M07. Solid Biofuels – Part 2

Source: biogasmagazine.com

Combustion

- Classification of furnaces
- Principles and examples of small furnaces
- Principles and examples big furnaces
- Efficiency of furnaces

Classification of furnaces

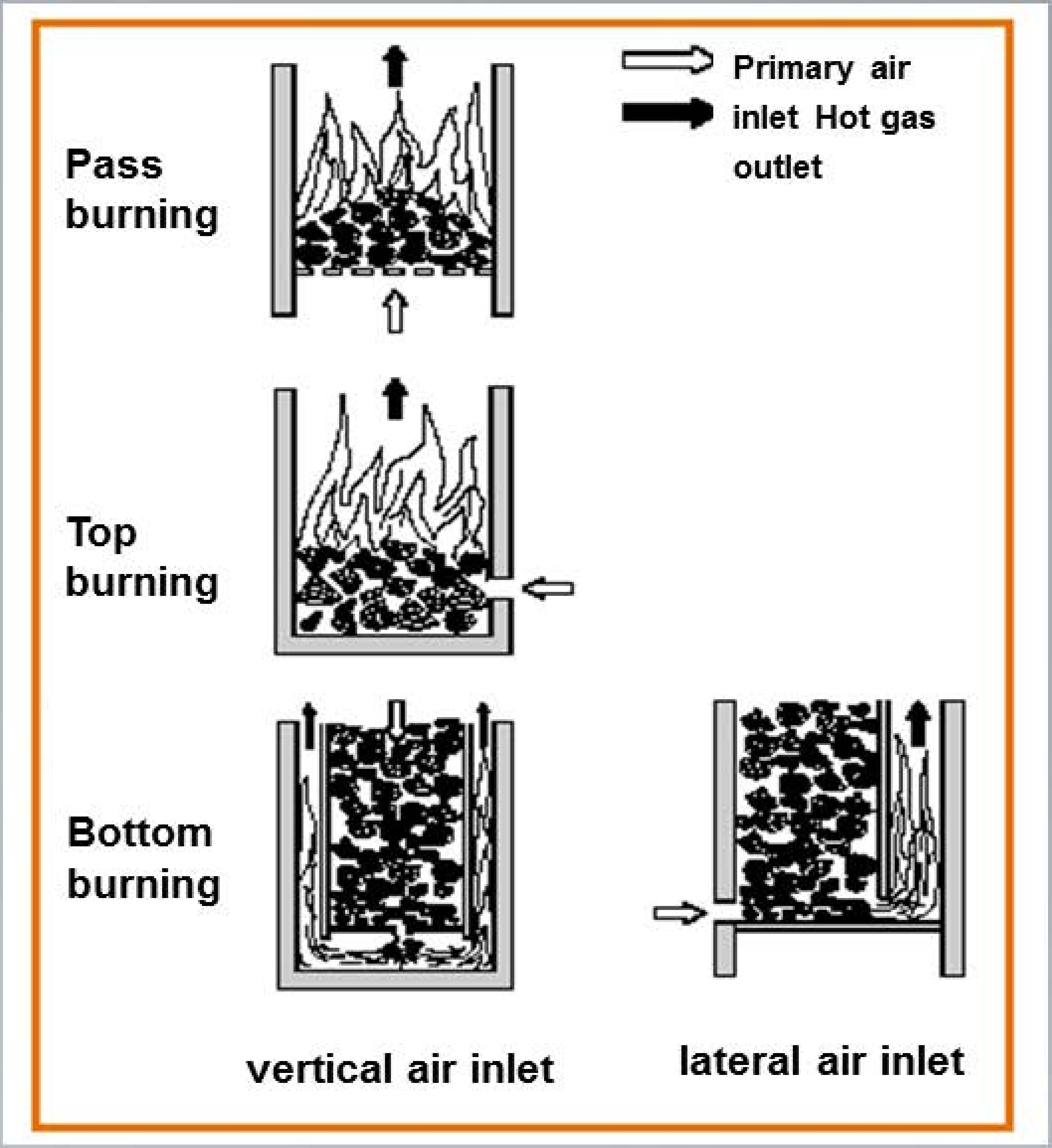
- Burner
  - Furnace (Heat)
    - for technical processes
      - Cooker
      - Steam boiler
      - other technical furnaces
    - for room heating
      - Central heating
        - Heating boiler 8 kW...>20 MW
          - Water (Air)
      - Individual heating
        - Stove (close) 2...30 kW
          - Air (Water)
        - Fireplace (open) 0...>5 kW
          - Air
  - Gasifier (CHP)


http://en.wikipedia.org/wiki/Wood-burning_stove


http://img.archiexpo.com/images_ae/sove-10315.jpg


http://www.heizung-huber.de/img/produkte/holzkessel3.jpg

Principles of combustion
in small manually operated furnaces



Source: Hartmann, H. et al:
Handbuch Bioenergie-Kleinanlagen.
FNR Gülzow, 2003

Modern small wood boilers
for logs and pellets

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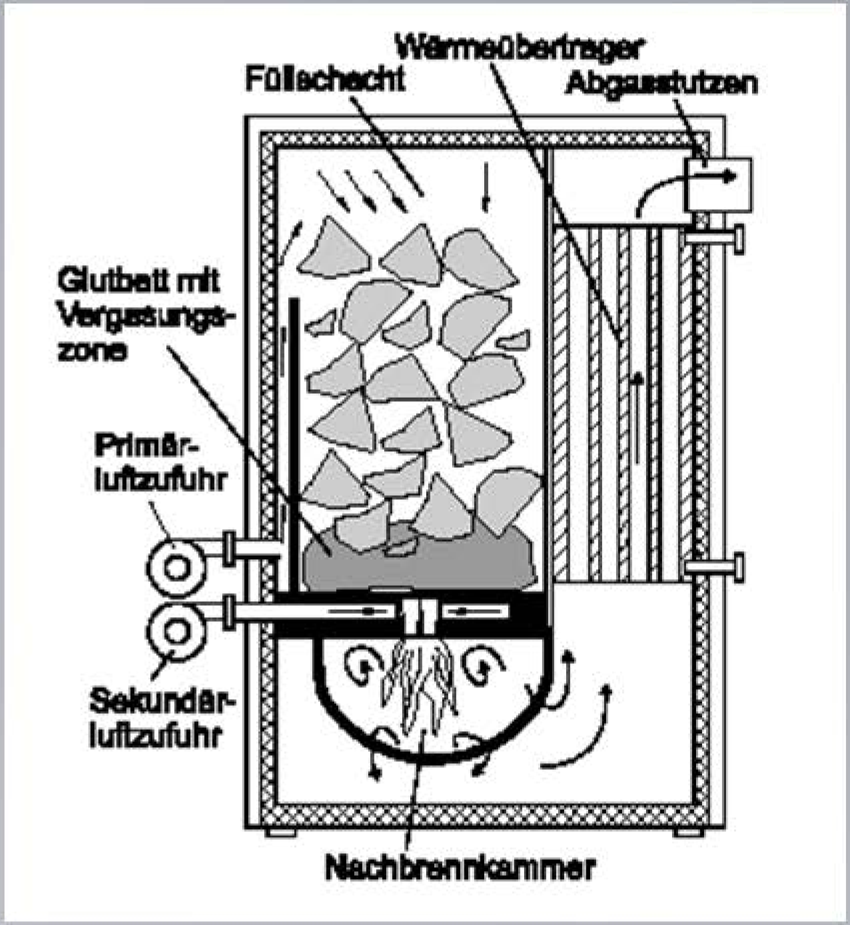
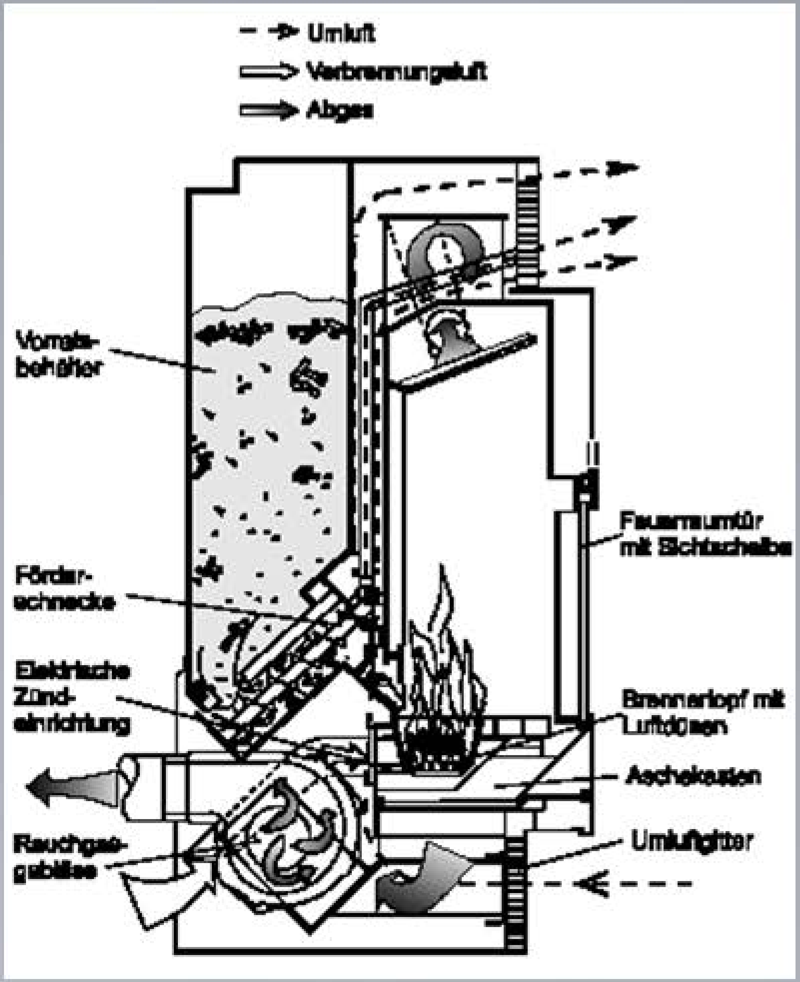
<u>Log/Chunk fed boiler</u>
with bottom burning

