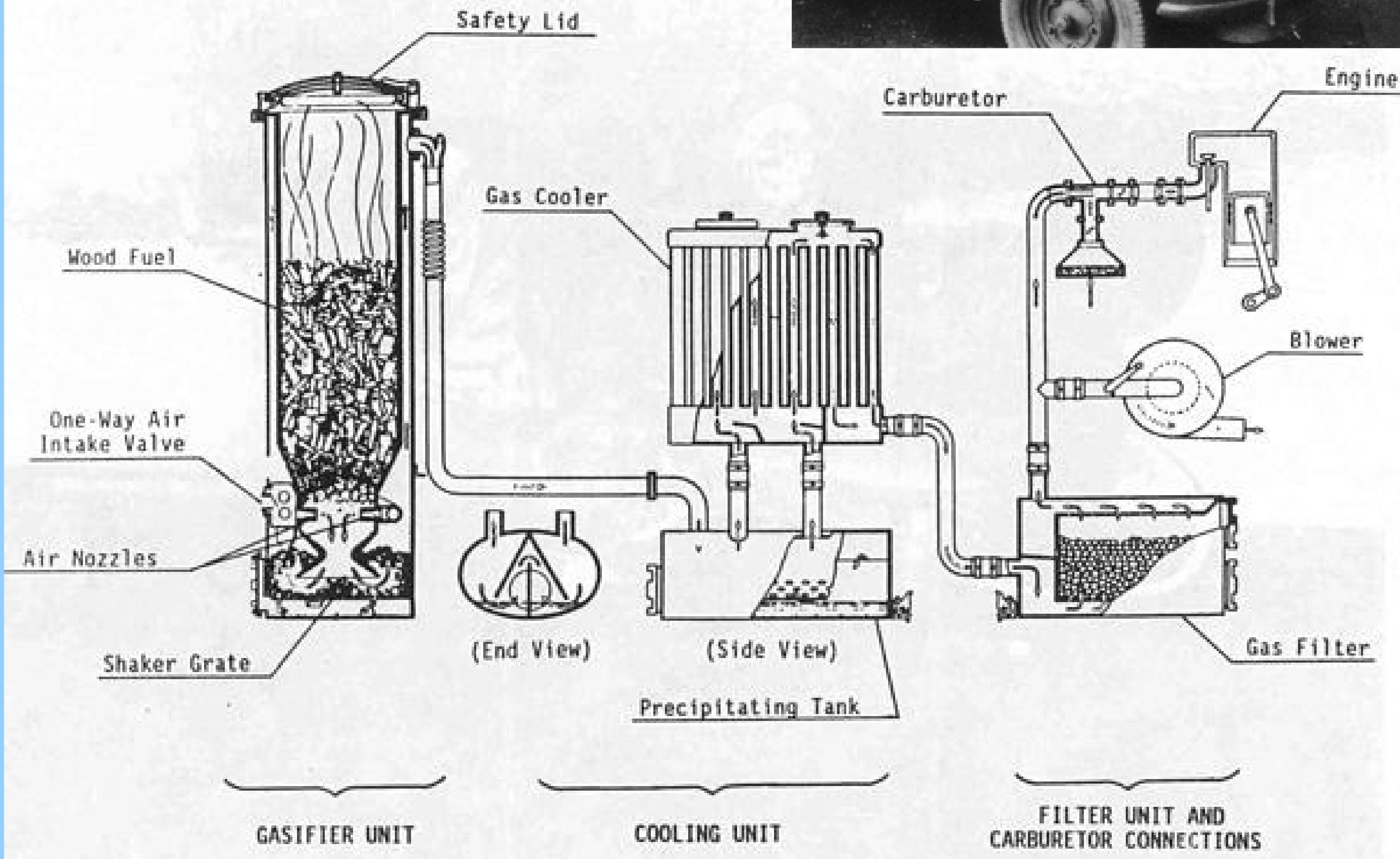


Fig. 1-2. Schematic view of the World War II, Imbert gasifier.

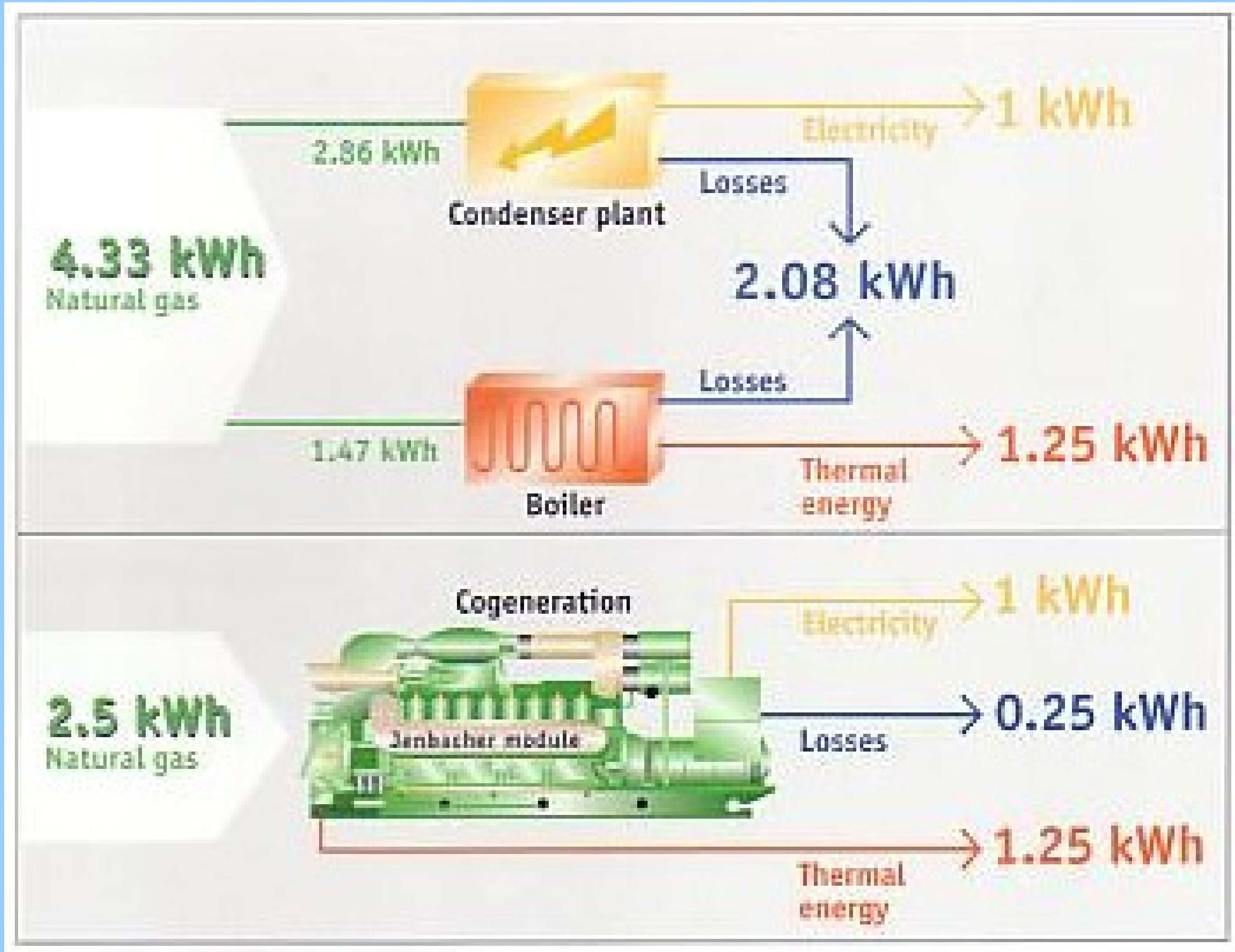
http://www.gengas.nu

Dry comp.:

Components	anaerob (wood)gas	producer gas	synthesis gas	Natural Gas
CH_4 [%]	8	5	3	98
CO_2 [%]	20	5	17	0,1
CO [%]	20	20	40	-
H_2 [%]	38	20	40	-
N_2 [%]	14	50	0	1-2
Hi [MJ/m3]	9,5	6,48	10,45	35,72

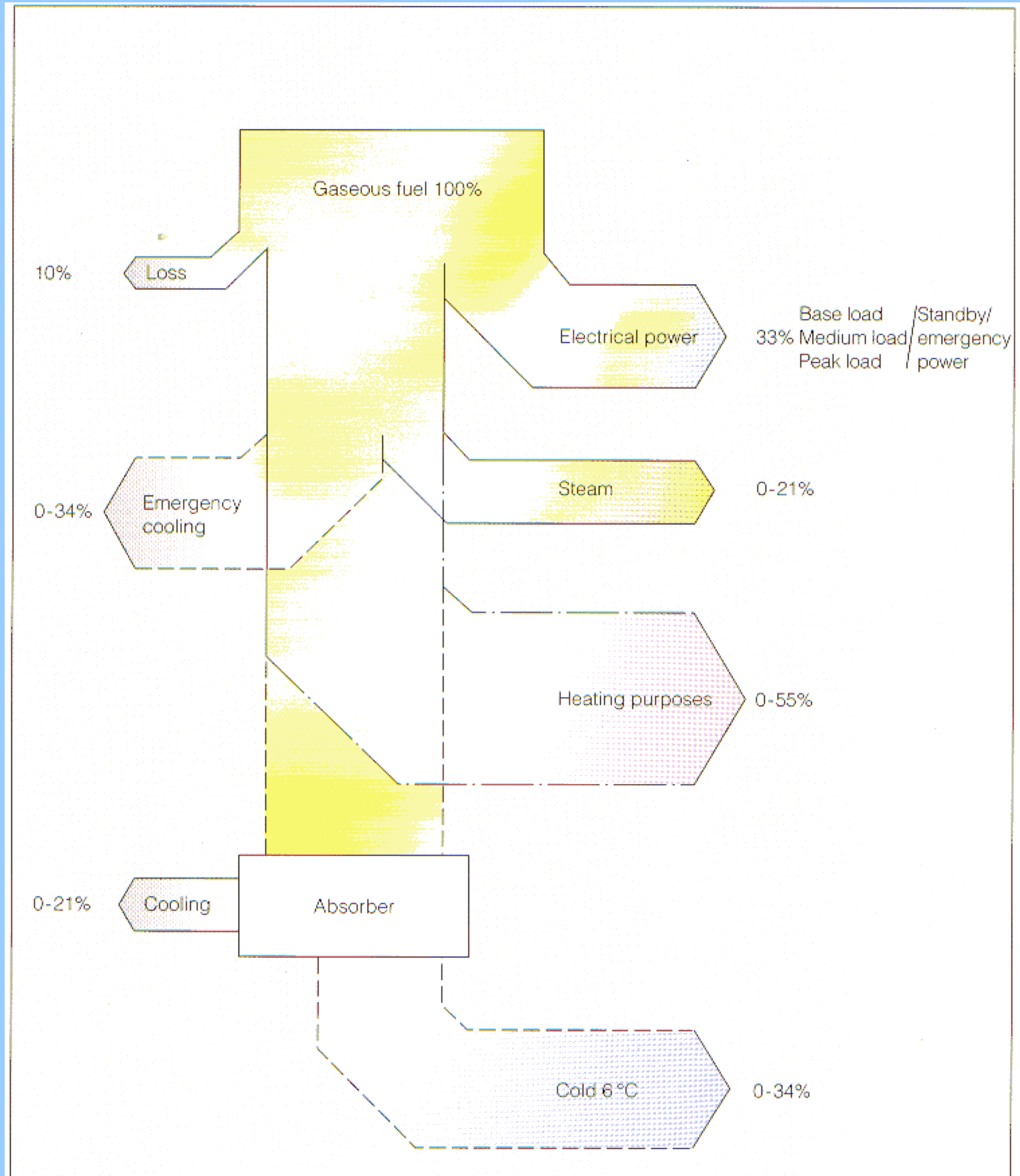
- anaerob (wood)gas : oxygen-free gasification,
- aerob gases:
  - producer gas : gasification with air
  - synthesis gas : gasification with controled O_2 and Steam