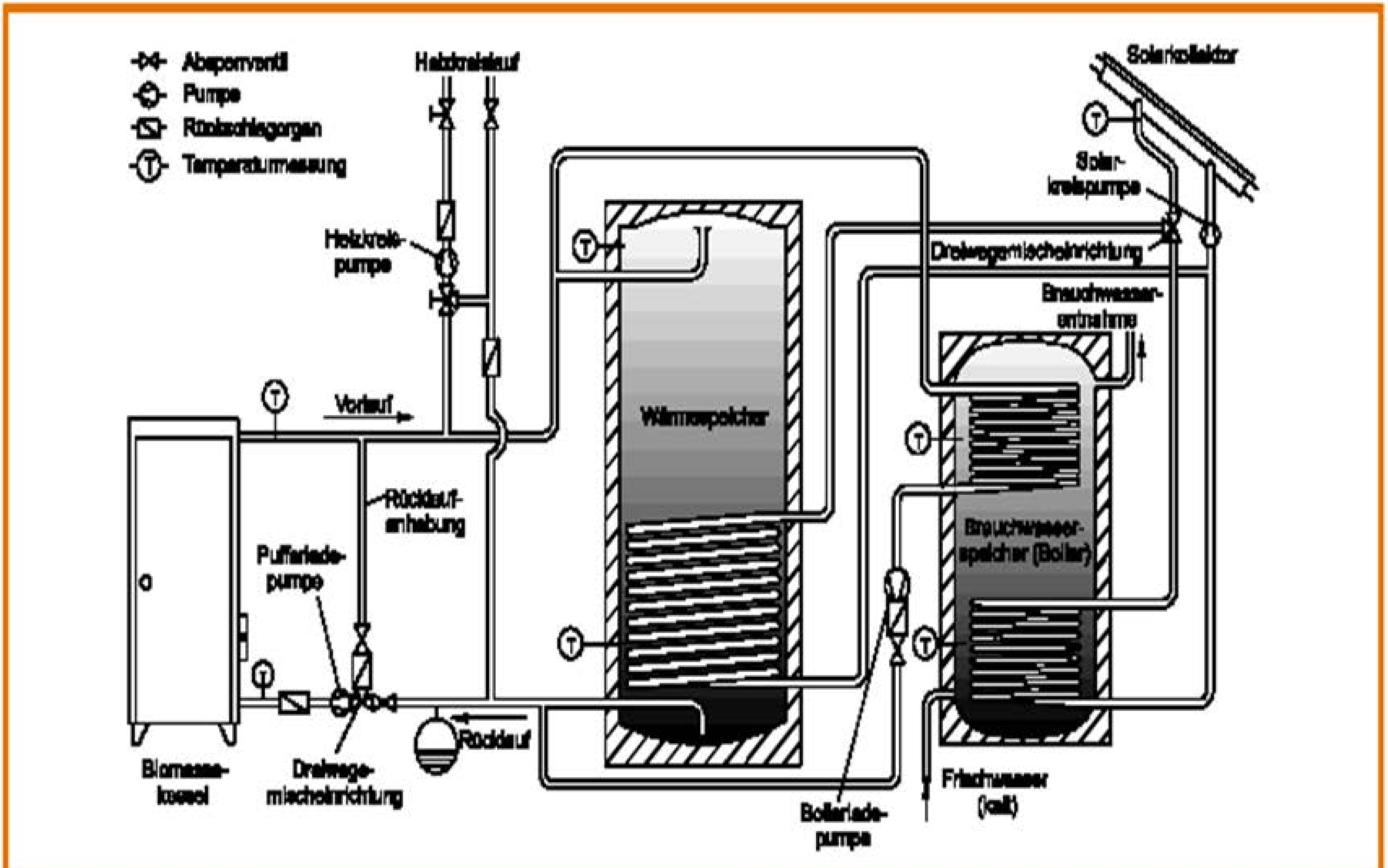


<u>Pellets fed boiler</u>
with bottom burning



Source: Hartmann, H. et al: Handbuch Bioenergie-Kleinanlagen. FNR Gülzow, 2003

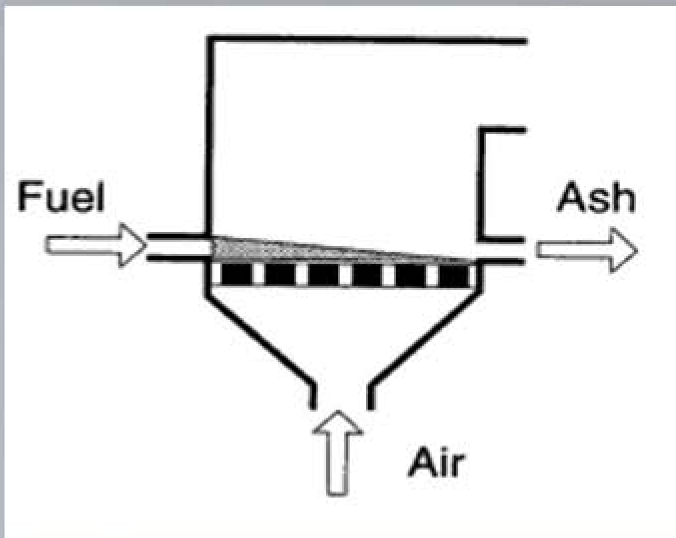
Small wood boiler heating system
combined with a solar heat

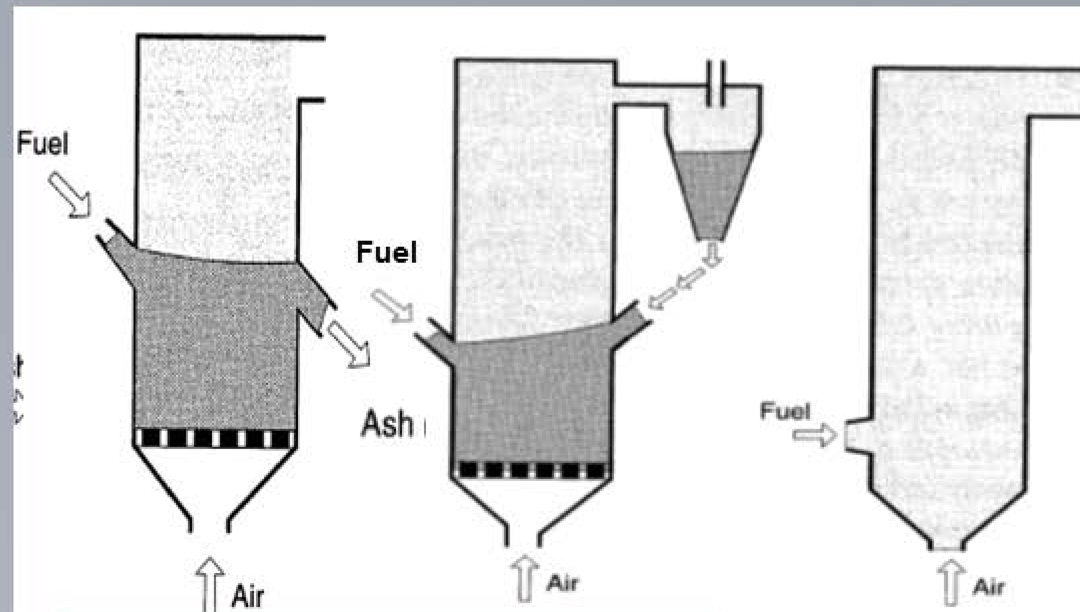


Source: Hartmann, H. et al: Handbuch Bioenergie-Kleinanlagen. FNR Gülzow, 2003

Large biomass boilers > 1 MW

Fixed bed, fluidized bed and dust combustion





Bubling fluidizied bed furnace

Circulating fluidizied bed furnace

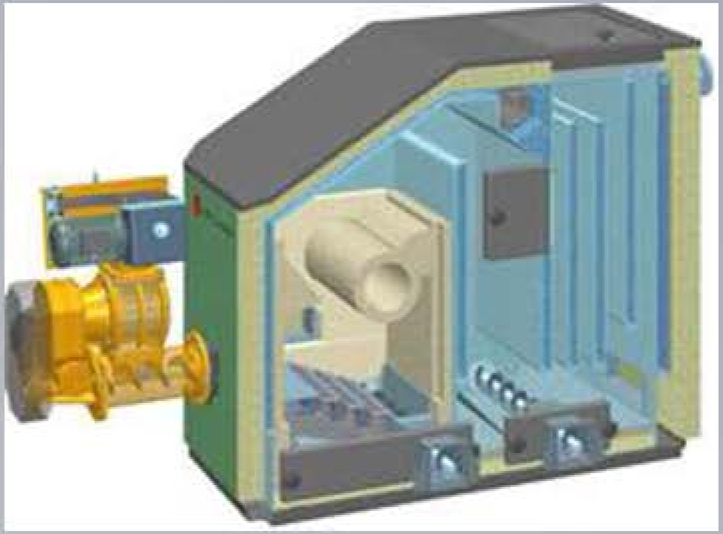
Dust firing

Fixed bed combustion is the most used principle. It is a **robust and cheap technology** and can be used for nearly **all types and sizes of fuels.** But the **emissions** are mostly higher and and the **efficiency are less** than later principles. See at the right → → →

Fluidized bed firing or combustion (FBC) and **injection or pulverized fuel firing (> 5 MW).** They can use a broad variety of fuel types (also difficult types), cause **low emissions,** such as NO_X and SO_2 (the latter by mixing with limestone particles). However, they need **small fuel particles** and the equipment and operation **costs** are high.

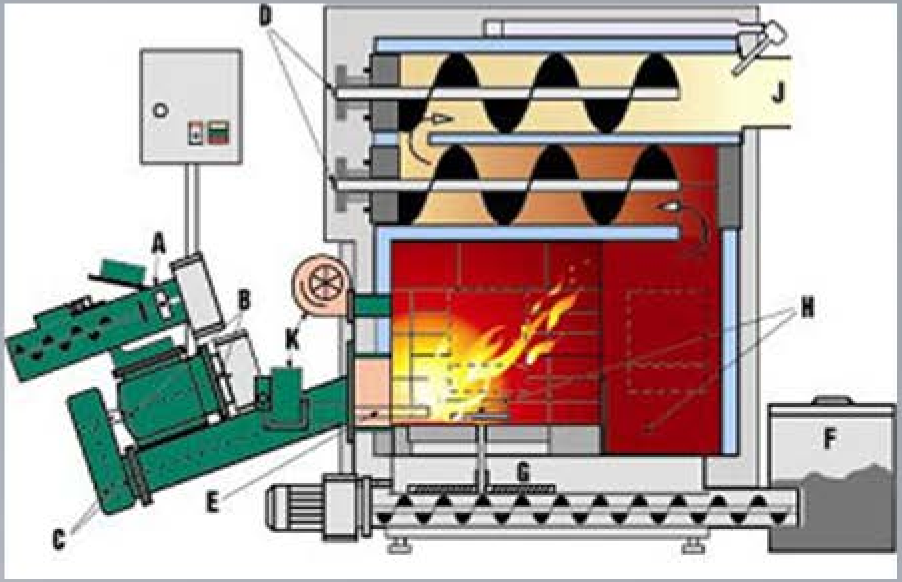
Large wood chip boilers
Examples of conventional fixed bed combustion

Grate firing system



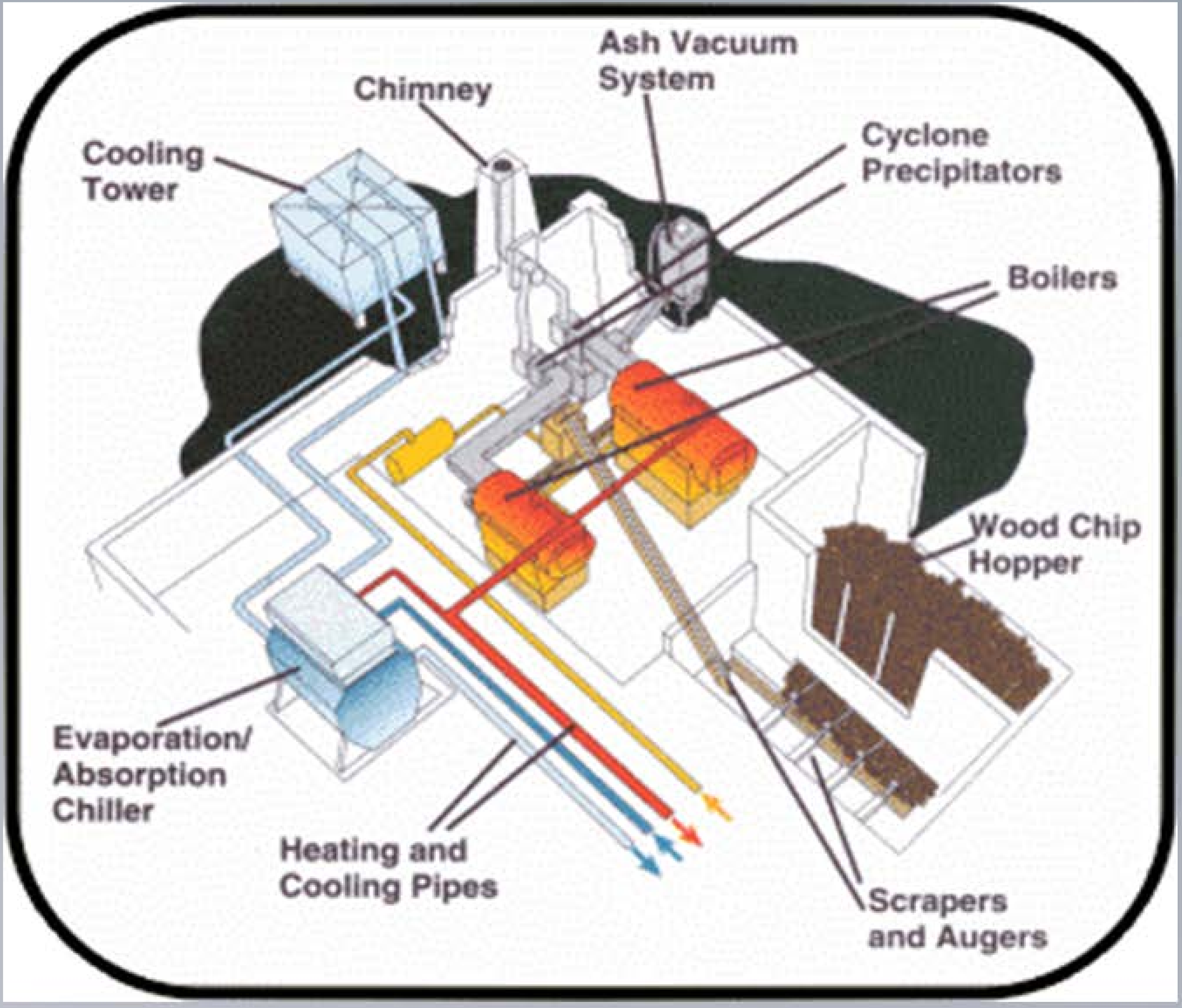
Source: HDG Bavaria

Underfeed system



Source: Holzabsatzfonds

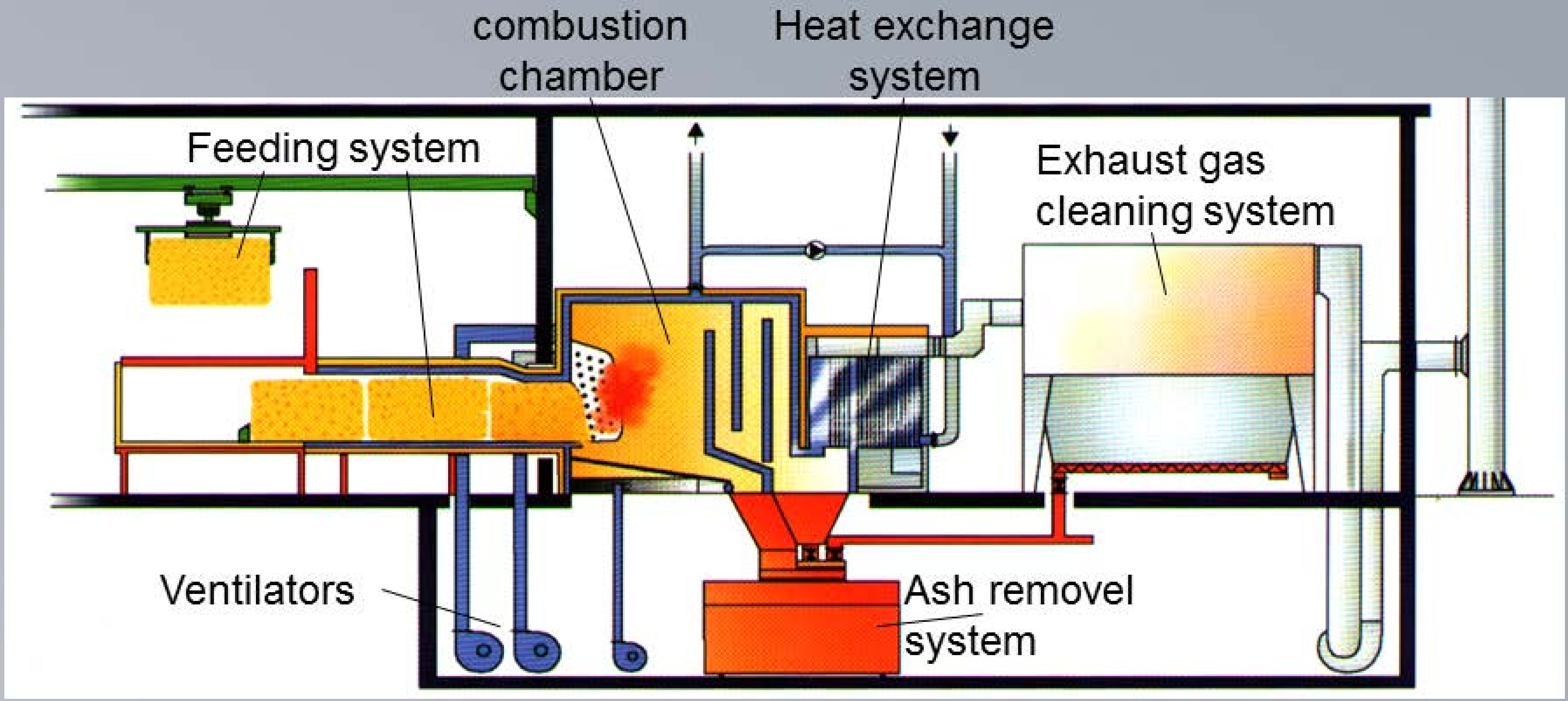
Entire combustion plant > 1 MW for wood chips



Source: liedlodge.org/graphics/fuelwood.gif

Entire combustion plant > 1 MW
for integral straw bales

„Burning of cigars“ - an interesting principle for direct combustion of rectangular straw bales

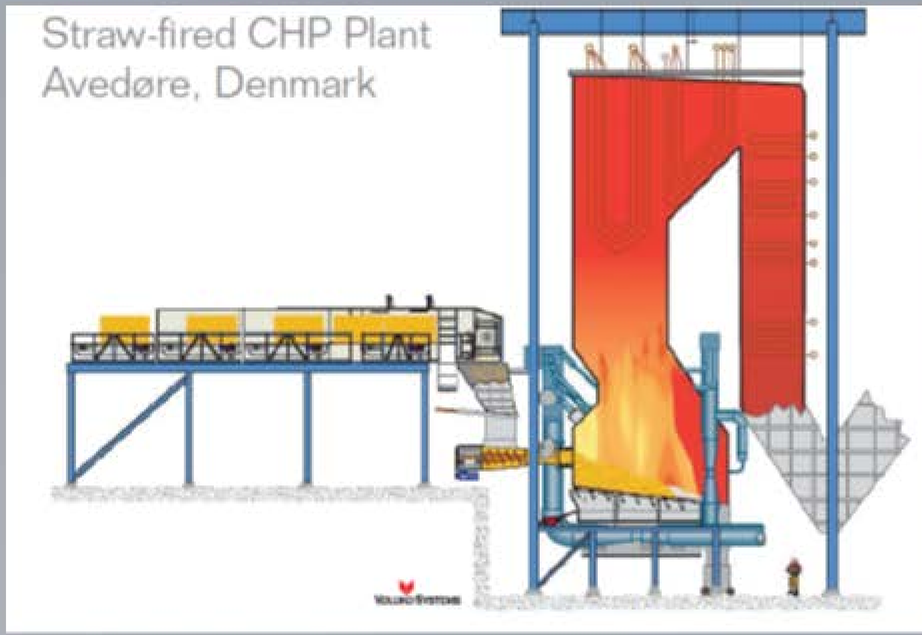


There were only one in Germany and a few ones in Denmark, but a lot of chopped straw boilers are in use!

Source: renac

Rice straw combustion
A technological challenge

Not in this way, but in that one → → →



<u>Special problems of rice straw:</u>

- Low heating value
- High ash content
- Low ash melting point
- High Cl content

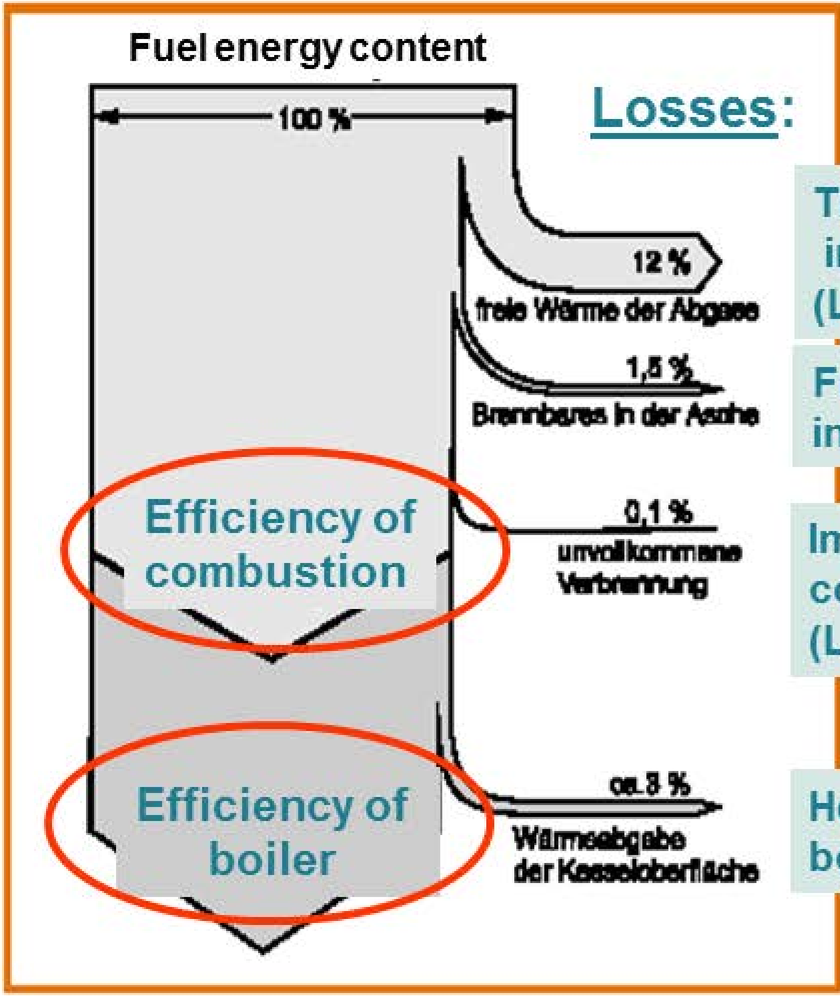
→ Adapted combustion technologies and/or combined combustion with better fuels.

Source: Intelligent-Sootblowing.com

Rice husks cause less problems!
See above.