Cogeneration



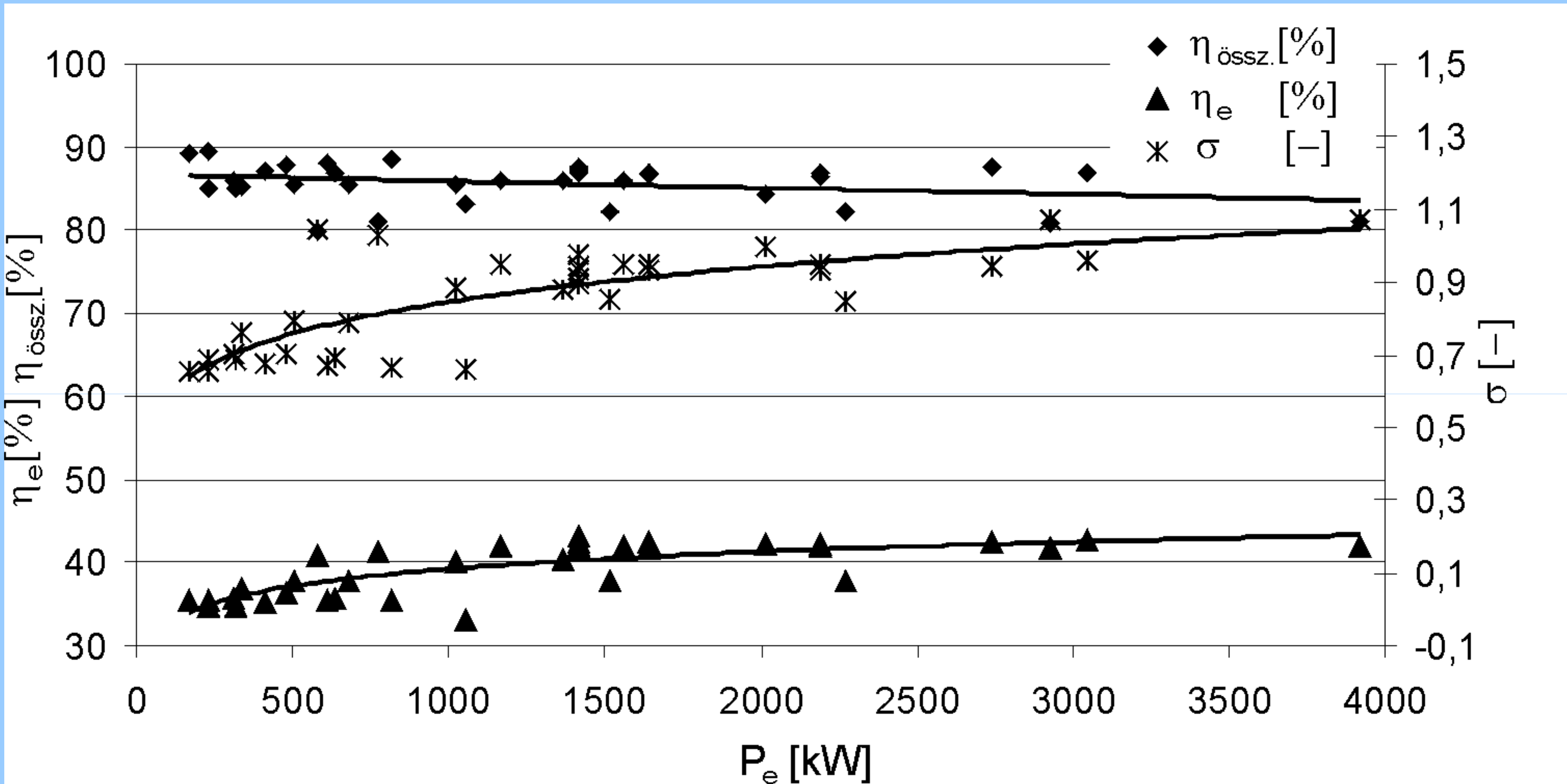
Source: Jenbacher

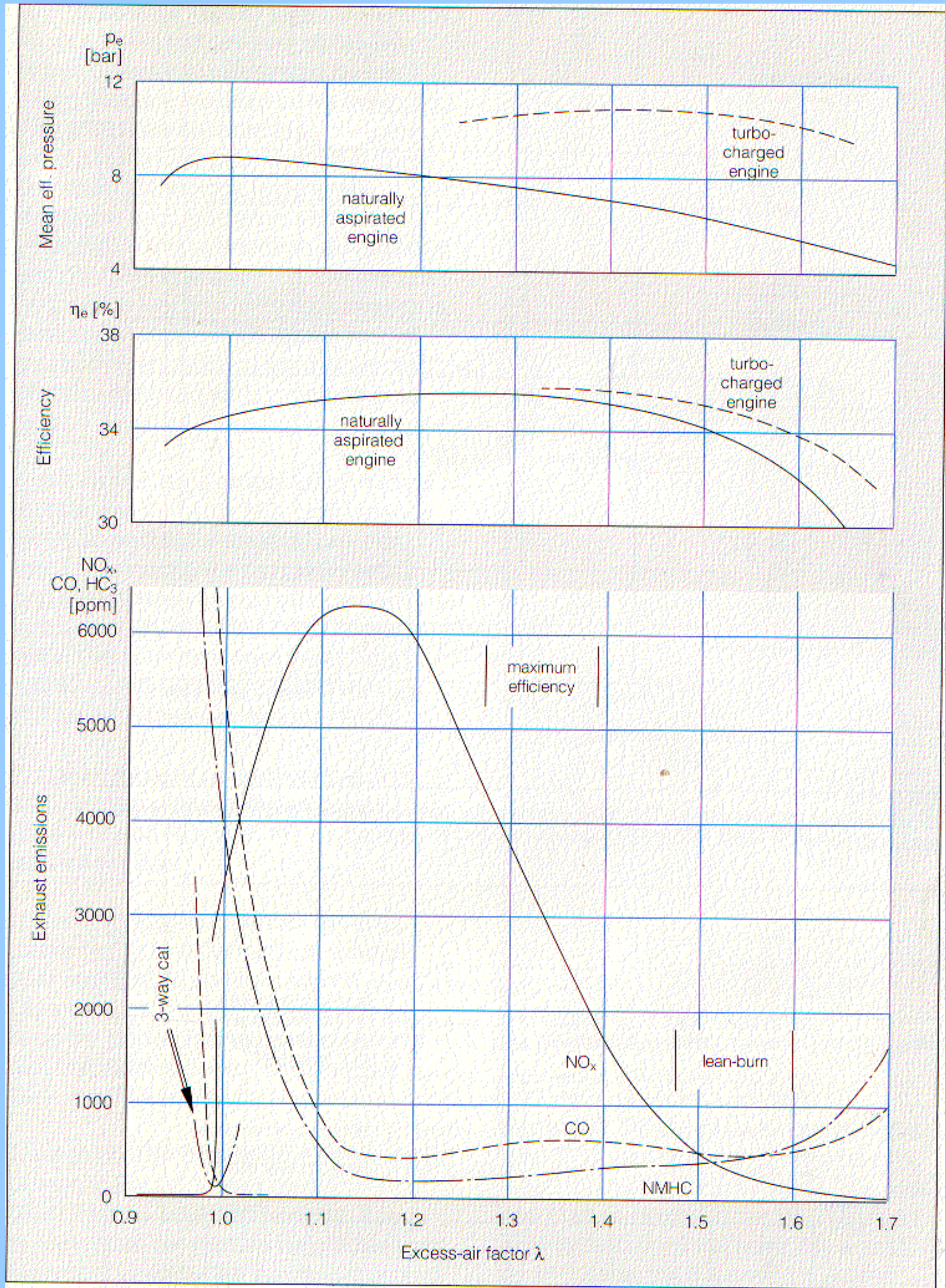
Versatility of energy conversation (power, heat and cold)



Source: DEUTZ

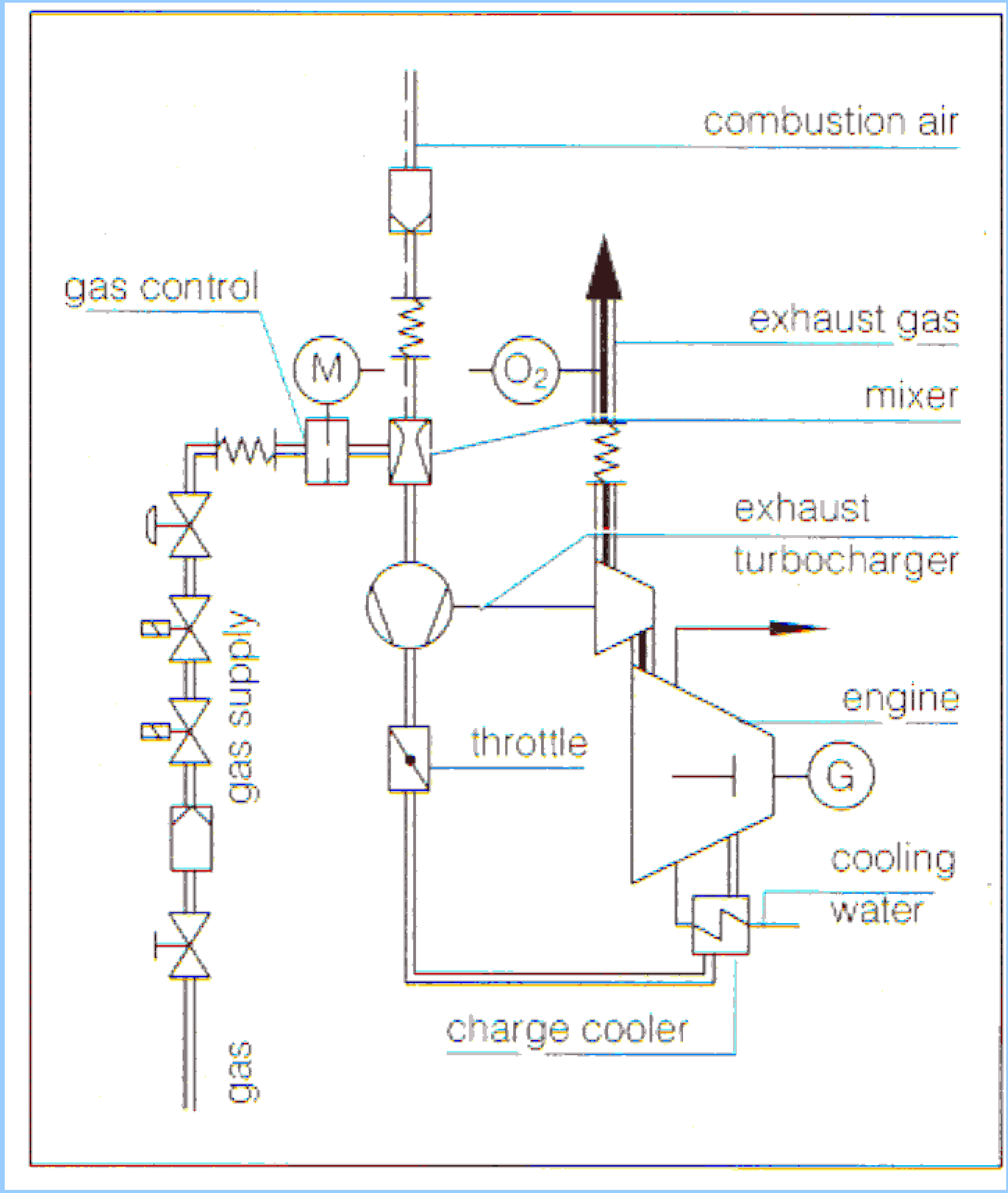
Electrical, total Efficiency and power-to-heat ratio