Efficiency of furnaces

Total losses of a boiler



Thermal losses in flue gas (L_{therm})

Fuel rests in ash

Imperfect combustion (L_{chem})

Heat loss of boiler surface

Source: Hartmann, H. et al: Handbuch Bioenergie-Kleinanlagen. FNR Gülzow, 2003

$$L_{therm} = {,}01 \frac{(T_E - T_A)\left[1{,}39 + \frac{122}{CO_2 + CO} + W\right]}{(HV_{db}/100) - 0{,}25W}$$

L_{therm}... Thermal losses
L_{chem}... Chemicla losses
T_E... Temperature of flue gas
T_A... Temperature of air
W... Moisture of fuel
HV_{db}... Heating value LHV_{DM}

$$L_{chem} = 0{,}01 \frac{11800}{(HV_{db}/100) - 0{,}25W} \frac{CO}{CO_2 + CO}$$

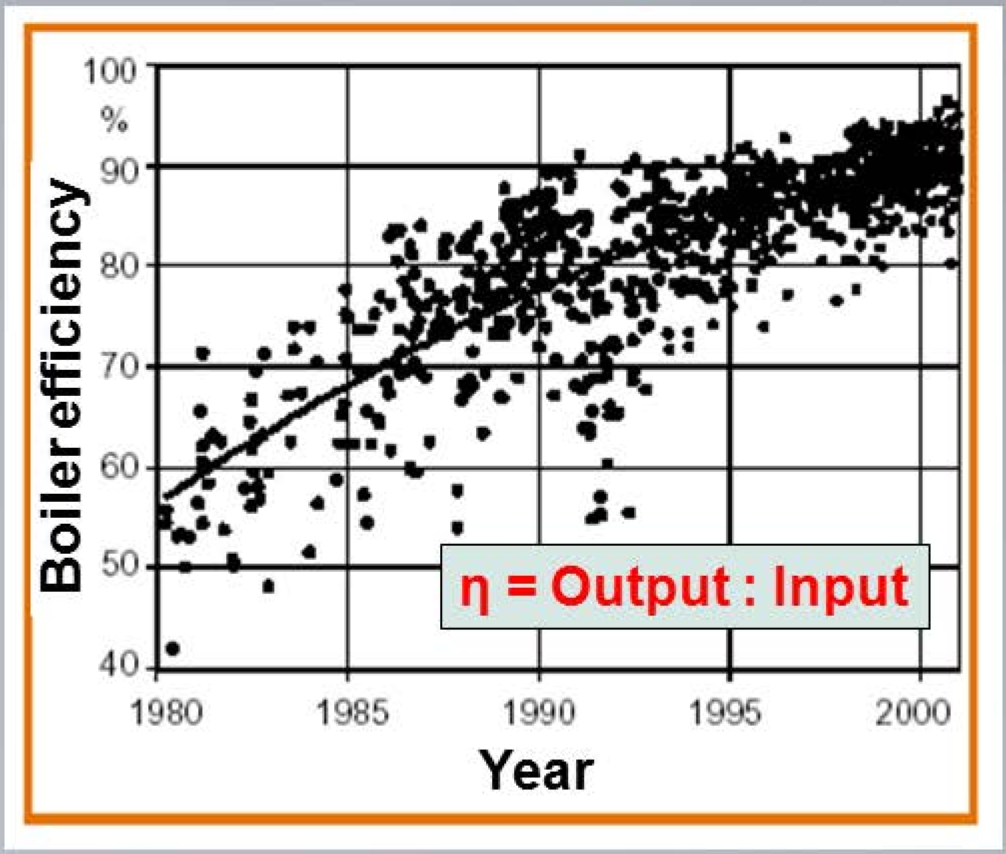
for wood combustion
$CO < 0{,}5\%$, $CO_2 > 5\%$
(vol%) e $t_E < 400°C$

CO_2 can be calculated on base of O_2:

$$CO_2 = 0{,}98(21 - O_2) - 0{,}61\ CO$$

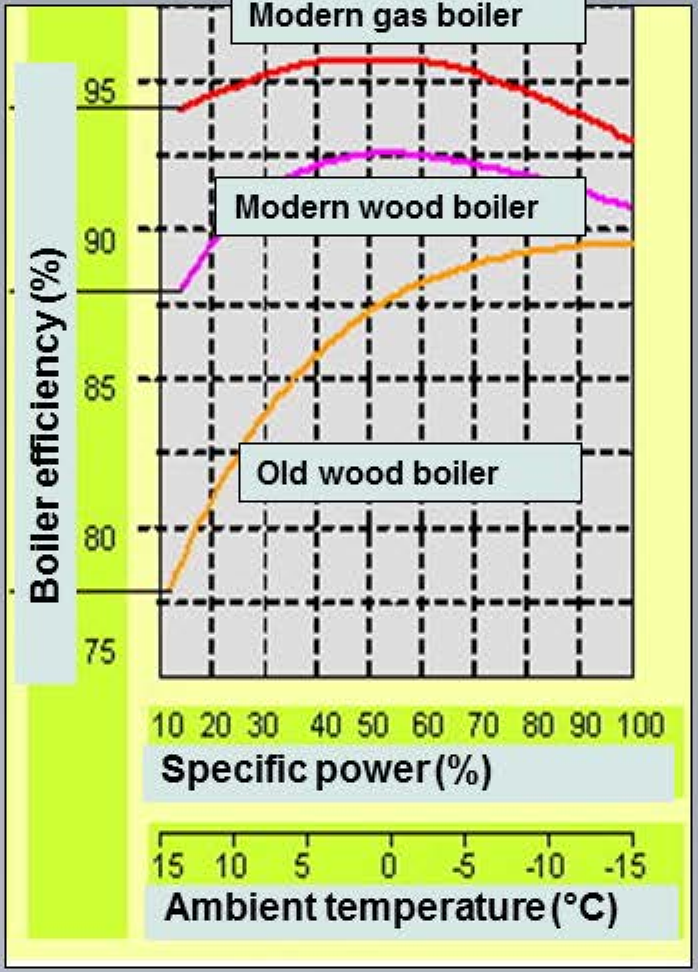
Efficiency of wood boilers
Trends and load dependancy

Development of the efficiency (η) of wood boilers in Europe



Source: Hartmann, H. et al: Handbuch Bioenergie-Kleinanlagen. FNR Gülzow, 2003

The boiler efficiency depends on load



Source: www.ing-büro-junge.de/ html/technik.html

Gasification

- History and Definition
- Chemical basics
- Classifications of gasifiers
- Characteristics of gases
- Practical problems of gasification

History

The Process of producing energy using the gasification method has been in use for **more than 180 years**. During that time **coal and peat** were used to power these plants. Initially developed to produce town gas for **lighting & cooking** in 1800s, this was replaced by electricity and natural gas, it was also used in blast furnaces but the bigger role was played in the production of synthetic chemicals where it has been in use since the 1920s.
During both world wars especially the **Second World War** the need of gasification produced fuel reemerged due to the shortage of petroleum. **Wood gas generators**, called Gasogene or Gazogène, were used to power motor vehicles in Europe. By 1945 there were **trucks, buses and agricultural machines** that were powered by gasification (9,000,000 vehicles all over the world).

However, the main problem up to now is the quality of gas!

Definition

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, biofuel, or biomass, into **carbon monoxide (CO) and hydrogen (H_2)** by reacting the raw material at **high temperatures** with a **controlled** amount of **oxygen and/or steam**. The resulting gas mixture is called **synthesis gas or syngas** and is itself a fuel.

Source: http://en.wikipedia.org/wiki/Gasification

Lanz-Bulldog with Imbert gasifier (1942)

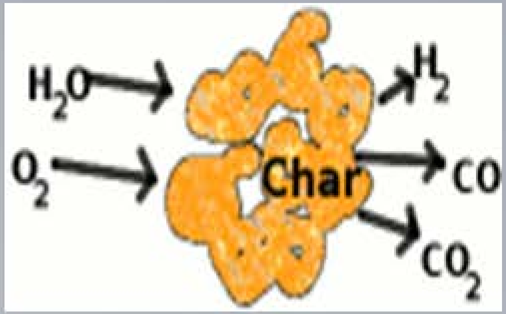
http://www.wka.tu-harburg.de/vergasung/wie/einleit.html und Ising, FNR 2000

Gasification process
Chemical basics

In a gasifier, the carbonaceous material undergoes **several different processes**:

1. The **pyrolysis** (or devolatilization) process occurs as the carbonaceous particle heats up. **Volatiles** are released and **char** is produced, resulting in up to 70% weight loss for fuel. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.
2. The **combustion** process occurs as the **volatile** products and some of the **char** reacts with **oxygen** to form **carbon dioxide** and **carbon monoxide**, which provides **heat** for the subsequent gasification reactions. Letting C represent a carbon-containing organic compound, the basic reaction here is
3. The **gasification** process occurs as the **char** reacts with **carbon dioxide** and **steam** to produce **carbon monoxide** and **hydrogen**, via the reaction
4. In addition, the reversible gas phase **water gas shift reaction** reaches **equilibrium** very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen

In an **ideal syngas** is **$CO : H_2 = 1 : 2$.**
This stoichiometric relation can be controlled by admixture of water (steam).
The energetic **efficiency** of the gasification is **60-80%**, incl. gas cleaning.



Source: http://en.wikipedia.org/wiki/Gasification

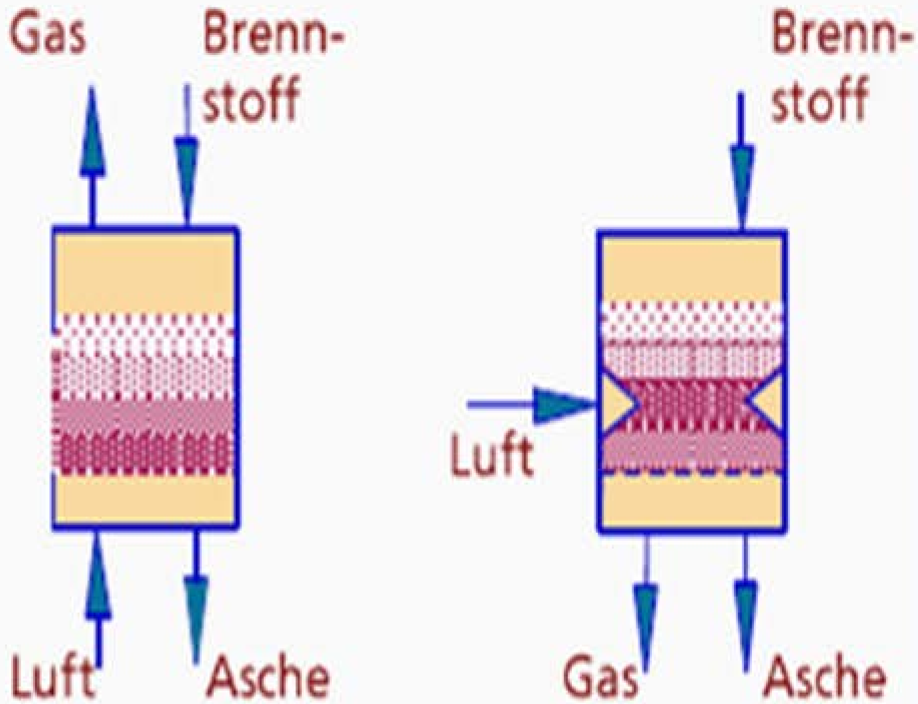
Classification of gasifiers (1)

Fixed bed gasifiers

Fixed bed:

(gravimetric movement)

- Zone of drying
- Zone of pyrolysis
- Zone of oxidation
- Zone of reduction



Counter-current fixed bed (up-draft) gasifier

Co-current fixed bed (down-draft) gasifier

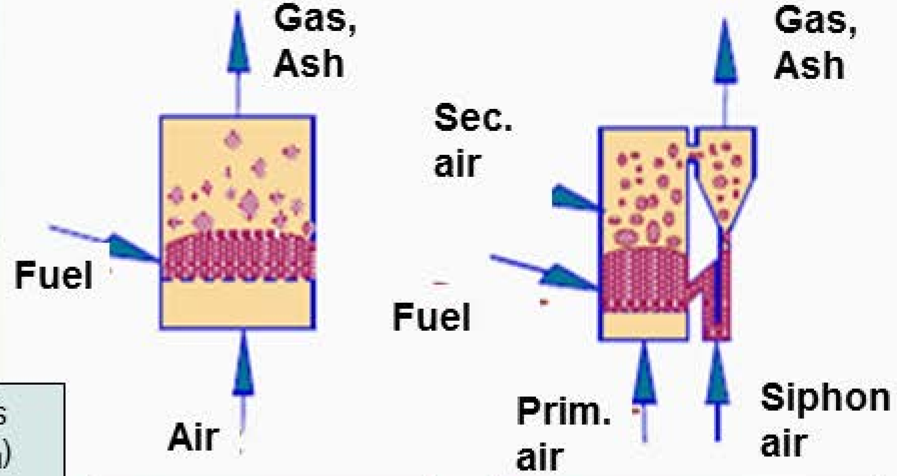
Source: renac

Classification of gasifiers (2)
Fluidized bed and other gasifiers

Fluidized bed:

Fluidized bed

Freeboard

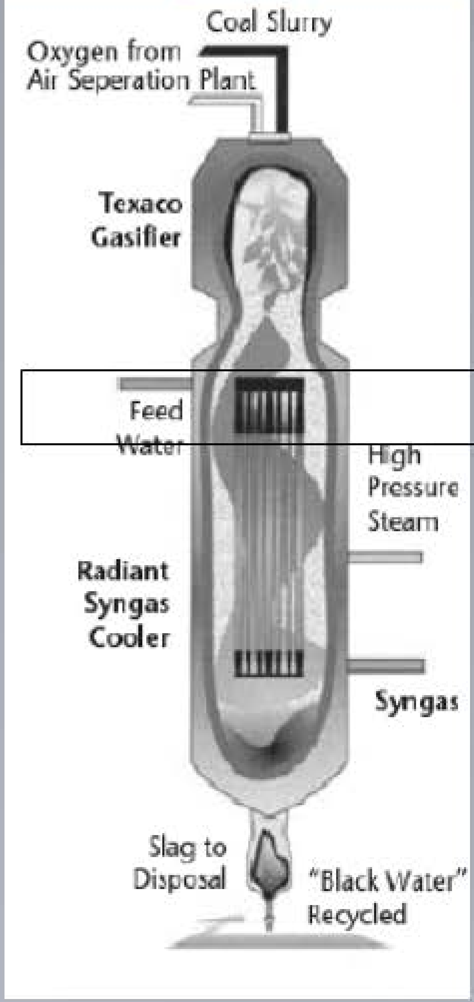


The world's largest biomass gasification plant (140 MW_{el}) is on base of a circulating fluidized bed gasifier and is located in Vaasa, Finland, but co-combustion with coal (Metso, 2013).

Stationary fluidized bed gasifier

Circulating fluidized bed gasifier

Another type: Fly-stream gasifier



Further types:

- Gasifier with rotating drum
- Gasifier with two phases
- etc.

Source: renac

Comparison of the principles
of gasifiers

	Content of tar in gas	Content of dust in gas	Constancy* of gas production	Scaling-up possibility	Typical power range
Fixed bed co-current	very low	moderate	partially bad (power)	bad	0.005 – 0.5 MW
Fixed bed counter-current	very high	moderate	moderate	moderate	0.5 – 10 MW
Fluidized bed stationary	moderate	high	very good	good	0.5 – 20 MW
Fluidized bed circulating	low	very high	very good	very good	1 – 100 MW

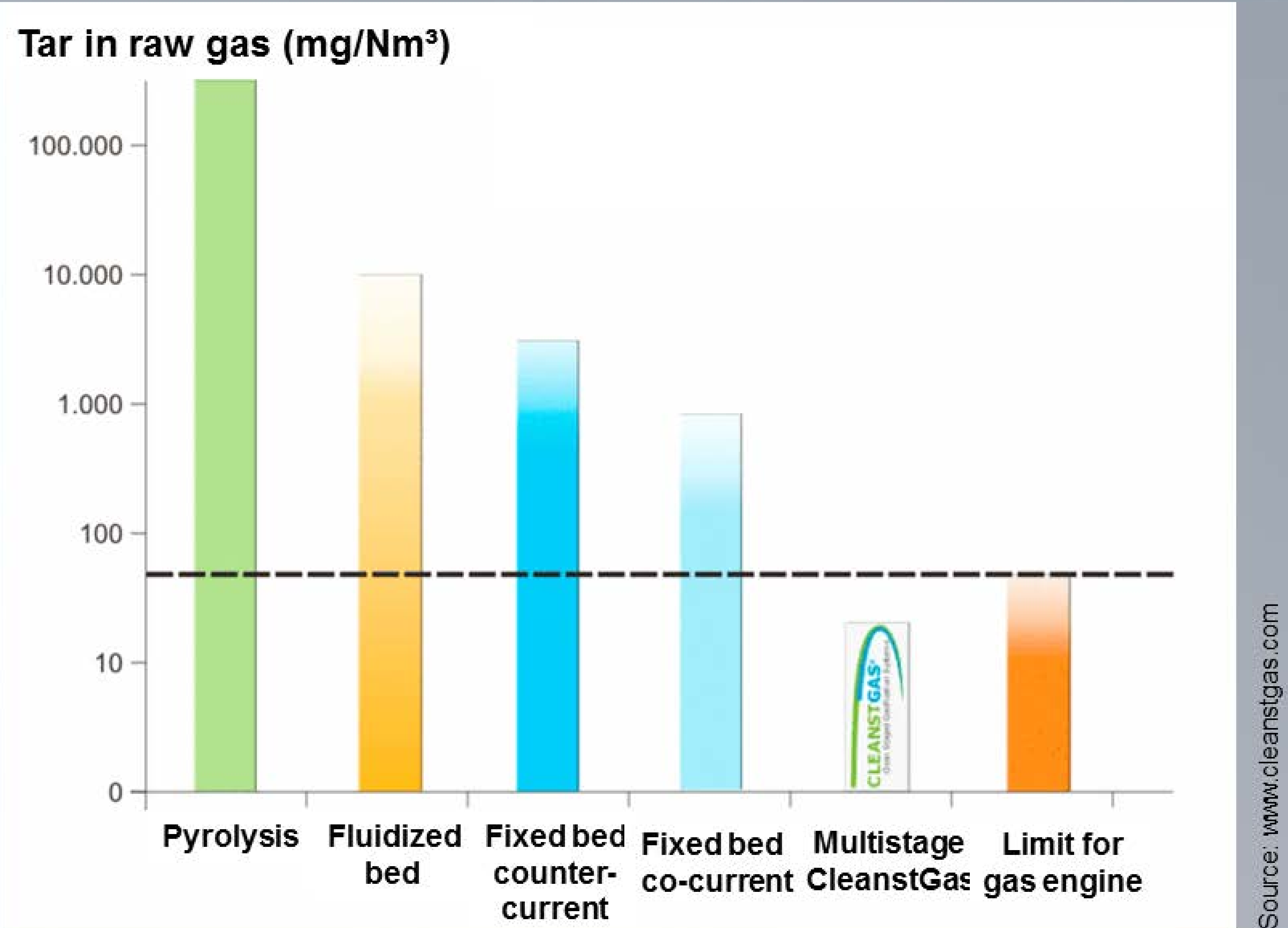
* Regarding amount and heating value of gas

Source: Dipl.-Ing. Markus Ising: Gülzower Fachgespräch »Energetische Nutzung von Biomasse durch Kraft-Wärme-Kopplung: Stand der Technik und Perspektiven für den ländlichen Raum«, Gülzow, 16.-17. Mai 2000. Fraunhofer-Institut für Umwelt- Sicherheits- und Energietechnik UMSICHT, Oberhausen

Tar content for use in engines at maximum: 50 - 100 mg/m³ !

Source: renac

Content of tar
from different types of gasifiers



Purification of syngas
Reasons and measures

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Gasifier → Purifier → Gas turbine / Gas engine / Fuel cell / Steam process

Purification (cleaning) of crude gas is necessary because of

- **Solid particles**
- **Tar**
- **Harmful gas components (NH_3, H_2S, COS, Alcali)**

→ Primary measures: **Selection or modificaton of gasifier typ**

→ Secondary measures:

- **Hot gas filter, Cyclone or Electrostatic separator**
- **Gas scrubber with various materials**
- **Catalysts, e.g. Nickel**
- **Dolomite ($CaMg(CO_3)_2$) as cracker**

Source: renac

Problems of the gasification
of biomass in practice

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- There is no standard equipment for gas purification available.
- High or varying contents of tar and other harmful gas components make it difficult to use the gas in engines.
- The disposal of waste (esp. tar) is problematically.
- Varying fuel properties cause problems in controlling the gasifier and in feeding it.
- The costs, esp. for investments, operation and maintenance are very high.

⇨ **So it is necessary to adjust all components and aspects.**

Not all problems are solved up to now.
The gasification of biomass is still a subject of research!

Nevertheless there are several biomass gasifiers on the market,
e.g. a 150 kW_{el} (CHP) wood pellet gasifier of Fa.Burkhardt/Germany and
a 50 kW_{el} (CHP) wood chip gasifier of Fa. Spanner Re2/Germany etc.

Heat-to-power conversion

- Principles of conversion
- Selected examples
- Efficiency

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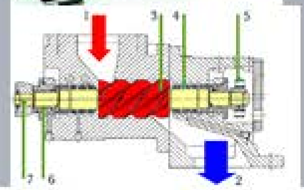
Conversion technologies
for production of electricity from solid biofuels

Combustion processes:

- **Generation of steam**
  - steam turbine process (1,0 – 20 MW_{el})

  - steam engine process (0,2 – 1,5 MW_{el})

  - steam screw type engines (0,1 – 2,5 MW_{el})



- **Organic Rankine Cycles** (0,1 – 3 MW_{el})

- **Stirling engines** (0,001 – 0,15 MW_{el})

Mostly State of the Art !

Gasification/Pyrolysis processes:

- **Generation of combustible gases** by gasification
  - electricity generation in internal combustion engines (0,005 – 5 MW_{el})
  - electricity generation in gas turbines (> 10 MW_{el})
- **Generation of Hydrogen** by reforming the combustible gases
  - electricity generation in Fuel cell systems (0,005 – 5 MW_{el})
- **Generation of Liquid Fuels** by biomass pyrolysis
  - electricity generation in internal combustion engines (0,005 – 5 MW_{el})

Experimental stage or pilot plants, R&D necessary !

Source: renac

Conversion of bioenergy to power (and heat)
via combustion

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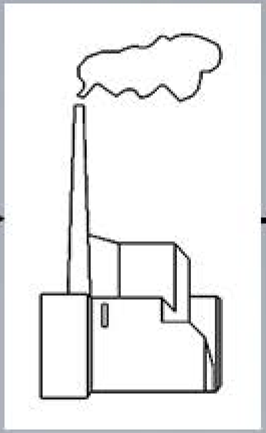
Cogeneration plant = CHP plant

Combined heat and power, or **cogeneration** is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat.