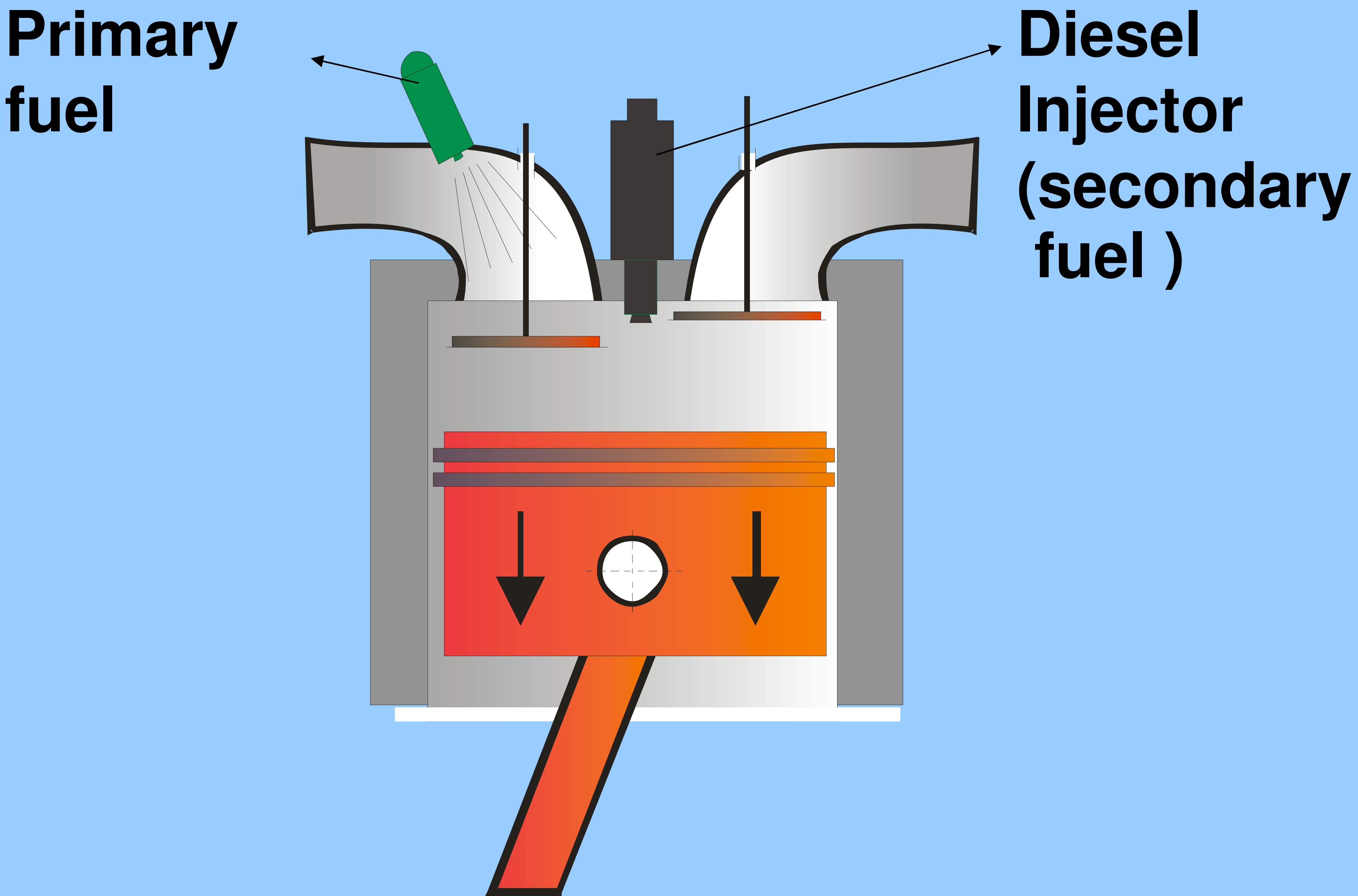
Source:DEUTZ

Fuel – Air mixture formation

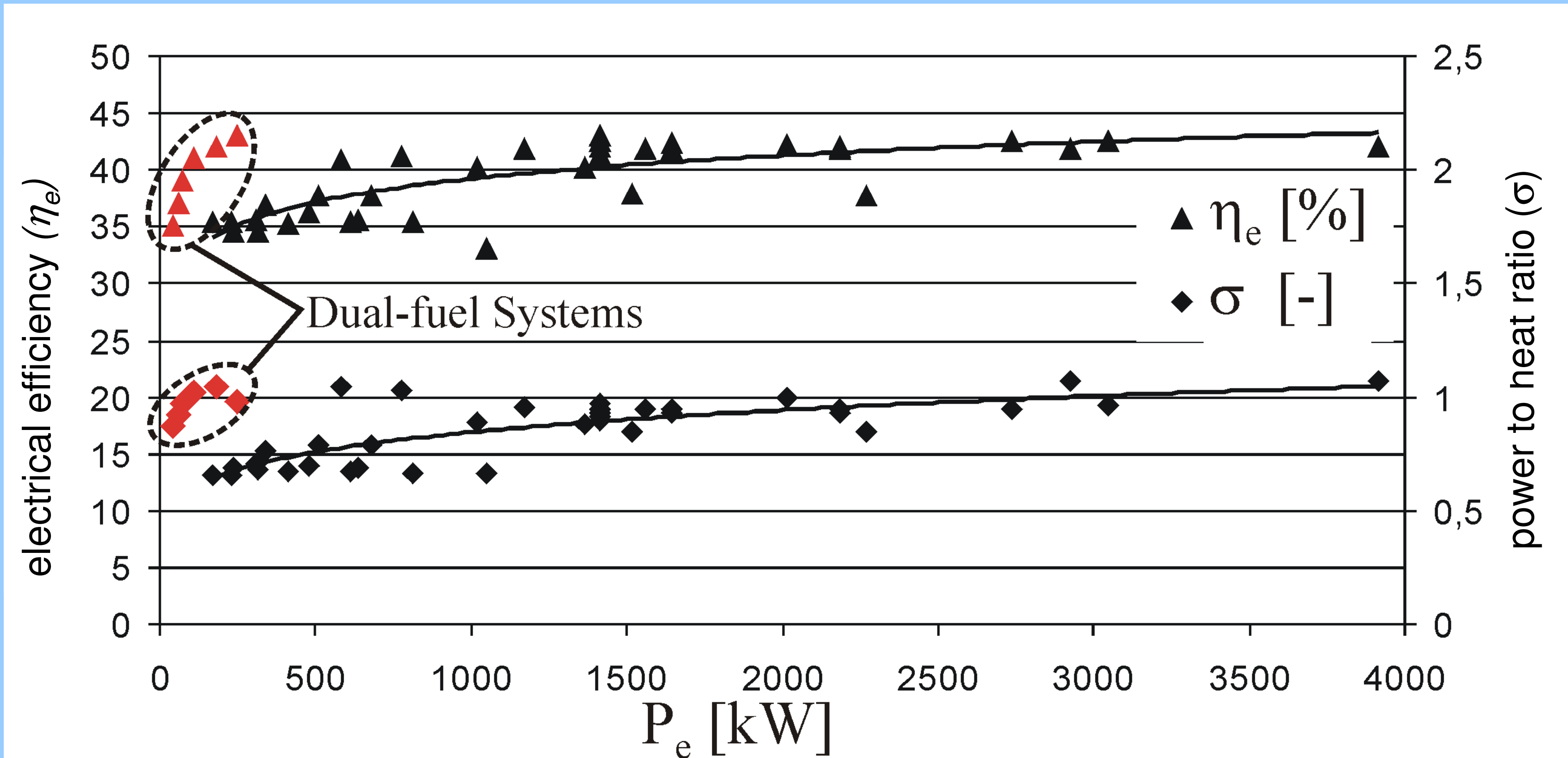


Source: DEUTZ

Dual fuel type CI Engines

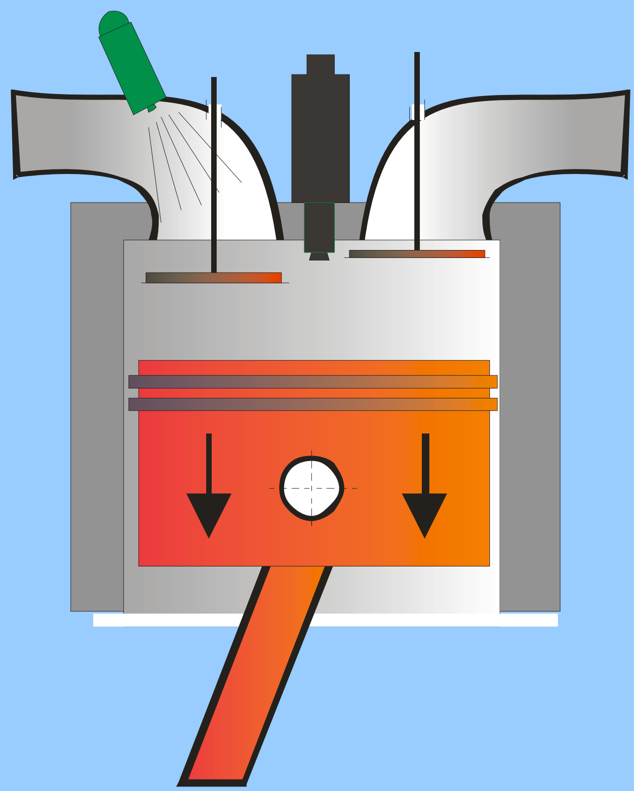


Dual fuel engine systems
(different biogas engines)

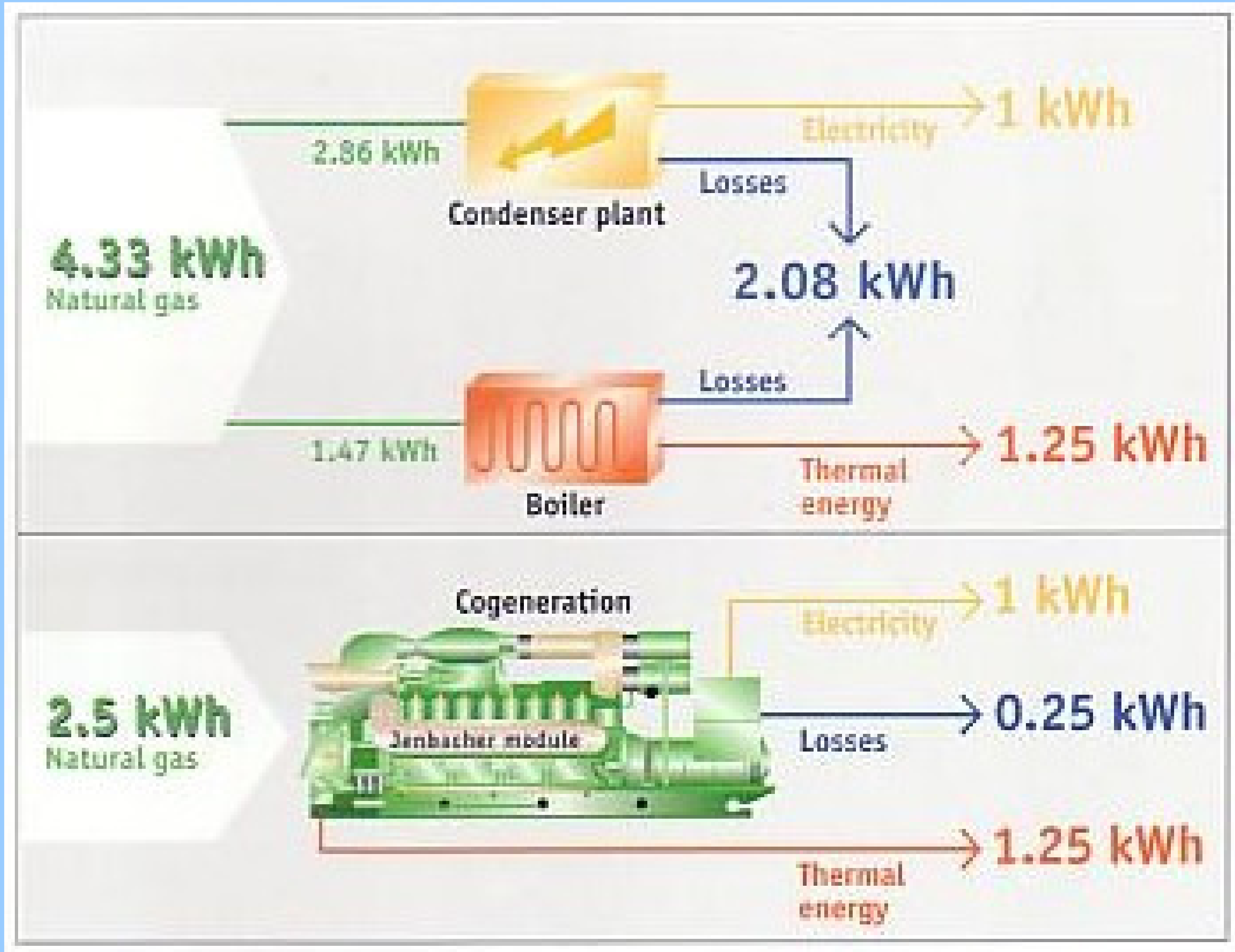


Benefits of the Dual Fuel Engines

- High Compression ratio
- Qualitative power control
- Fuel Flexible



Cogeneration



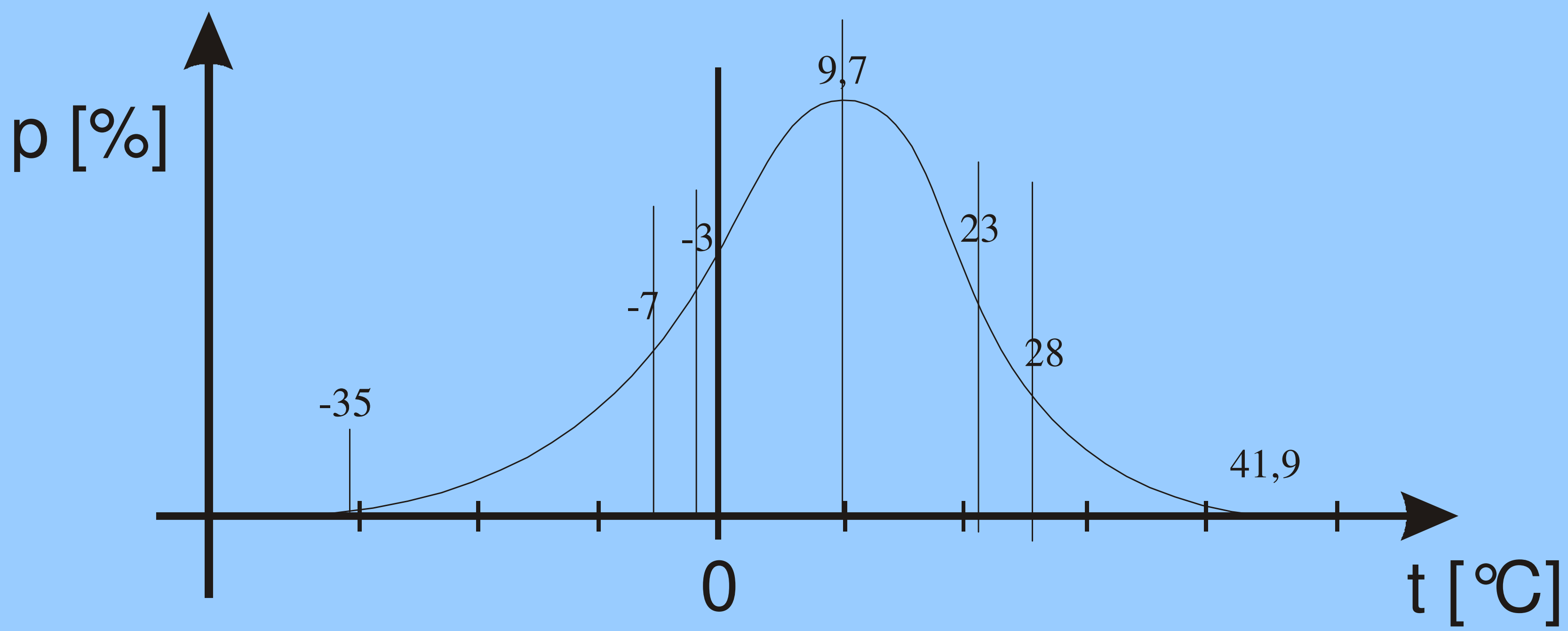
Source: Jenbacher

Gasengine Cogeneration

Utilisation:

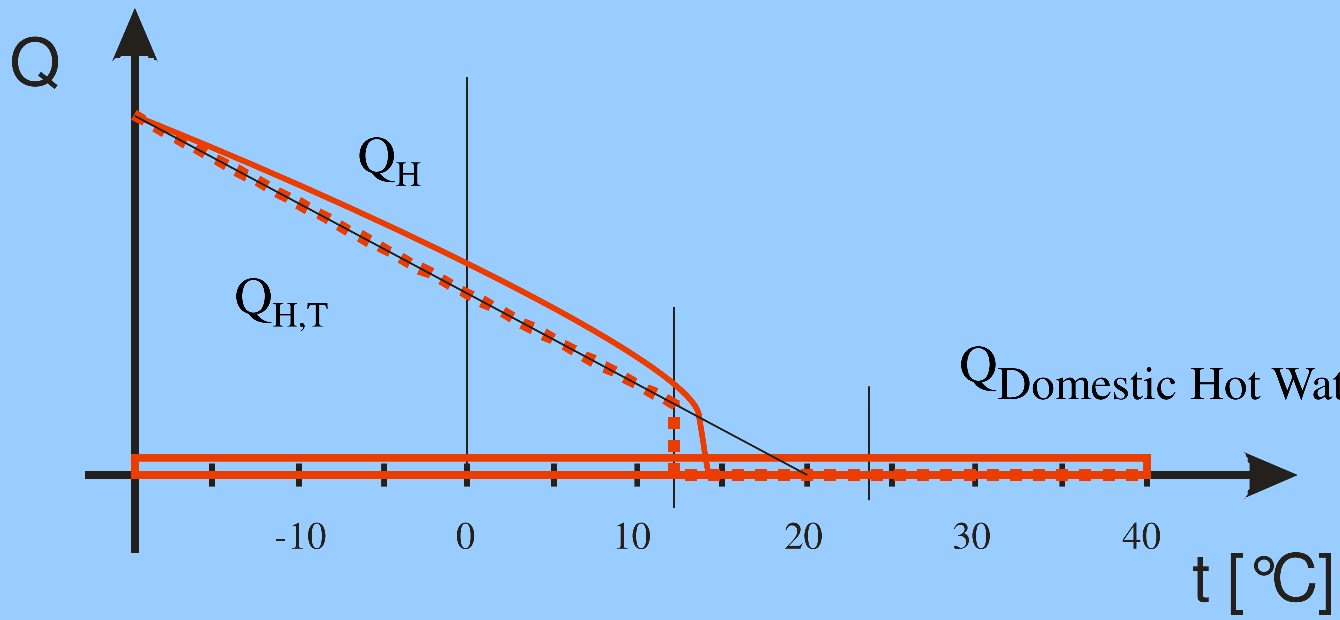
- Low temperature heating purposes (heating of flats or buildings).
- High Electrical power costs are generate good retunrs, better than a boiler.
- Major industrial facilities, primarily in the electricity supply to the primary heat recovery while at the same time.