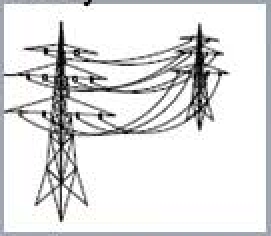
Biomass 100 %

Emissions



Combustion 85 – 90%

↓ Ash



Power* 15 – 30 %

Heat 50 – 60 %

Losses 15 - 25 %

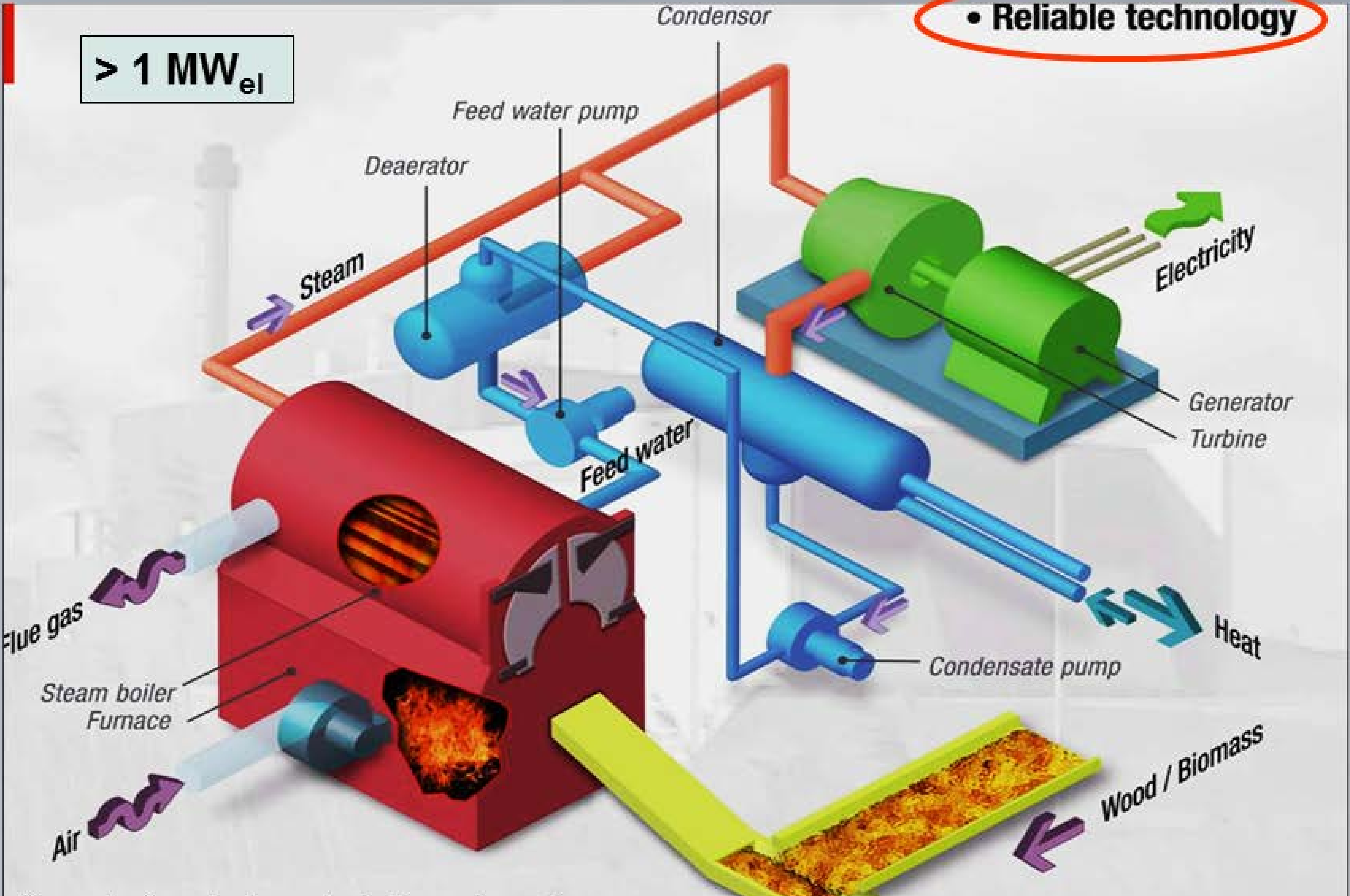
* own power demand (5 - 10% of the total output) is considered

In a (mere) **power plant,** without heat usage, the <u>electric</u> efficiency is **up to 35%** because of further conversion processes of the heat.

The power generation via **<u>gasification</u>** and gas turbine, gas engine etc. is theoretically more efficient, and also applicable for < 1 MW_{el}, but currently not reliable (gas quality etc.). See above!

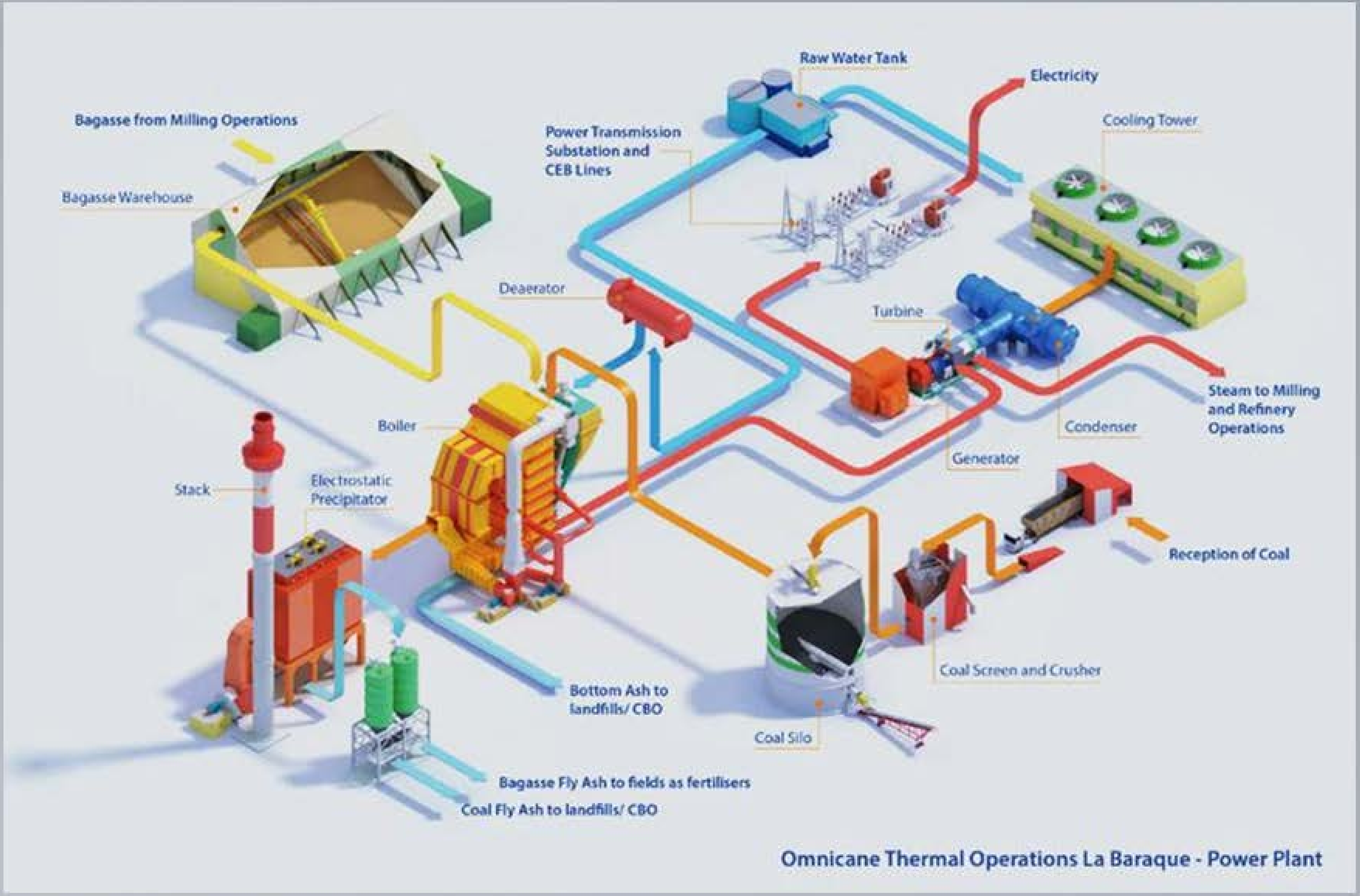
Source: renac

Wood fed cogeneration plant
with a steam turbine



Source: businessdevelopment.gr/en/images/cogen.jpg

Bagasse fed cogeneration plant
with a co-fired fuel and a steam turbine



Rice husk power plant
with a steam turbine

- Net capacity: 20 MWe
- Project start: Jan. 2004
- Start of operation: Dec. 2005
- Thermal-electrical conversion efficiency: 30%
- Rice husk consumption: 144 000 t/y from 30 rice mills
- Capital cost: US$ 36 million
- Operator: A.T. Biopower
- Pichit/Thailand

Source: cept.co.th

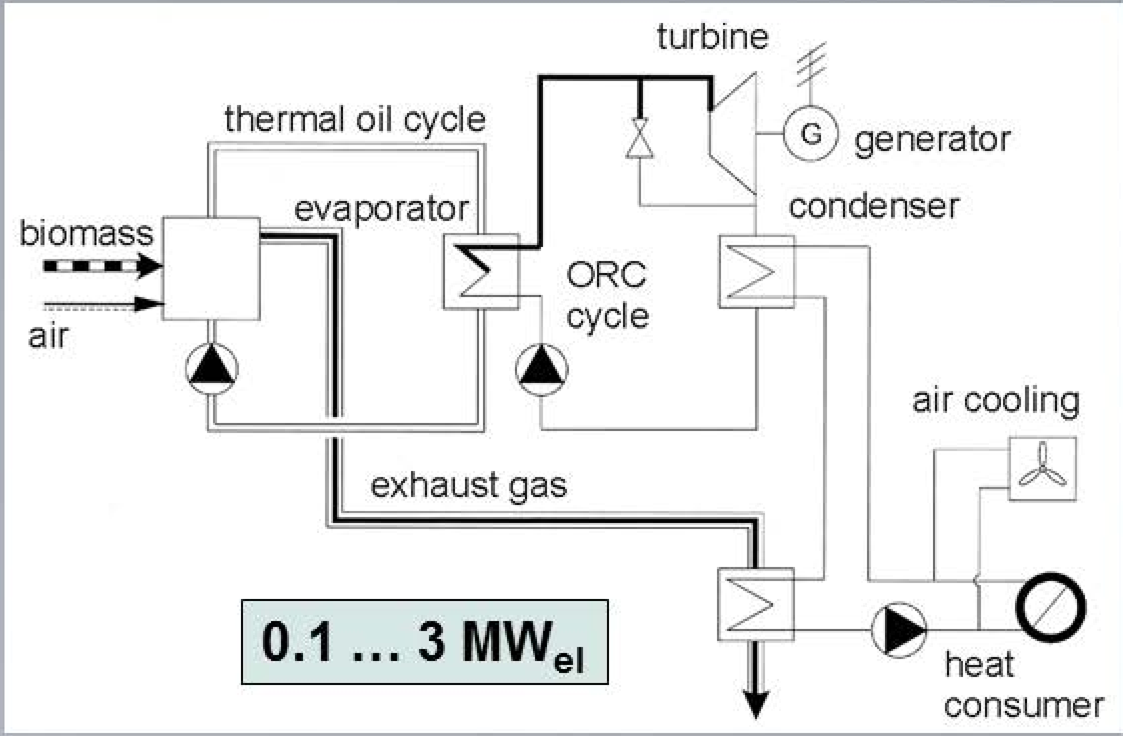
Organic Rankine Cycle process
for medium-size CHP plants

ORC Process
Organic Rankine Cycle

named after Willam J.M. Rankine, 1820-1872, Scotland

As medium, organic matter is used with **low boiling and condensation temperature.**

Temperature range of boiler **70-100°C**.
Control of upper temperature needed,
thermal oil used for a boiler.



Simplified scheme of ORC process (Kaltschmitt, Hartmann, 2001)

Via combustion
a very low **efficiency** of **electricity** generation,
less than 10…17%.

Wood fed cogeneration plant
basing on Organic Rankine Cycle

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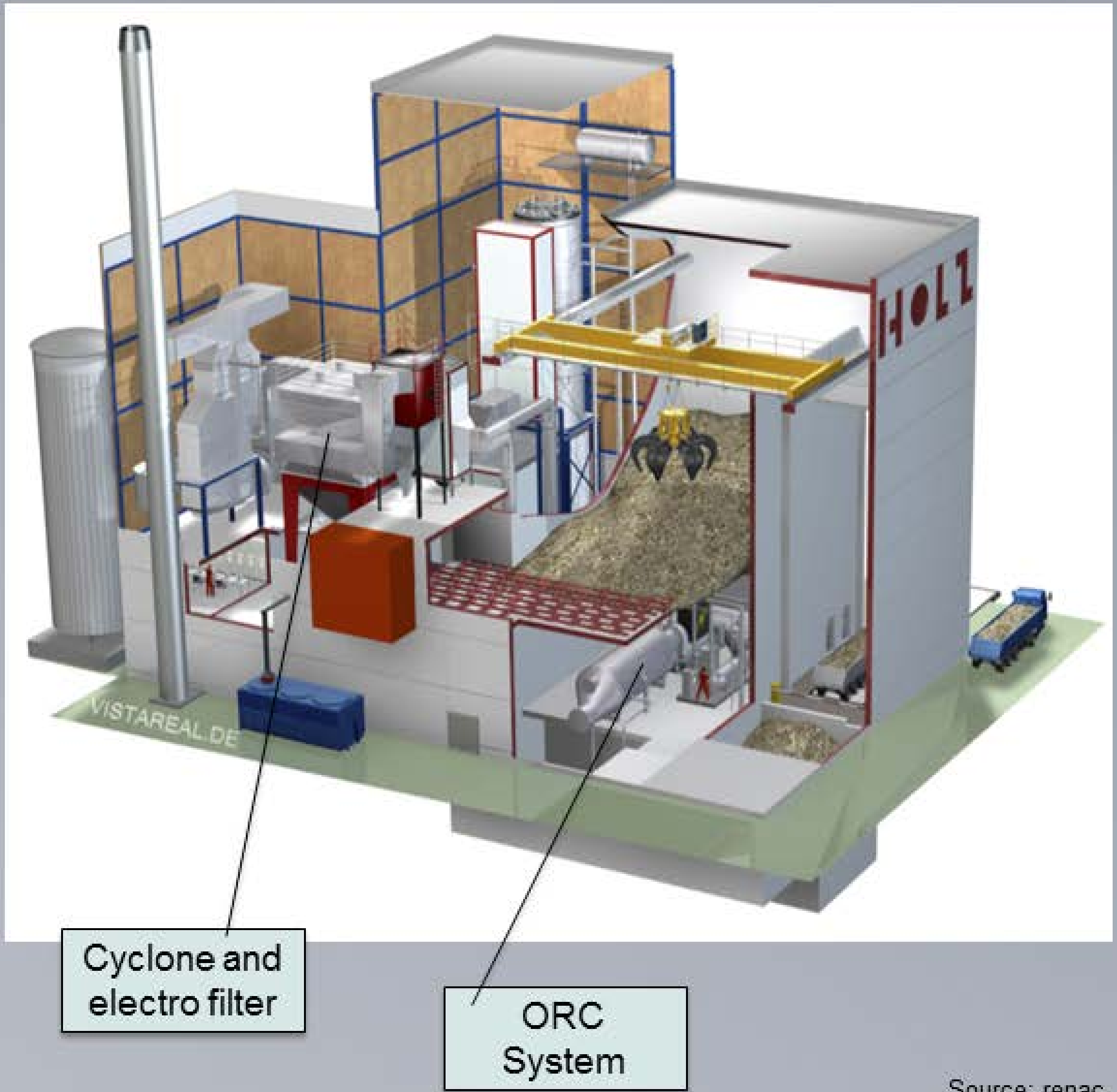
Specifications:

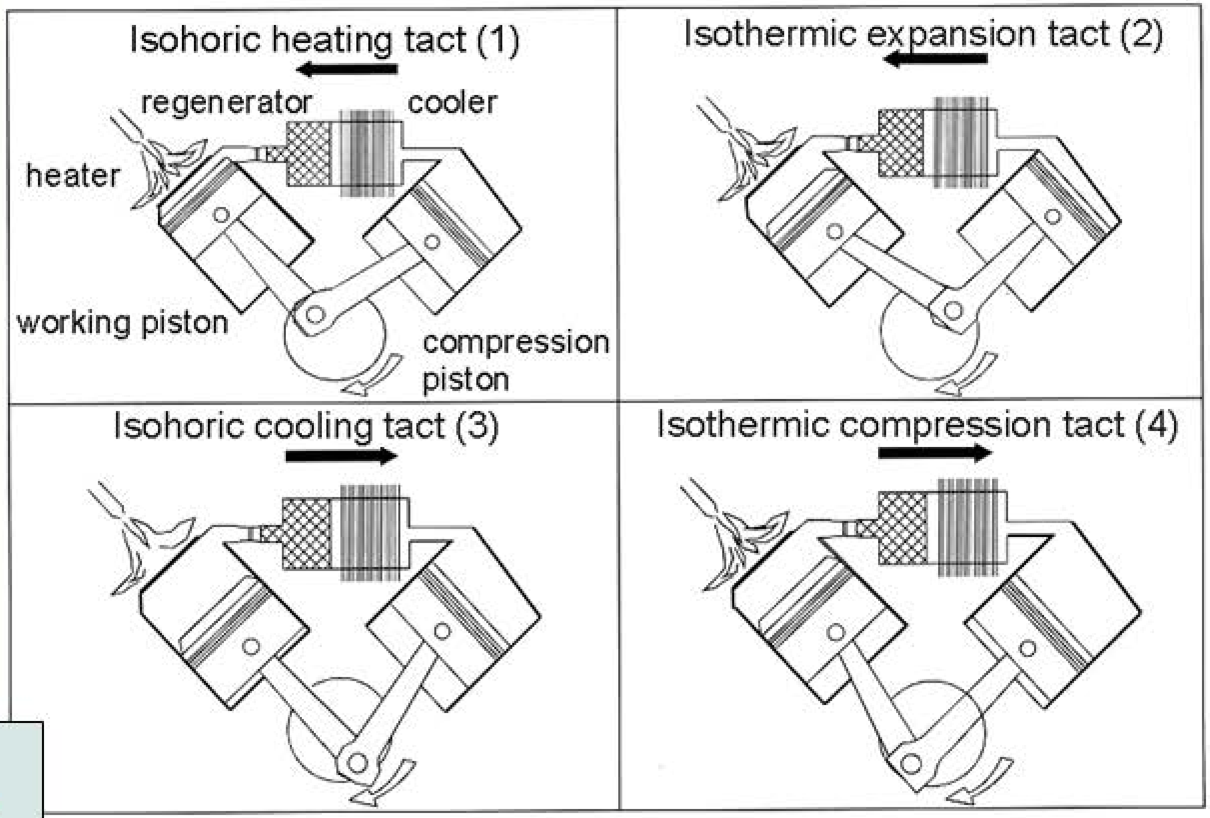
- 1,9 MW electric power
- 12 MW thermal power
- 30 000 t/year of natural wood chips
  - 4 fixed vendors, 20 km range
  - 7 trucks per weekday
- CO_2-Savings: 23 000 t/year
- Invest: 13 Mio. €
- Building time: 1,2 years
- Hamburg-Lohbrügge Germany



Source: renac

Stirling process
for small power units

Invented by Robert Stirling in Scotland, **1815**. **Any heat** source can be used, e.g. solar heat, but you need a temperature **difference**.
Very important to have big regenerator, porous material, high heat capacity. Always the **same gas** inside the engine.



Simplified scheme of an Alpha Stirling engine (Kaltschmitt, Hartmann, 2001)

The efficiency of **electricity** generation is only **up to 10...25%.**

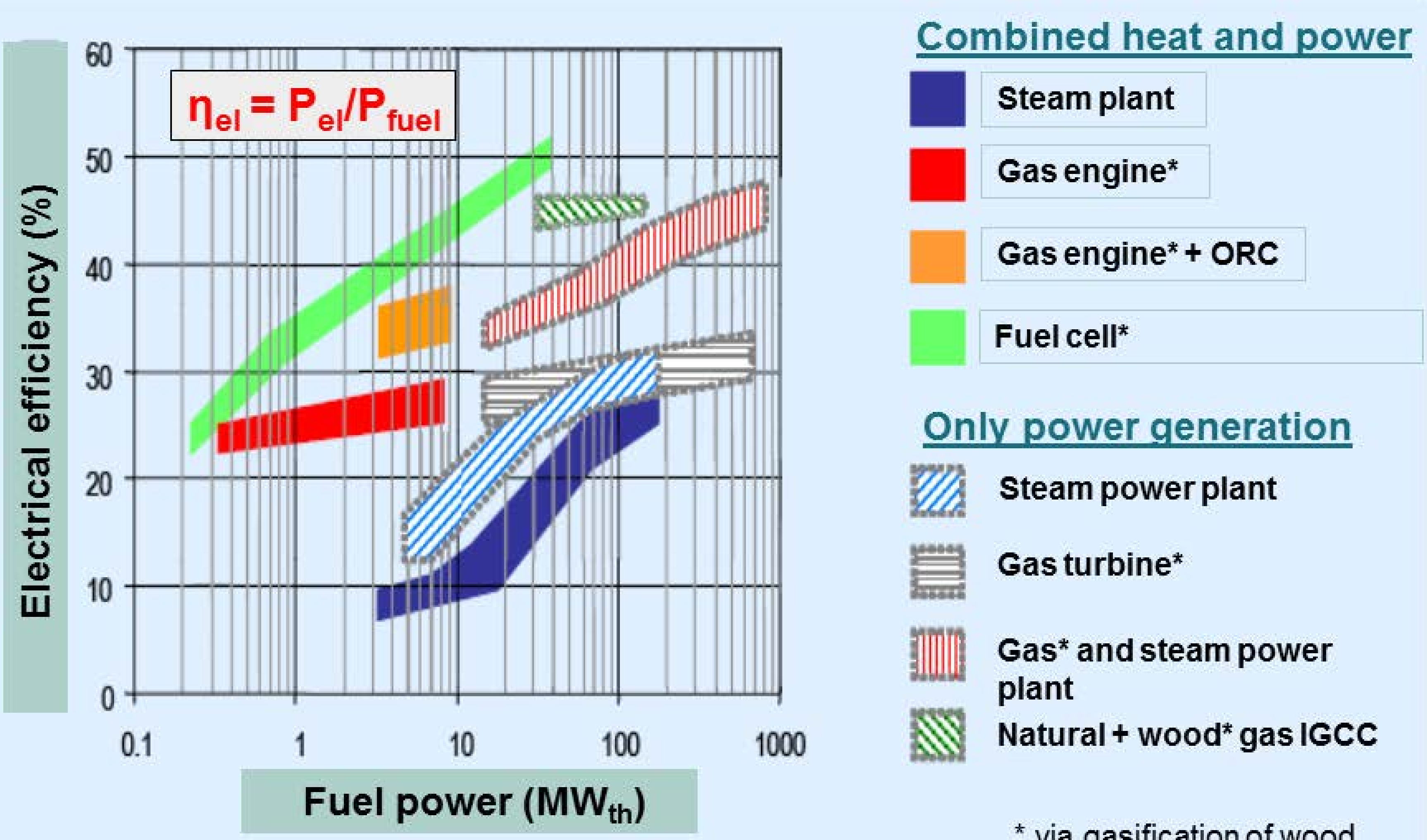
1 … 150 kW_{el}

More details in:
http://en.wikipedia.org/wiki/Stirling_engine

Isochoric heating tact (1) – Gas is heated by regenerator.
Isothermal expansion tact (2) – Gas expands using thermal energy of external heater.
Isochoric cooling tact (3) – Gas flows though regenerator to the cool zone.
Isothermal compression tact (4) – Heating of cool zone.