Annual Temperature Fluctuations (Hungary)



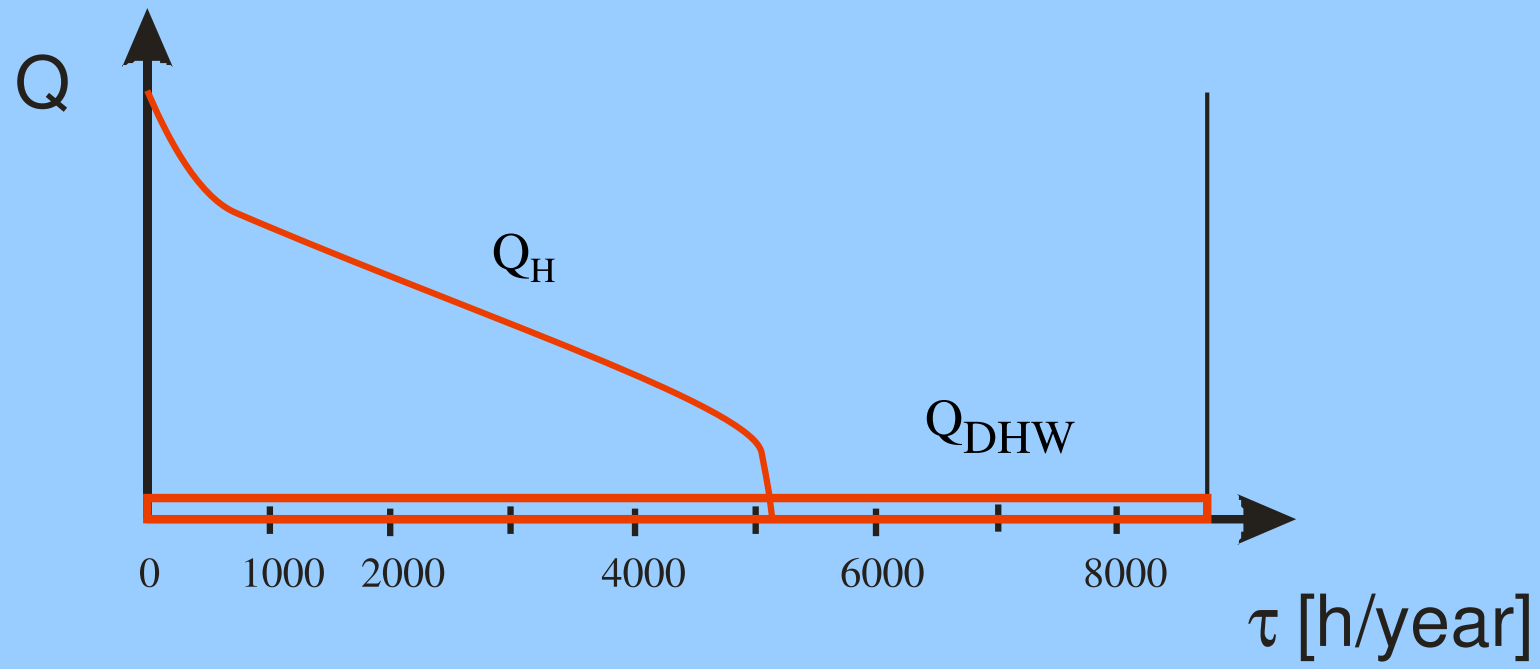
Heating Demand

Heating Demand as a Function Of External Temperature



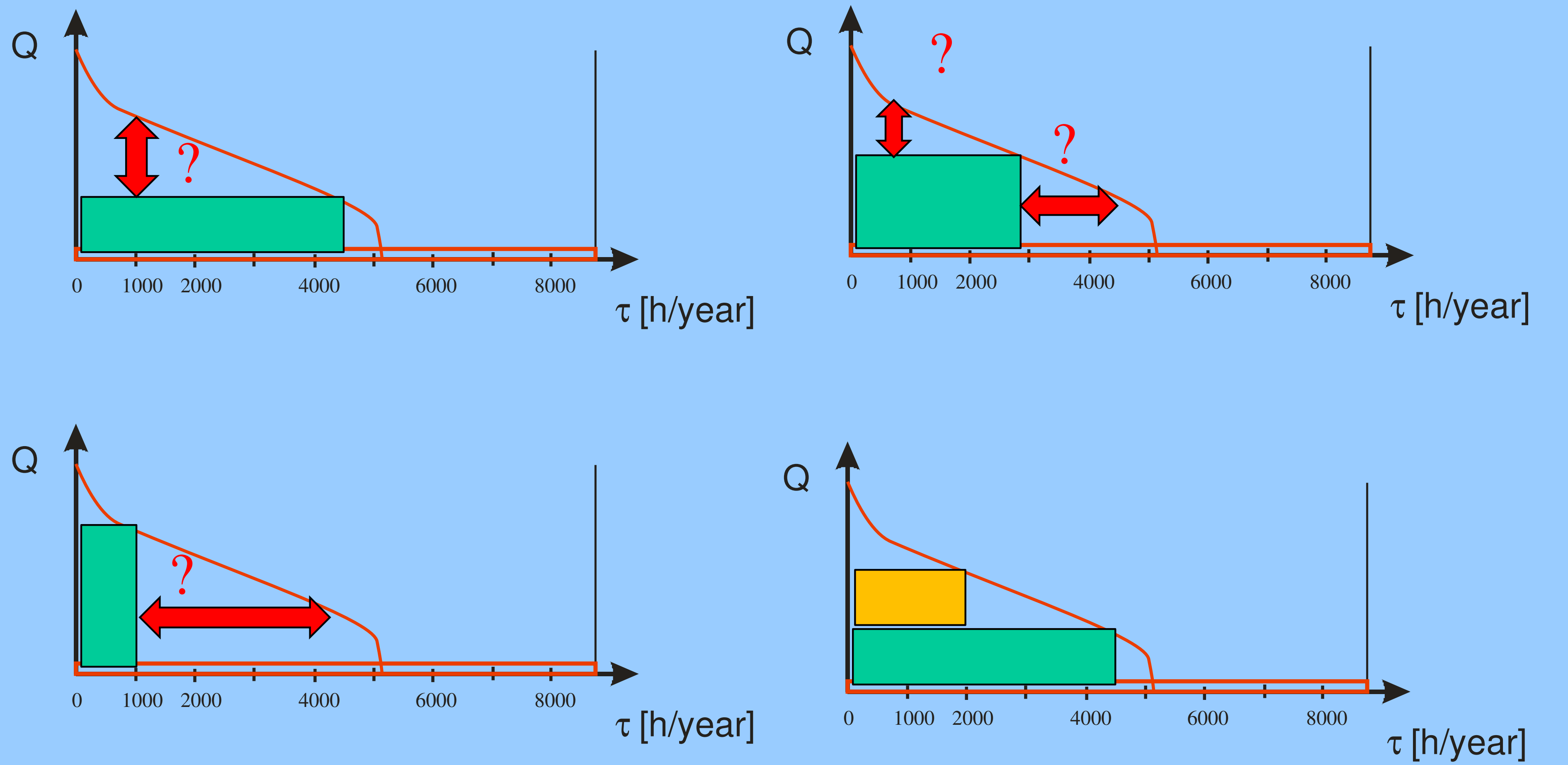
Heating Demand

annual heating demand

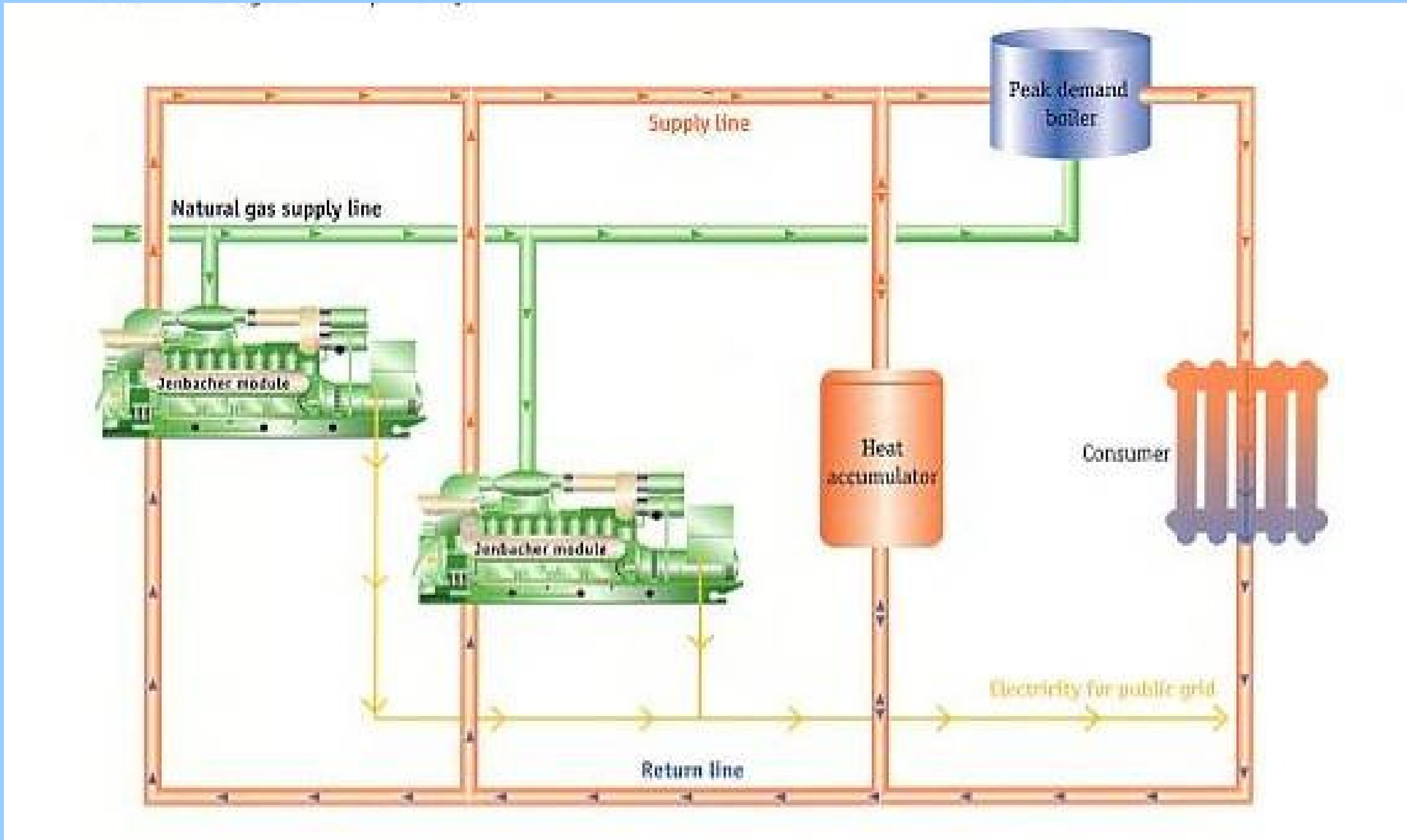


Heating Demand

Annual Heating Demand

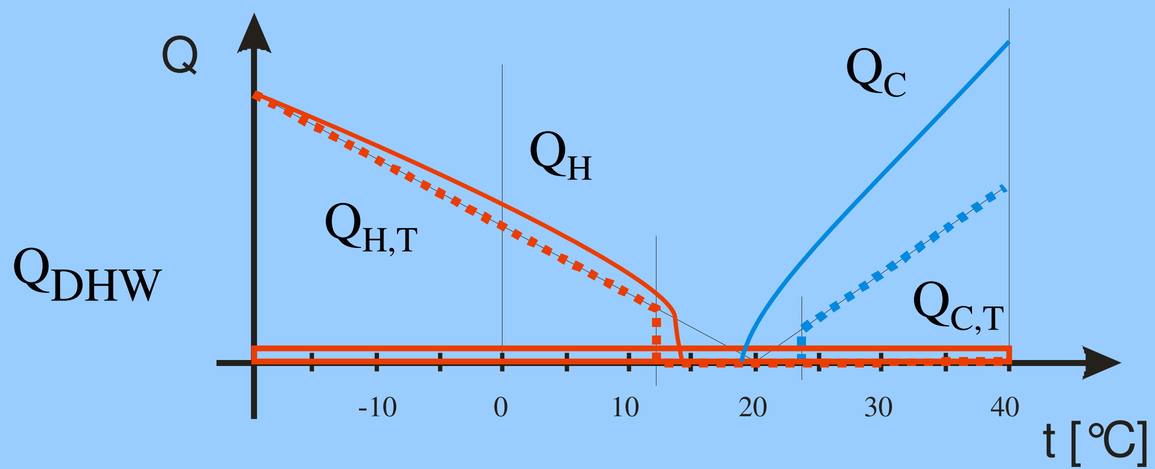


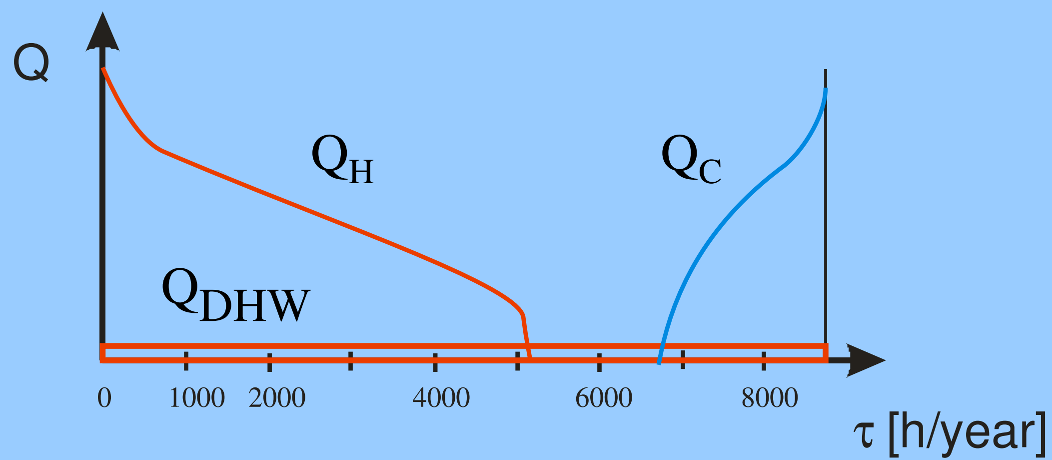
Cogeneration



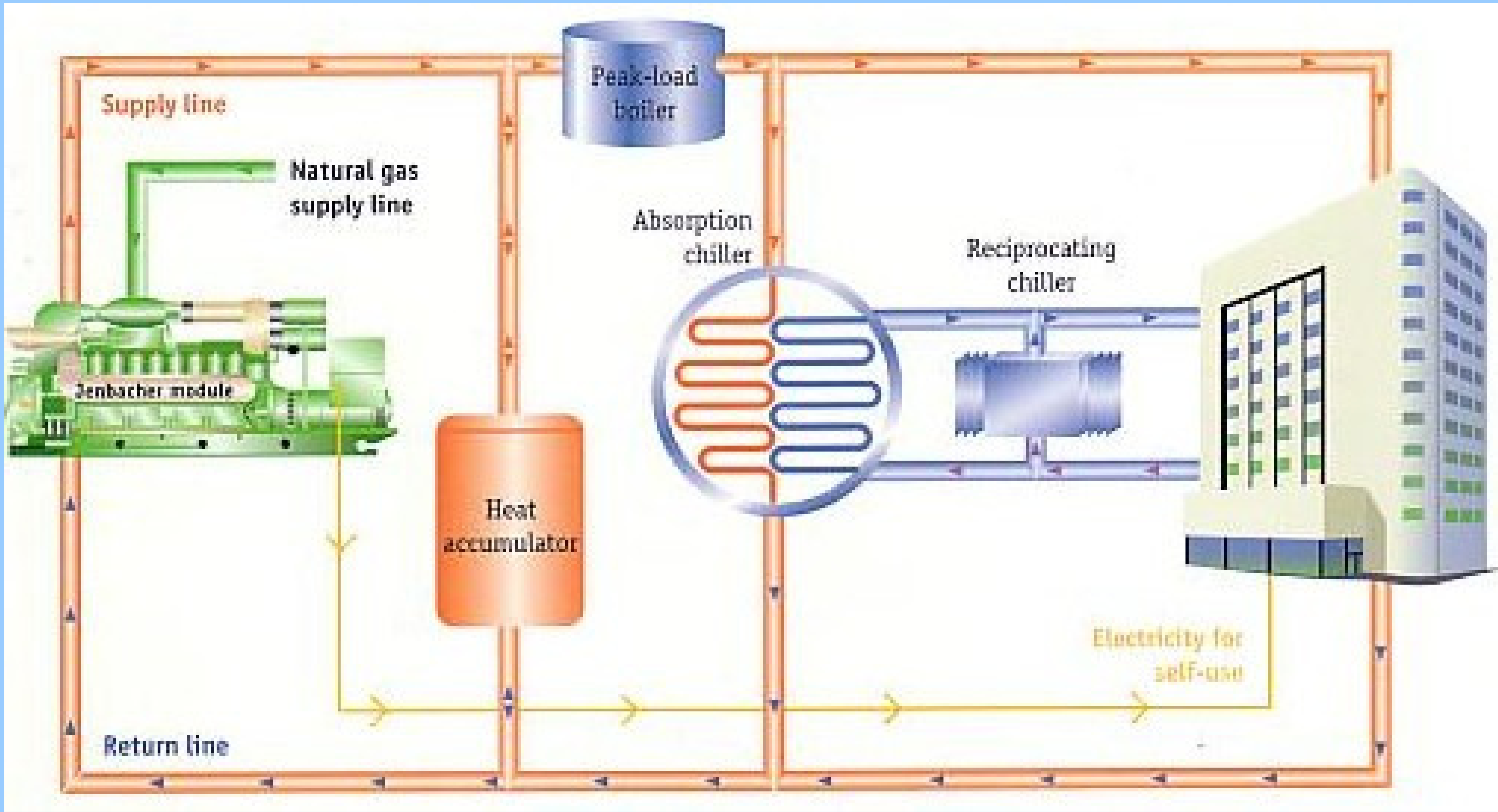
Source: Jenbacher

Cooling and Heating demand



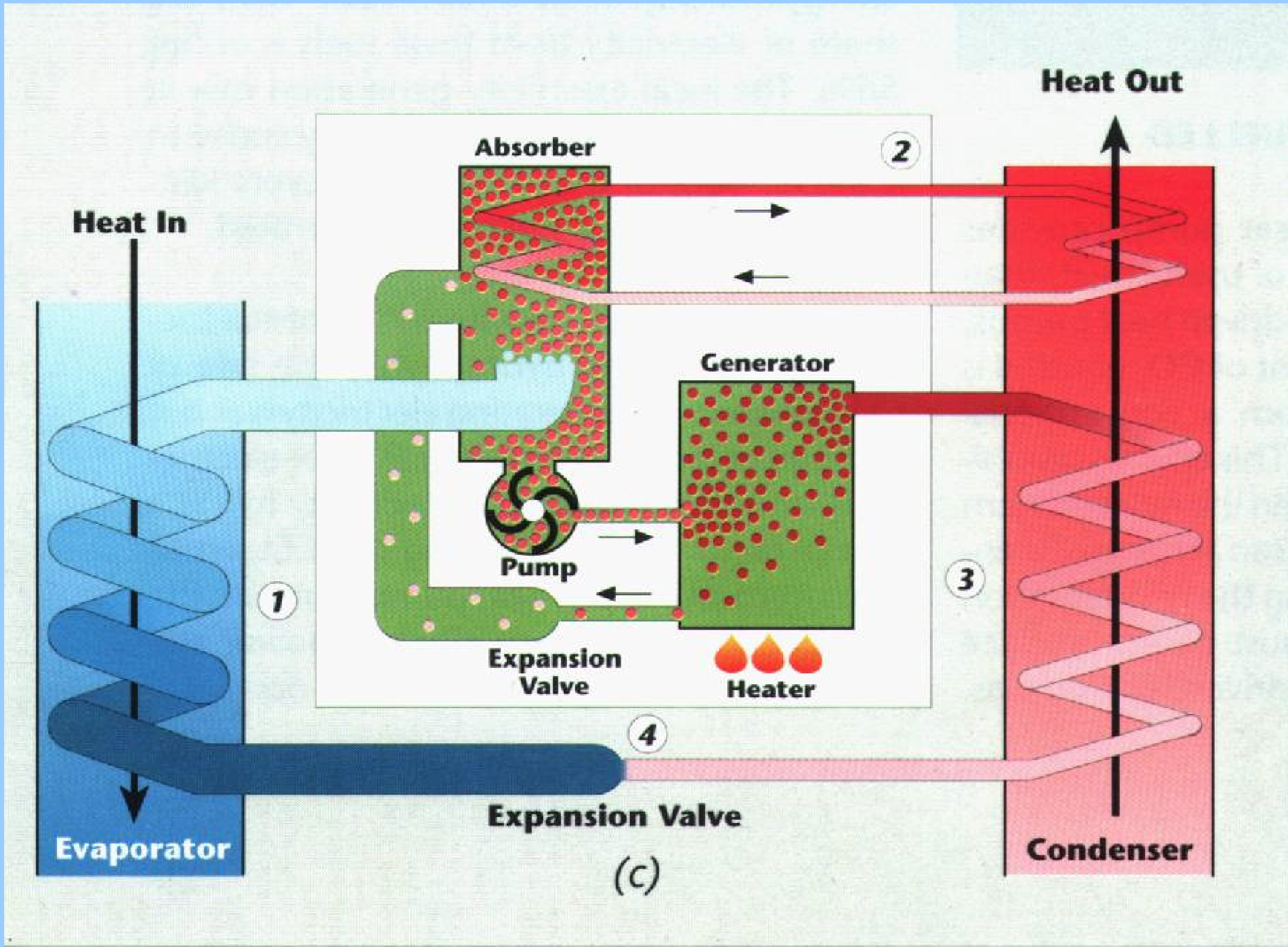


Trigeneration



Source: Jenbacher

Absorption cooler



Source: https://iitbuildingscience.wordpress.com/2013/10/07/absorption-cooling/

Advantages through the combination of cogeneration with absorption chillers

- increase of the module operation time through additional utilization of exhaust heat on summer
- decrease of the connected electrical load and hence reduction of energy costs.

Parameters of the Gasous Fuels

- Heating Value
- Metan Number
- Ignition Limits
- Wobbe number
- ….
- ..

Parameters of the Gasous Fuels

Fuel	Denomination; composition % by vol.	M kg/kmol	V_{mF} m_n^3/kmol	ϱ_F Density kg/m_n^3	H_o kWh/kg	H_u kWh/kg	H_u kWh/m_n^3	L_{min} m_n^3 L/m_n^3 F	$V_{of.}$ m_n^3/m_n^3 F	$V_{otr.}$ m_n^3/m_n^3 F	ϱ_A Density/ Exh. gas kg/m_n^3	Ignition limits λ_u	λ_o	MZ	λ_5	$V_{5tr.}$ m_n^3 5%/m_n^3 F	$g(CO_2)$ kg(CO_2)/kWh F
H_2	Hydrogen	2.016	22.43	0.0899	39.39	33.33	2.996	2.379	2.878	1.88	–	9.83	0.14	0	1.247	2.467	0
C	Carbon	12.01	(22.41)	(0.536)	2.87	2.87	(4.88)	4.762	4.756	4.756	–	–	–	–	1.312		0.402
S	Sulphur	32.06	(22.41)	(1.431)	2.57	2.57	(3.68)	4.762	4.739	4.739	–	–	–	–	–	–	0
CH_4	Methane	16.042	22.38	0.717	15.42	13.89	9.971	9.537	10.53	8.53	.234	1.99	0.59	100	1.280	11.195	0.198
C_2H_4	Ethylene	28.052	22.25	1.261	13.97	13.10	16.521	14.39	15.38	13.37	.287	2.25	0.14	15	1.290	17.548	0.239
C_2H_6	Ethane	30.068	22.17	1.356	14.41	13.19	17.89	16.85	18.35	15.32	.256	1.92	0.36	43.7	1.284	20.107	0.221
C_3H_6	Propylene	42.078	21.973	1.915	13.59	12.72	24.35	21.86	23.37	20.31	.287	2.03	0.37	18.6	1.290	26.657	0.247
C_3H_8	Propane	44.094	22.01	2.003	13.99	12.88	26.00	24.24	26.26	22.19	.265	1.92	0.39	33	1.286	29.122	0.228
C_4H_{10}	Butane	58.12	21.50	2.703	13.76	12.71	34.34	32.26	34.84	29.63	.270	2.04	0.33	10	1.287	38.893	0.230
H_2S (burnt to SO_2)	Hydrogen sulphide	34.082	22.15	1.538	–	4.23	6.52	7.23	7.71	7.00	.407	3.06	0.17	–	1.290	8.791	0
CO	Carbon monoxide	28.01	22.41	1.250	2.81	2.81	3.51	2.381	2.875	2.875	.502	2.94	0.14	75	1.377	3.775	0.563
CO_2	Carb. dioxide	44.01	22.26	1.9771	–	–	–	–	–	–	–	–	–	–	–	–	–
Nat. gas	$CH_4=88.5$ $C_2H_6=4.7$ $C_3H_8=1.6$ $C_4H_{10}=0{,}2$ $N_2=5{,}0$	(17.83)	(22.29)	0.798	11.05	12.68	10.14	9.684	10.72	8.73	.238	1.90	0.59	80–90	1.282	11.462	0.201
Sew. gas	$CH_4=65$ $CO_2=35$			1.158		5.65	6.5	6.20	7.20	5.89	.271	1.94	0.54	134	1.297	7.736	0.303
Landf. gas	$CH_4=50$ $CO_2=40$ $N_2=10$			1.274		3.94	4.77	4.77	5.77	4.77	.286	1.90	0.49	136	1.312	6.254	0.355
Diesel fuel	C=86% by wt. H=14% by wt.			–		11.6		11.25	12.0	10.5	.295	–	–	–	1.2	13.4 per kg	0.264

Basic data acc. to [2]

Ignition limits λ_u, λ_o converted from $z = 100/(1 + \lambda \cdot L_{min})$, for gas mixtures acc. to [3] and [7].

- M: molar mass
- V_{mF}: molar volume
- H_o: gross calorific value
- H_u: net calorific value
- L_{min}: min. air requirements
- $V_{of.}$: wet exhaust gas volume at $\lambda = 1$
- $V_{otr.}$: dry exhaust gas volume at $\lambda = 1$
- ϱ_A: exhaust gas density
- MZ: methane number
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Fig. 16 Fuel characteristic values

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C	Carbon	12.01	(22.41)	(0.536)	2.87	2.87	(4.88)	4.762	4.756	4.756	–	–	–	–	1.312		0.402
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- F and index F — related to fuel, i. e., gaseous fuel

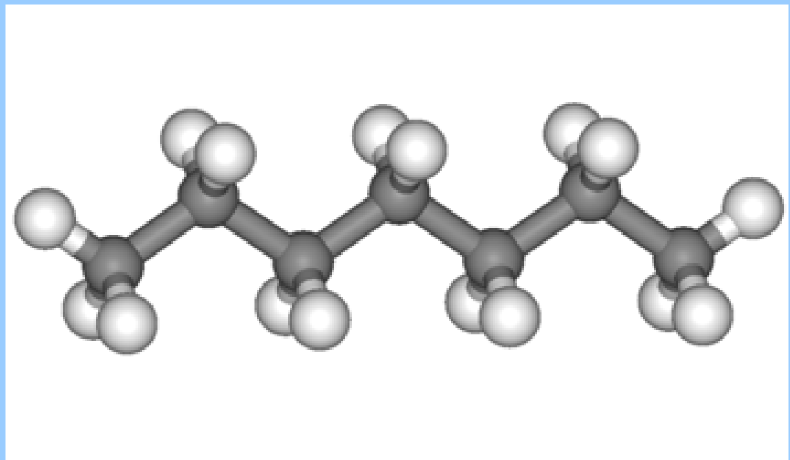
Fig. 16 Fuel characteristic values

Source: DEUTZ

The Octane Number (MON, RON)

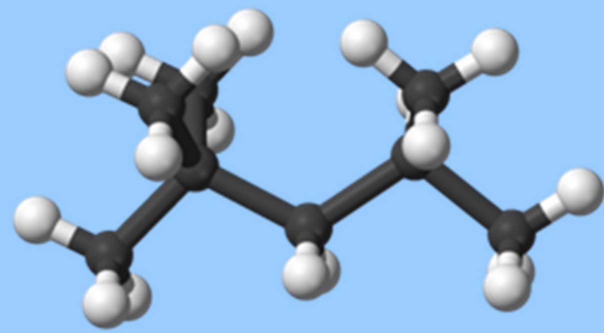
The Octane Number is numerical representation of the antiknock properties of (motor) fuel, compared with a standard reference fuel, such as isooctane, which has an octane number of 100

MON,
RON



n-heptane
0

H_2
0



iso-octane
100

CH_4
100

MN,

- The most common type of octane rating worldwide is the **Research Octane Number** (**RON**). RON is determined by running the fuel in a test engine with a variable compression ratio under controlled conditions, and comparing the results with those for mixtures of iso-octane and n-heptane.

- There is another type of octane rating, called **Motor Octane Number** (**MON**) or the aviation lean octane rating, which is a better measure of how the fuel behaves when under load.

Theoretical combustion process

1 CH_4 + 2(O_2 +$^{79}/_{21}$ N_2) -> 1 CO_2 +2 H_2O + 2($^{79}/_{21}$ N_2)

- Theoretical flue gas composition::

  On a wet basis: 9,5% CO_2 +19,0% H_2O + 71,5 %N_2

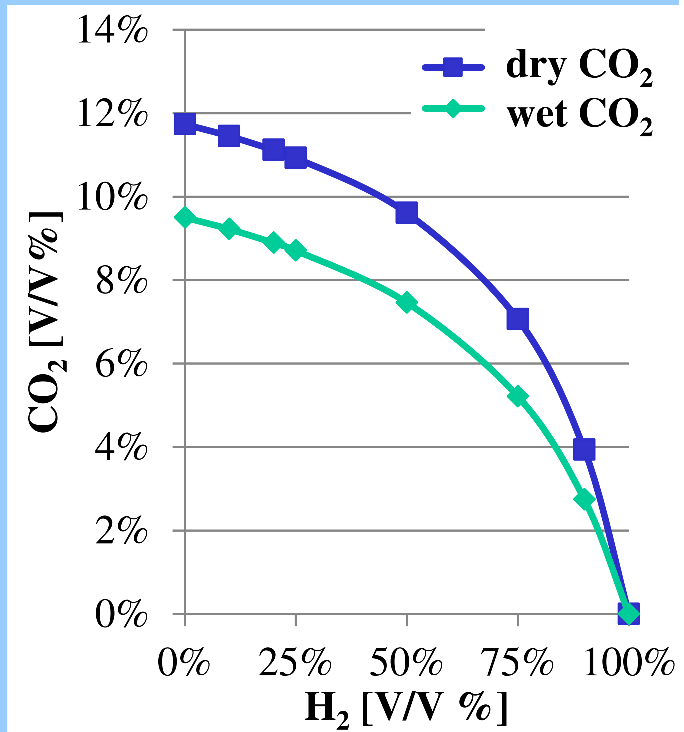
  On a dry basis: 11,7% CO_2 +0 % H_2O + 88,3 %N_2

1 H_2 + $^{1}/_{2}$ (O_2 +$^{79}/_{21}$ N_2) -> 0 CO_2 +1 H_2O + $^{1}/_{2}$($^{79}/_{21}$ N_2)

- Theoretical flue gas composition::

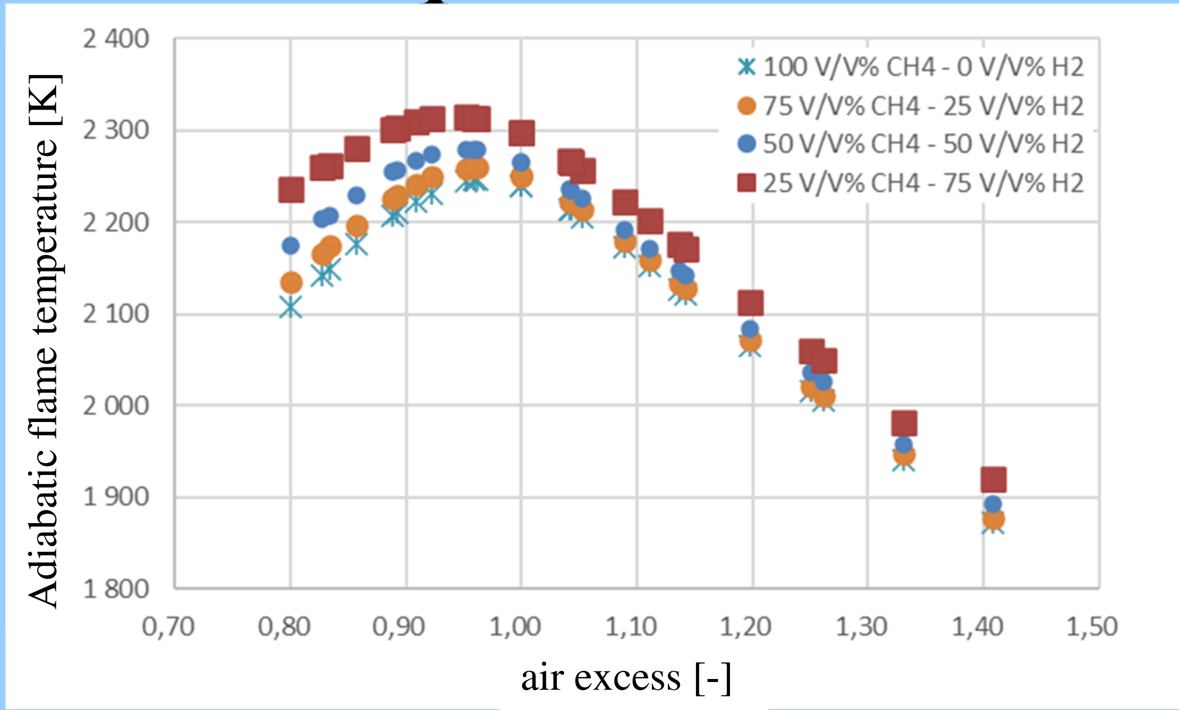
  On a wet basis: 0% CO_2 +34,71% H_2O + 65,3 %N_2

  On a dry basis: 0% CO_2 +0 % H_2O + 100 %N_2



Adiabatic flame temperature

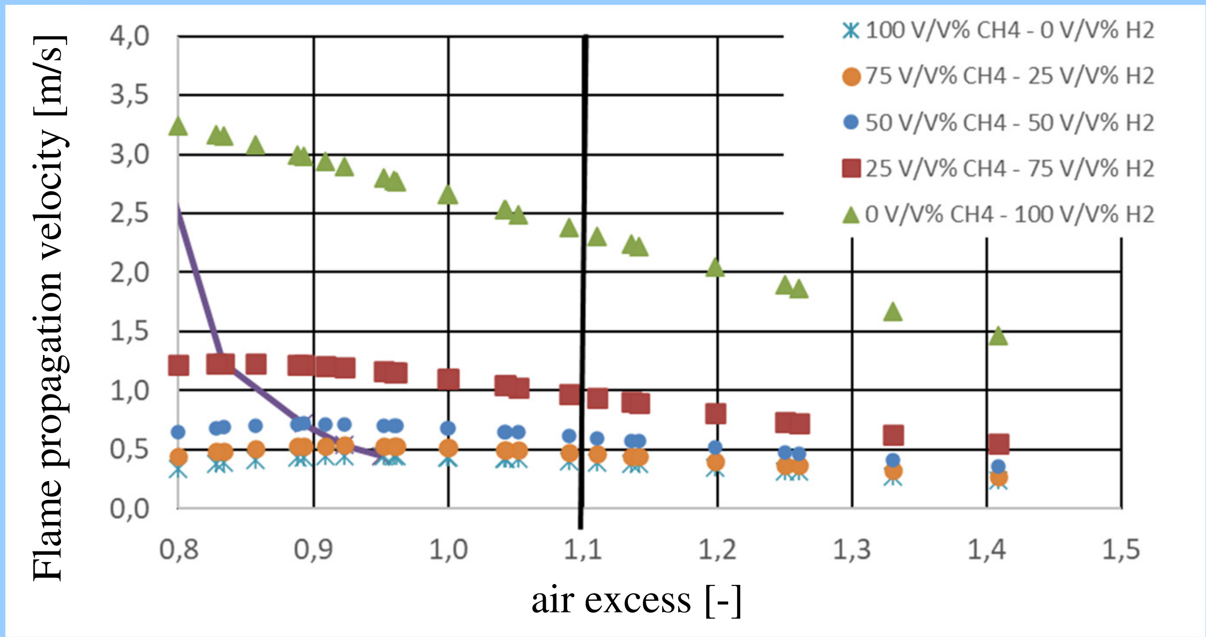
The adiabatic flame temperature is of great importance for the course of combustion and the occurrence of chemical reactions, it is also crucial for the formation of emissions (e.g. NOx).



Adiabatic flame temperature as a function of air excess in case of different H2 mixing (GRI 3.0 mechanism, To= 323 K, Po= 0.1 Mpa)

Laminar flame propagation velocity

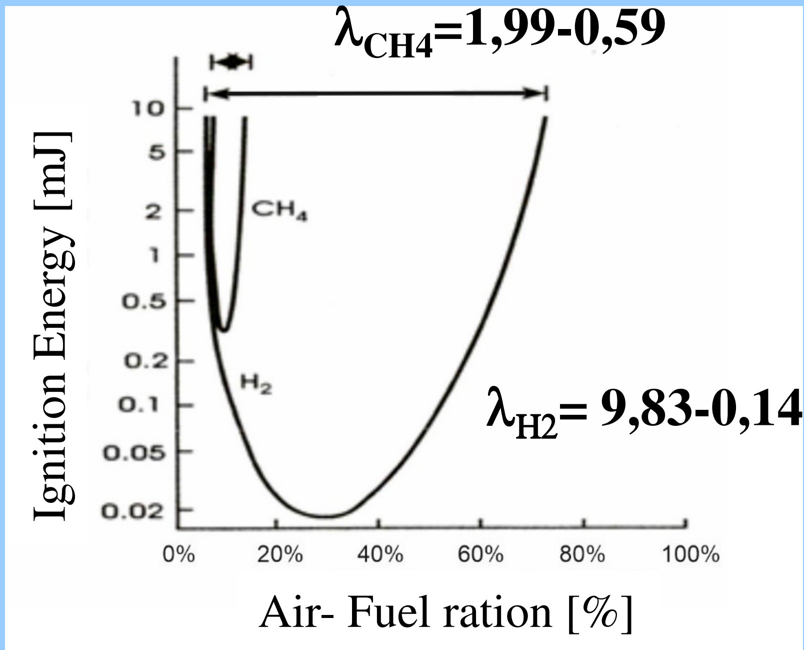
The laminar flame speed is a parameter that characterizes the speed of combustion. The laminar flame speed increases continuously with the addition of hydrogen.
For CH_4, the maximum is between 0.9-1 by mixing H_2, the Maximum shifts to a rich range

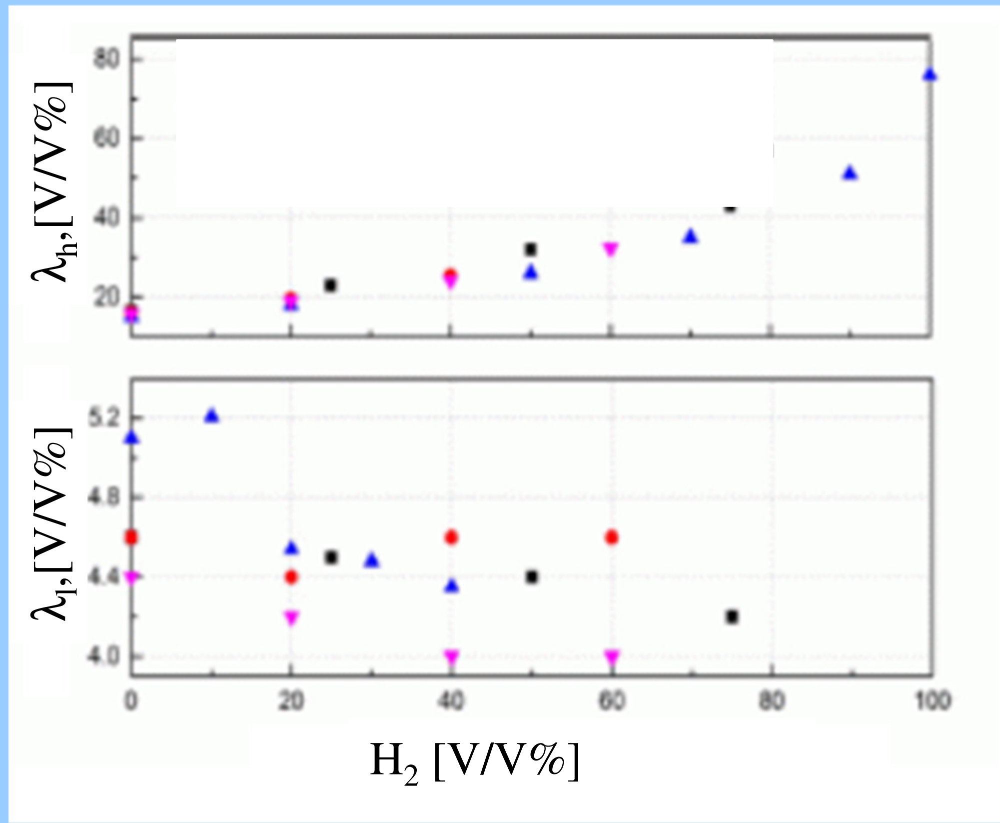


A lamináris lángterjedési sebesség függvényében különböző H2 bekeverés esetén (GRI 3.0 mechanizmus, To= 323 K, Po= 0,1 Mpa)

Lower and upper ignition limit (λ_l,λ_h)

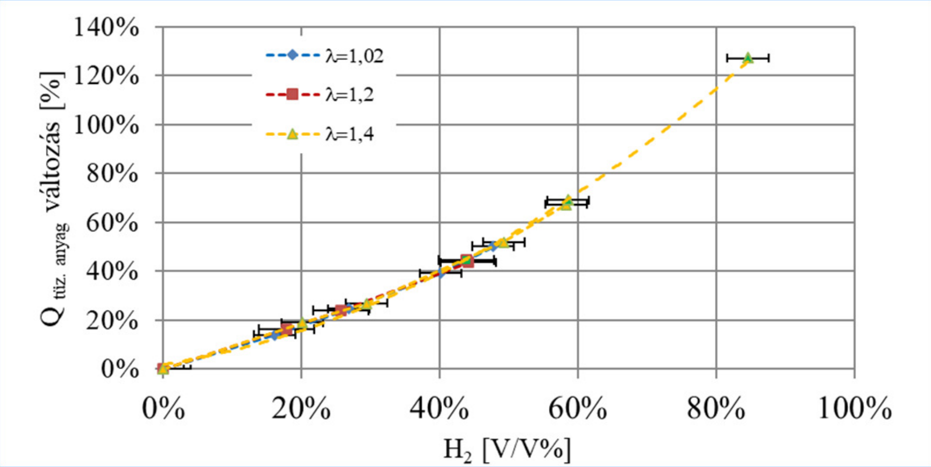
Fuels between the lower and upper ignition limits can be ignited, and mixtures outside the limits cannot be ignited.

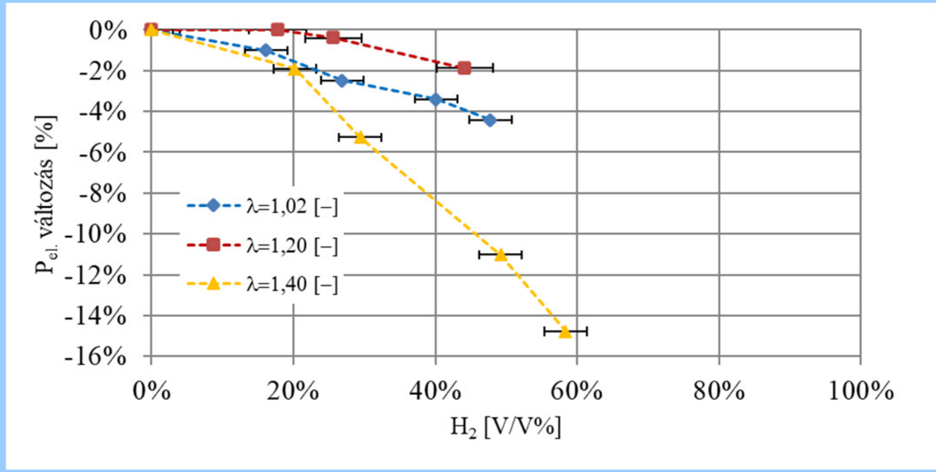


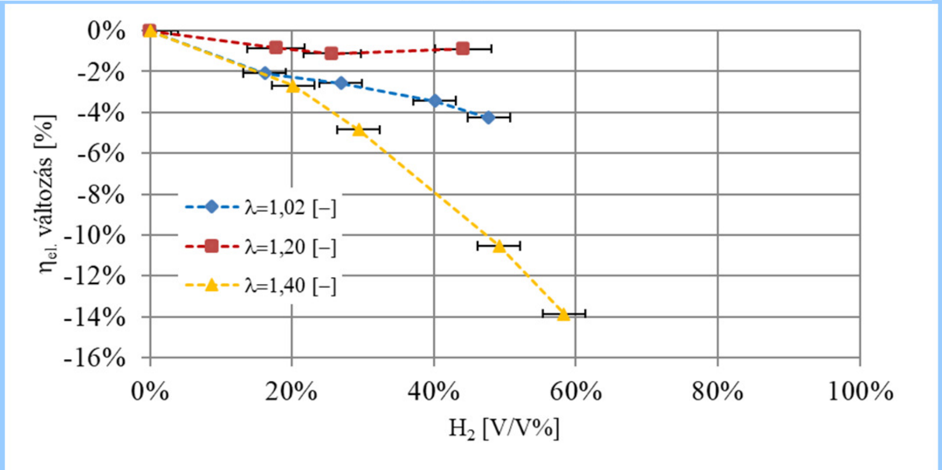


Gyulladási határok metán-hidrogén keverékek esetén, különböző mérési módszerekkel meghatározva

LHV value and heat input







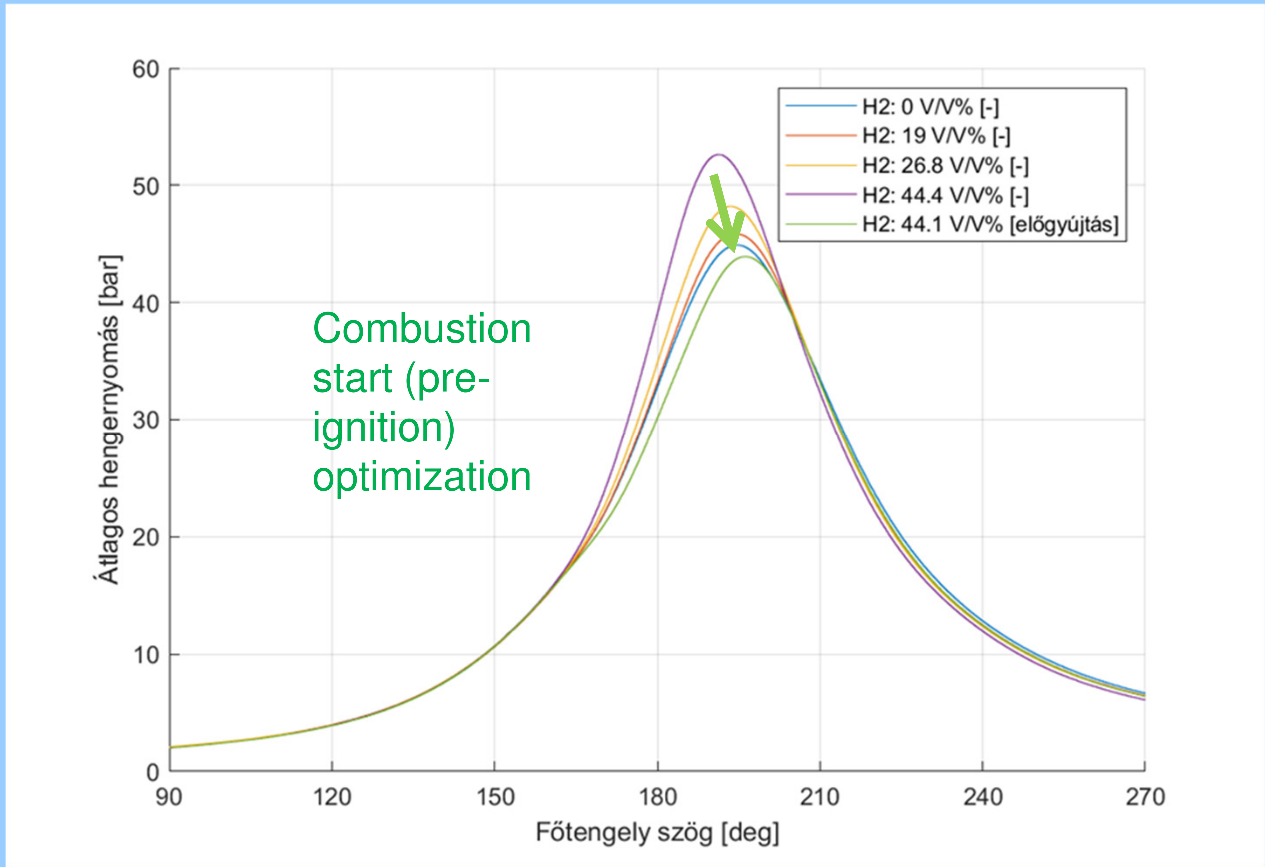
At a constant excess of air, the fuel flow rate increased by mixing H2, but performance and efficiency decreased

Acceleration of combustion > combustion start (pre-ignition) optimization

Dobi-Szakál, Gyöngy ; Szalontai, Péter ; Lukács, Kristóf ; Meggyes, Attila ; Bereczky, Ákos: Hidrogénbekeverési kísérletek energiatermelés céljára gázmotorokban, MAGYAR ENERGETIKA 30 : 1 pp. 2-6. , 5 p. (2023)

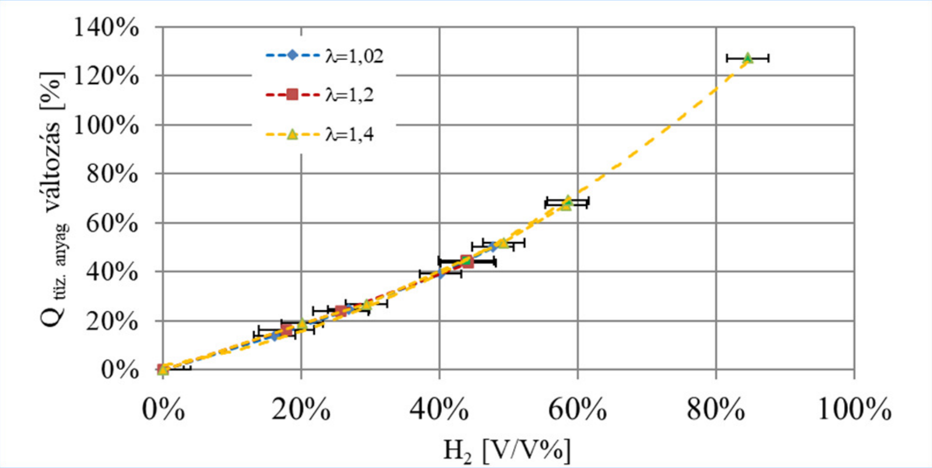
Combustion start (pre-ignition) optimization

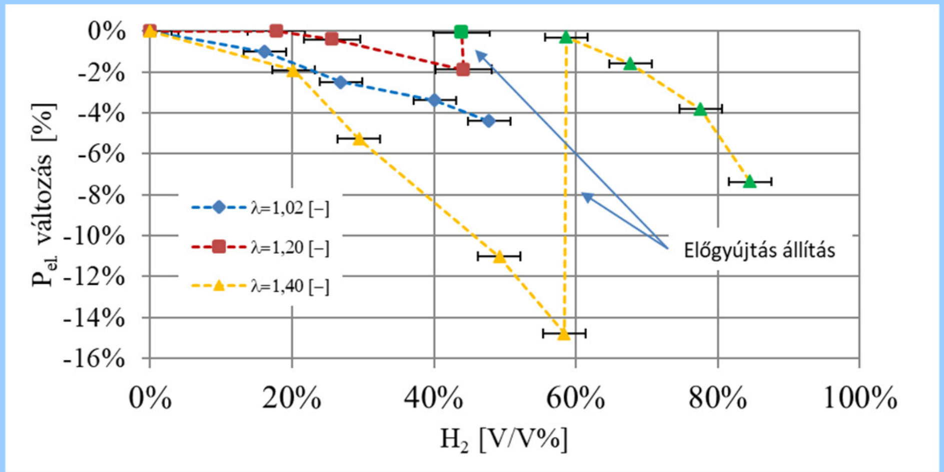
Average combustion chamber pressure results l=1.2[-] for excess air as a function of crankshaft angle for different hydrogen blendings

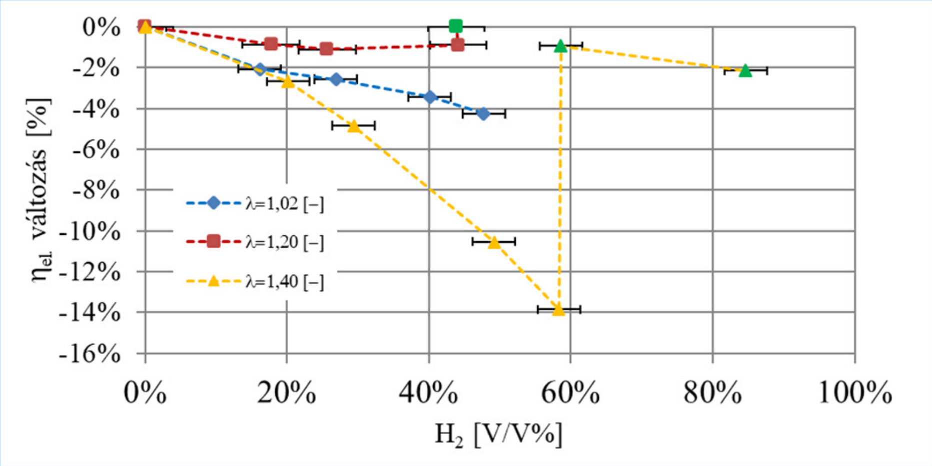


Dobi-Szakál, Gyöngy ; Szalontai, Péter ; Lukács, Kristóf ; Meggyes, Attila ; Bereczky, Ákos: Hidrogénbekeverési kísérletek energiatermelés céljára gázmotorokban, MAGYAR ENERGETIKA 30 : 1 pp. 2-6. , 5 p. (2023)

LHV value and heat input







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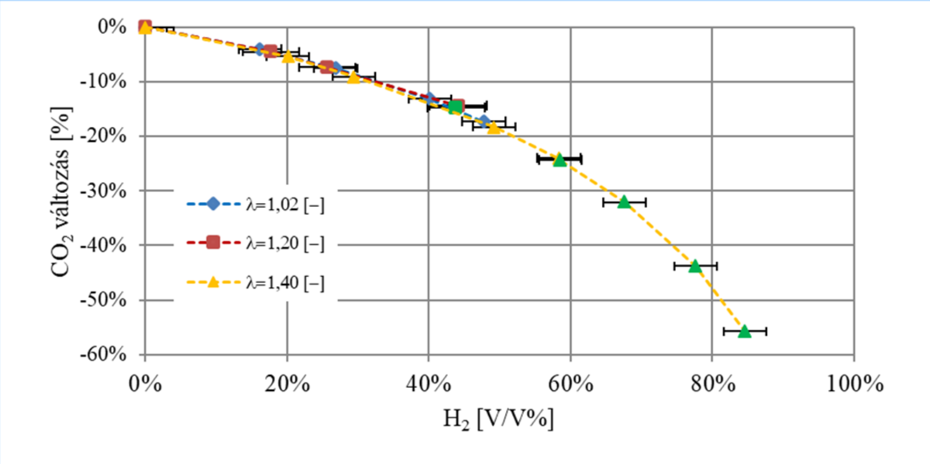
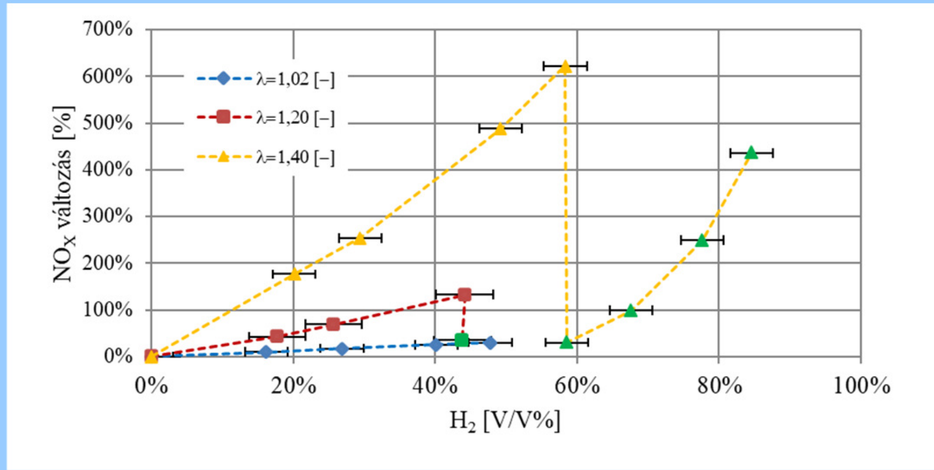
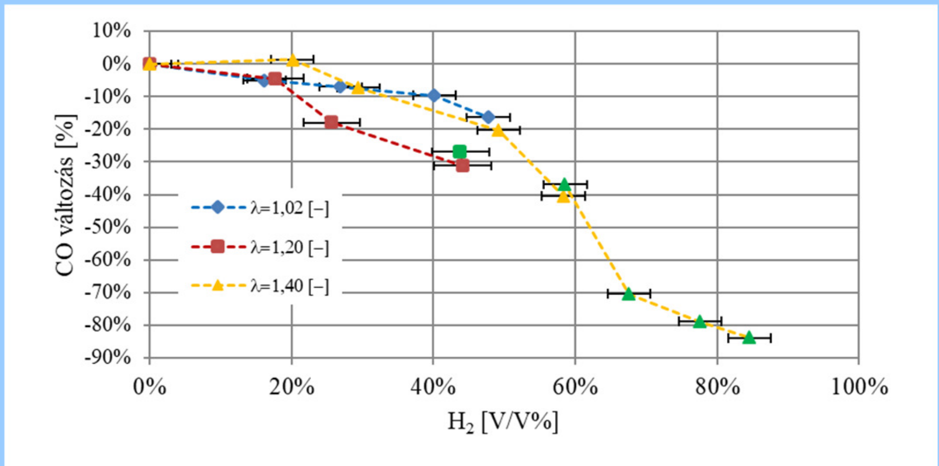
Emissions







Dobi-Szakál, Gyöngy ; Szalontai, Péter ; Lukács, Kristóf ; Meggyes, Attila ; Bereczky, Ákos: Hidrogénbekeverési kísérletek energiatermelés céljára gázmotorokban, MAGYAR ENERGETIKA 30 : 1 pp. 2-6. , 5 p. (2023)

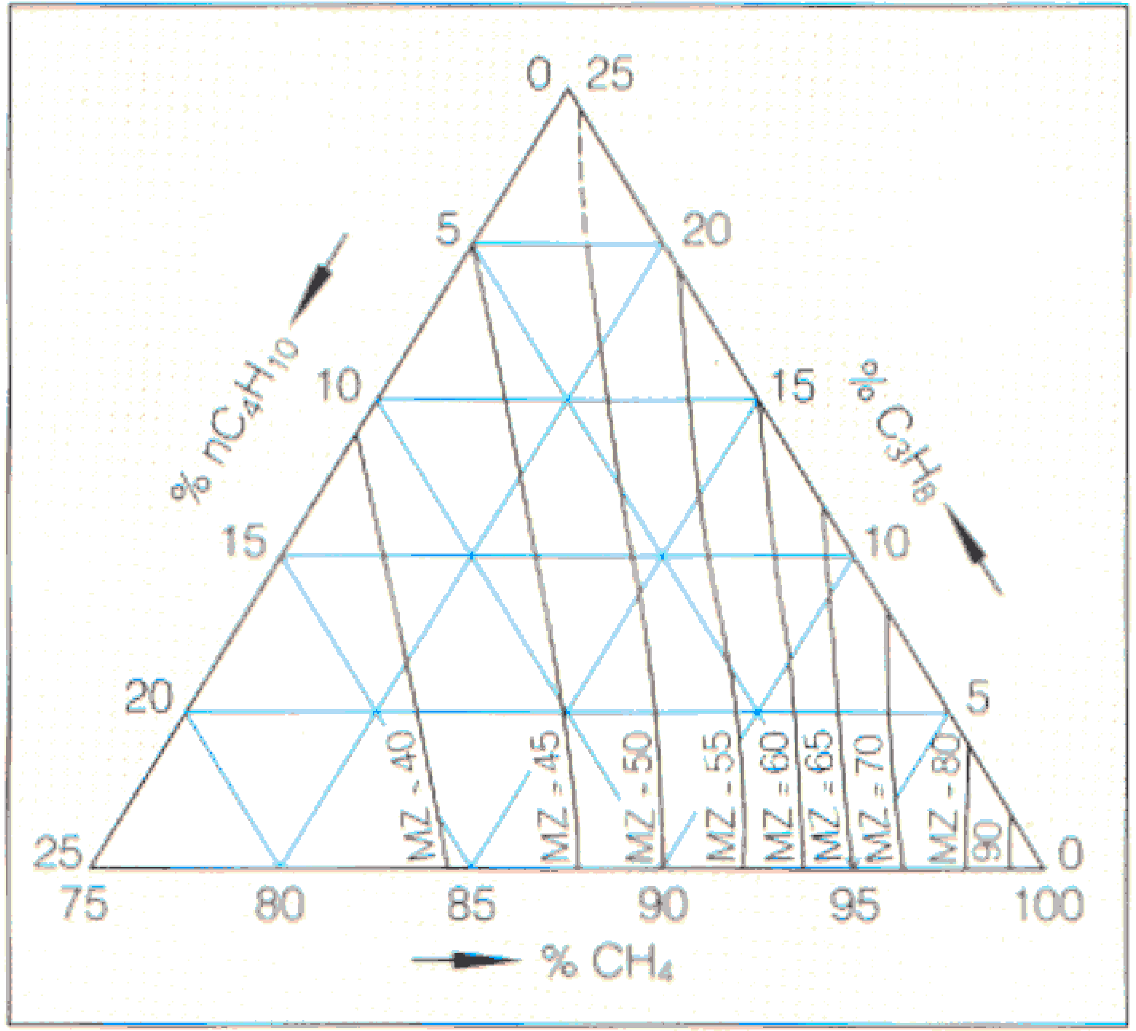


Fig. 17 Determining the methane number of the three-component mixture of methane/propane/butane

Source: DEUTZ

Wobbe index

- The Wobbe index is a measurement of the degree to which fuels can be interchanged.

$$Wobbe\ Index = Wo = \frac{LHV}{\sqrt{d}}\ [\frac{kJ}{kg}]$$

LHV: lower heating value

d: Relative density of the fuel compared with air

$$d = \frac{\rho_{mix.}}{\rho_{air}}$$

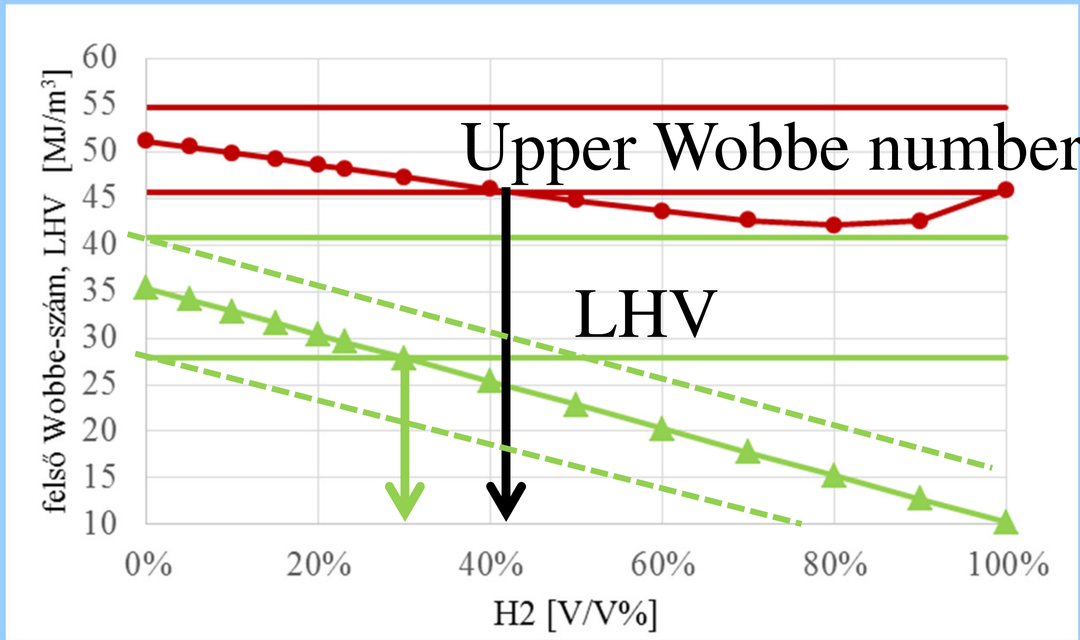
Injector burners(domestic burners)

The Wobbe number characterizes the interchangeability of (fuel) gases:
if another type of gas is to be used on a gas-consuming appliance running with a given type of gas (e.g. H2 mixing), the amount of energy released will only be the same (interchangeable) if their Wobbe numbers are the same
MSZ 1648:2000: 45.66-54.78 MJ/m3 (2H gases)

$$\text{Higher Wobbe number } W_{o,i} = \frac{H_s(HHV)}{\sqrt{d}},$$

Parameter	~~Dimension~~	H2	CH4	NG
compression factor(@15 °C, Pn)	Z [-]	1,001	0,998	0,998
Density (@15 °C, Pn)	kg/m^3	0,085	0,678	0,730
Relative density(@15 °C, Pn)	-	0,070	0,554	0,596
Theoretical combustion air demand[V/V %]	-	2,390	9,700	9,820
LHV 15/15°C	MJ/m^3	10,22	34,02	35,39
Lower Wobbe number	MJ/m^3	38,75	45,70	45,84

Injector burners (domestic burners)



When hydrogen is mixed into NG, the calorific value (LHV) and Wobbe number of the mixture are removed from the prescribed ranges,
However, how much mixing depends on the gas into which the hydrogen is mixed (LNG, interconnector network, etc.).

Injector burners (domestic burners)

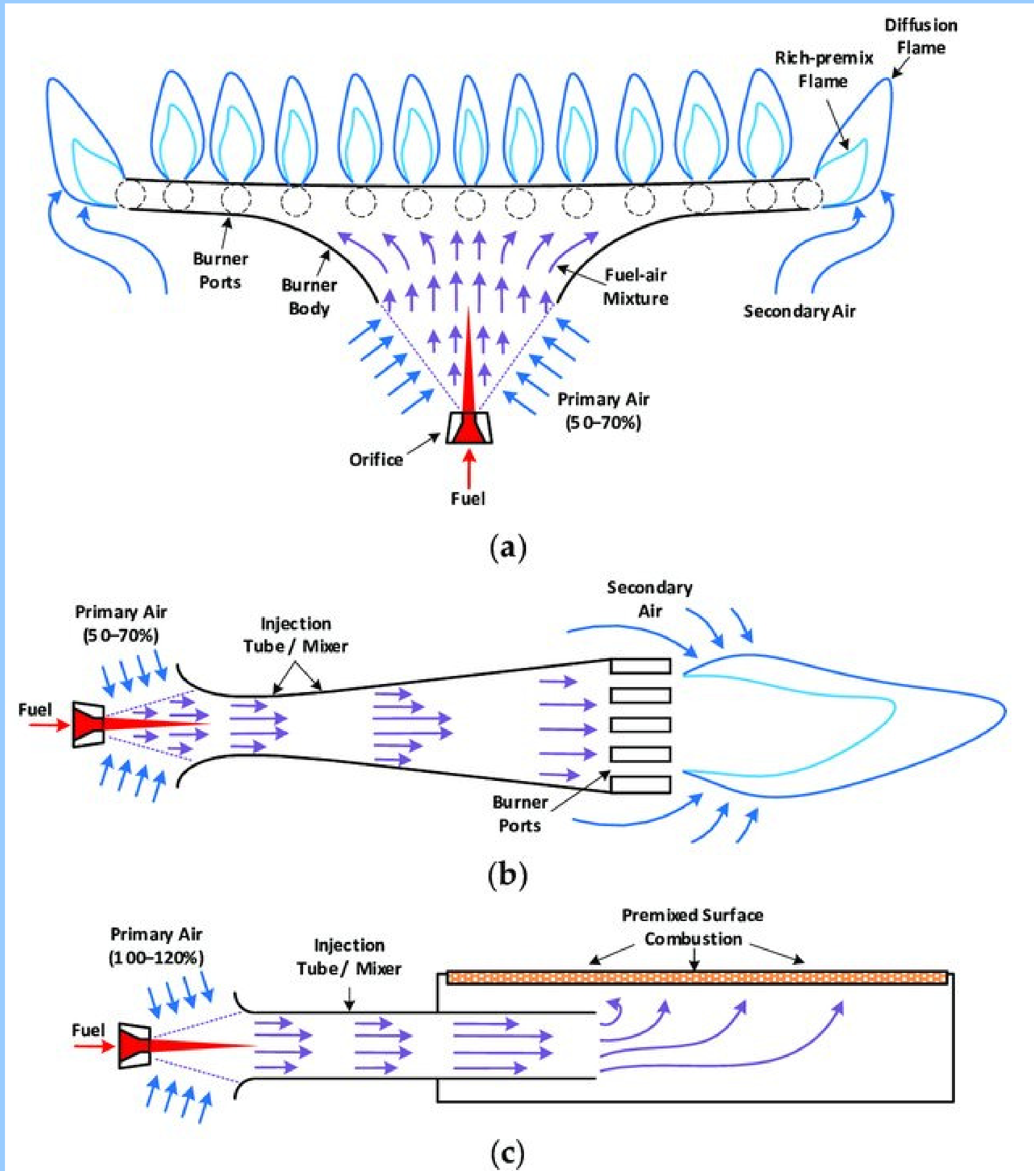
For gas nozzle burners, in which the density of the exhaust gas varies negligibly with a small change in pressure, the Bernoulli equation for incompressible media can be used: $p_0 + \frac{w_0^2 \rho_0}{2} = p_1 + \frac{w_1^2 \rho_1}{2}$

From here gas outflow rate: $w_1 = \sqrt{\frac{2(p_0 - p_1)}{\rho_1}}$

If the pressure difference between p_0 before and after the nozzle is constant (25 mbar), the density of the fuels decreases (e.g. ρ_{H2} = 0.090 kg/m^3, ρ_{CH4} = 0.718 kg/m^3 (15 °C; p_n)) the gas outflow rate increases, of course many losses are not taken into account here (viscosity, flow rabies, etc.).

$$\dot{V}_{fuel} = \sigma \frac{D^2 \pi}{4} \sqrt{\frac{2\Delta p}{\rho_{fuel}}} \left[\frac{Nm^3}{s}\right]$$

Injector burners (domestic burners)



p_1: *ambient* (*Primary air*) *pressure*

p_0: *Fuel pressure*

Impact of Hydrogen/Natural Gas Blends on Partially Premixed Combustion Equipment: NOx Emission and Operational Performance, February 2022, Energies 15(5):1706

Injector burners (domestic burners)

The heat induced by the fuel can also be written in the following equation:

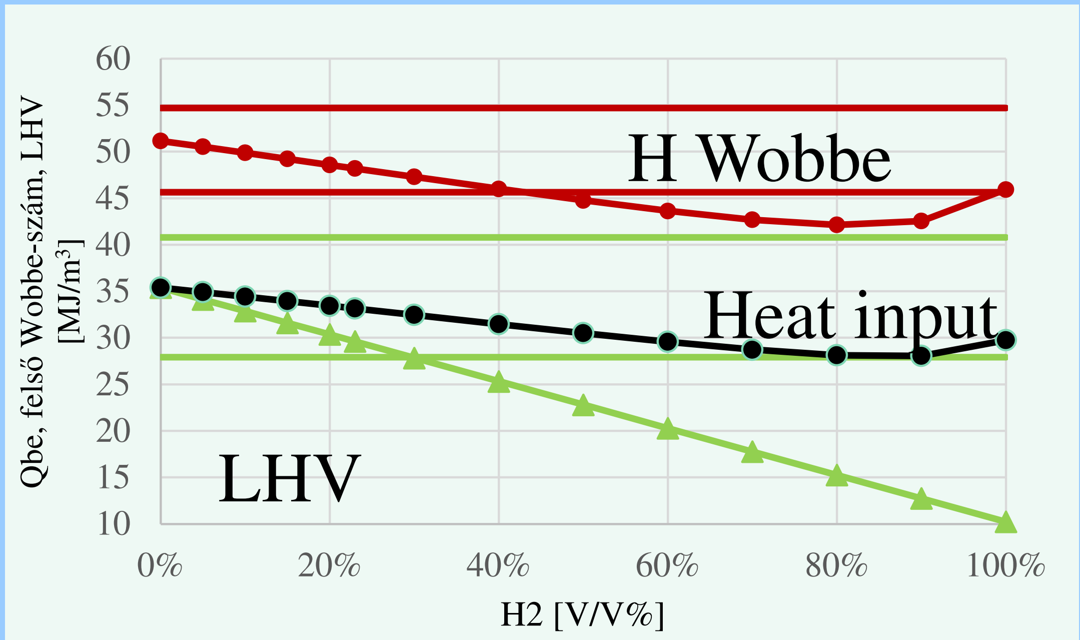
$$\dot{Q}_{in} = \sigma \frac{D^2\pi}{4} \sqrt{\frac{2\Delta p}{\rho_{air}}} \frac{LHV}{\sqrt{\rho_{fuel}}} = \sigma \frac{D^2\pi}{4} \sqrt{\frac{2\Delta p}{\rho_{air}}} WI_{i,fuel}$$

σ [-] Nozzle constriction factor,
D [m] Nozzle diameter,

The Wobbe index is therefore an important parameter

Lezsovits Ferenc, Kun-Balog Attila: TÜZELÉSTECHNIKA GYAKORLATA Segédlet és Példatár alapján

Injector burners (domestic burners)



When mixing 20 V/V% H2 into natural gas, the calorific value decreases to 86%, but the square root of density increases to 1.1%, so the theoretical flow rate increases, so the theoretically transferable heat decreases to only 95%!

A number of losses were not taken into account (viscosity, flow rabies, etc.)