isochoric = constant volume
isothermal = constant temperature

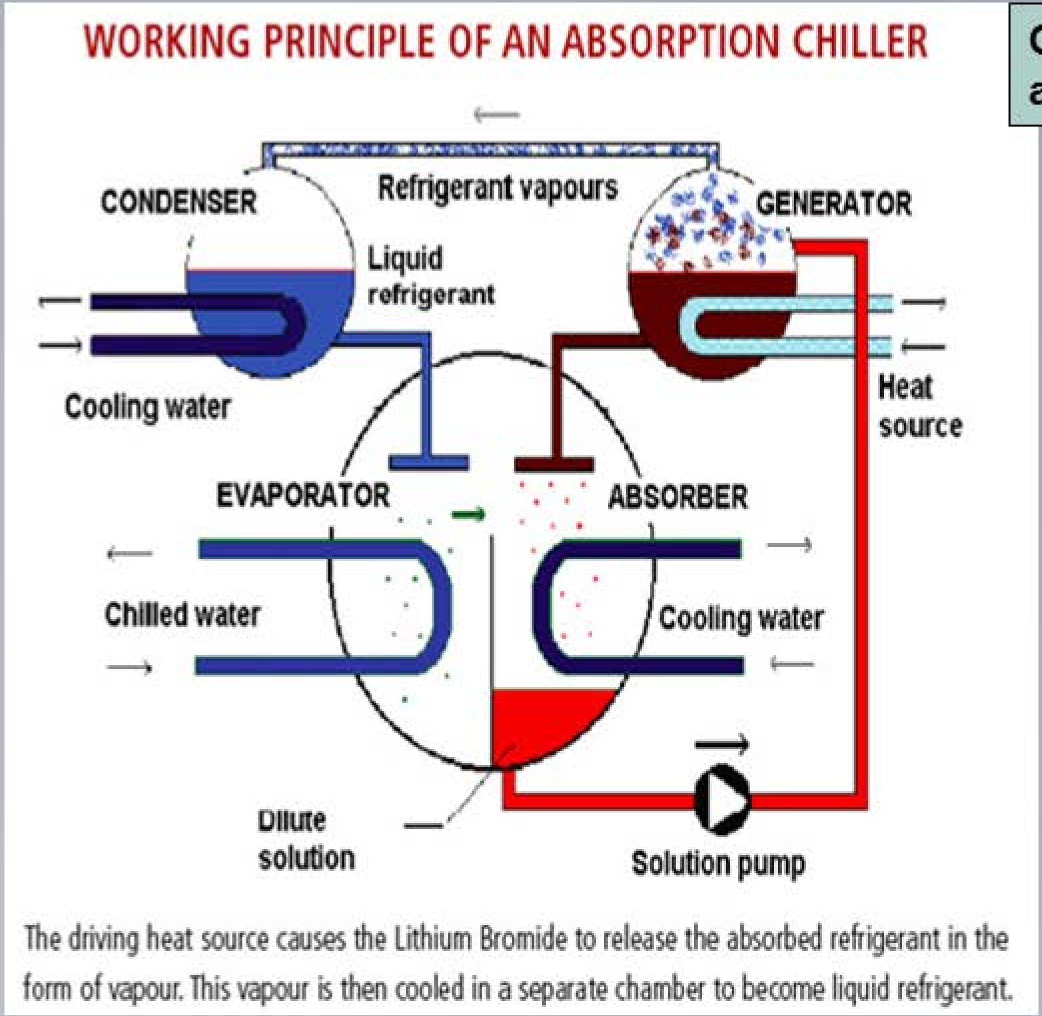
Efficiency of power generation
on base of wood



Source: S. Biollaz, Workshop Essen 2008

IGCC = Integrated Gasification Combined Cycle = gas and steam power

CCHP – an interesting option (1)
Combined cooling, heating and power



Source: cesenergy.ie/img/adsorb.jpg

CCHP = Combined Cooling, Heating, and Power generation = Trigeneration

CCHP is the simultaneous production of mechanical power (often converted to electricity), **heat and cooling** from a **single heat source** such as fuel or solar energy.

As with cogeneration, the "**waste heat**" byproduct that results from power generation is harnessed, **thus increasing the overall efficiency** of the system.

In warmer climates the need for heating is limited to a few winter months. There is, however, significant need for cooling (air conditioning) during the summer months. Heat by micro combined heat and power (MCHP) in this case is used to produce cooling, via absorption cycles. This "expanded" cogeneration process is known as trigeneration or combined heat, cooling and power production (CHCP).

CCHP – an interesting option (2)

Combined cooling, heating and power

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Specifications of thermal chillers

> 10 kW !

No practical relevance

In tropics better Solar Heat!

Item		Absorption chillers			Adsorptions chillers
Number of steps		1-stufig	2-stufig	1-stufig	1-stufig
Sorbent		Lithiumbromid		Wasser	Silikagel
Refrigerant medium		Wasser		Ammoniak	Wasser
Refrigerant agent		Wasser		Wasser-Glykol	Wasser
Driving heat temp.	°C	80 - 110	130 - 160	80 - 140	55 - 100
Chill temperature	°C	6 - 20		-60 bis 20	6 - 20
Cooling water temp.	°C	30 - 50		30 - 50	25 - 35
Driven by		Hot water	Hot water, Steam, Direct fire	Hot water, Steam, Direct fire	Hot water
COP*		0,6 - 0,8	0,9 - 1,4	0,3 - 0,7	0,4 - 0,7
Power range	kW	10 - 7,000		10 - 10,000	50 - 500

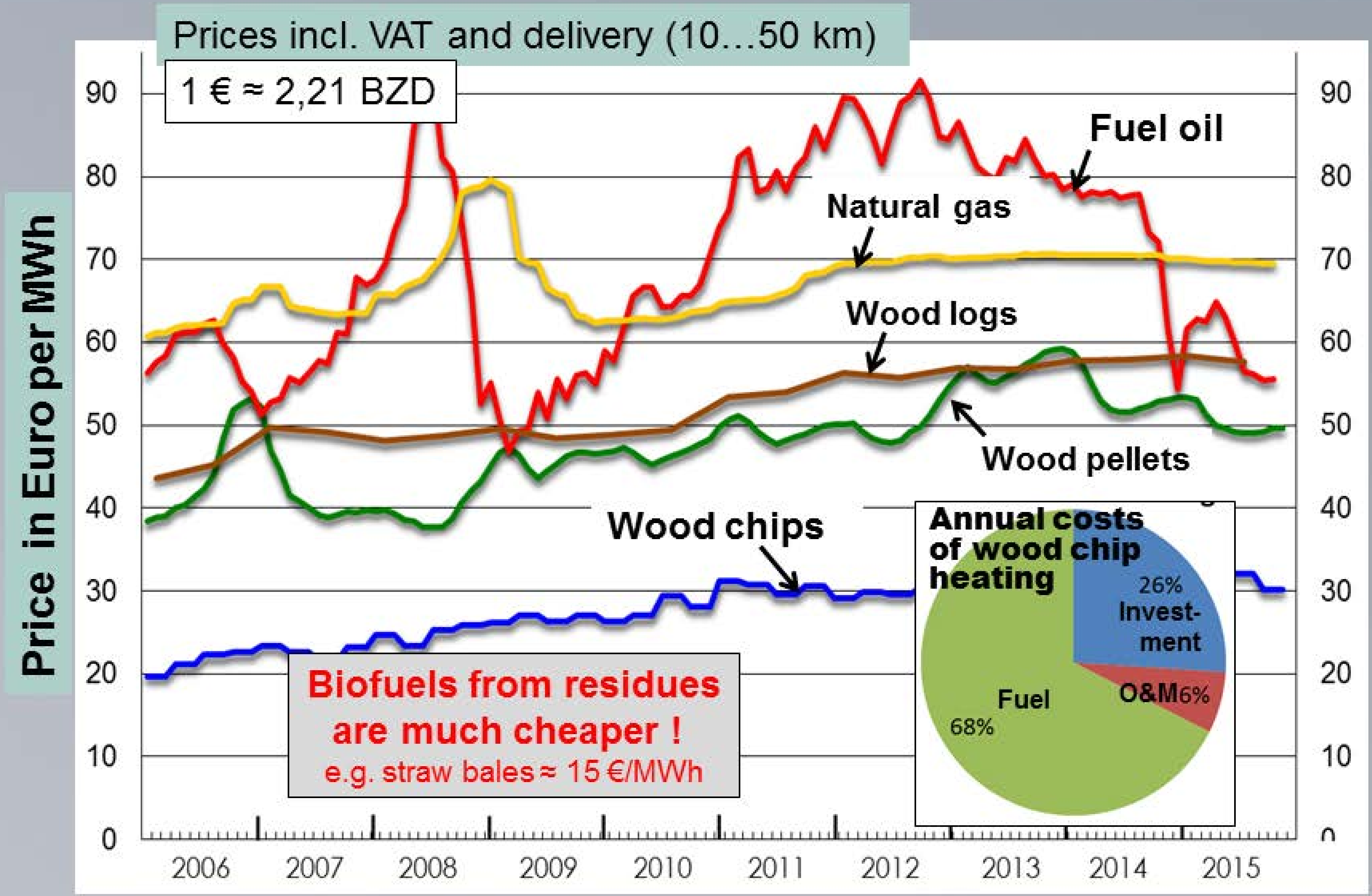
* COP = Coefficient of performance = Cooling power / Heating power
EER = Energy Efficiency Ratio (used in U.S.A.) = 3.413 COP

Source: Leitfaden Bioenergie. FNR 2005

Economy and ecology

- Prices of fuels and boilers
- Emissions and limits
- GHG emissions

Development of prices
of solid biofuels in Germany



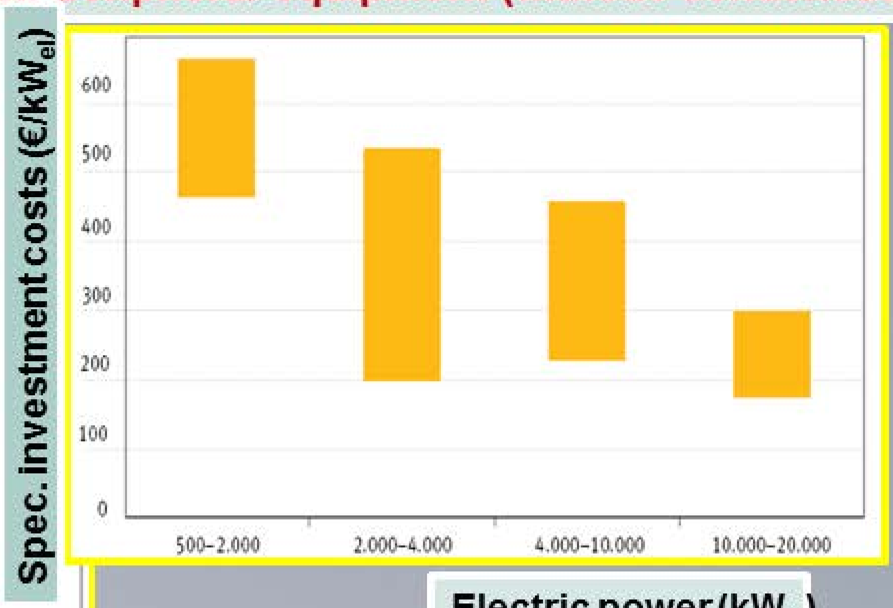
Source: TFZ Straubing and Carmen e.V. 2015

Investment costs of bioenergy plants
fed with solid biofuels

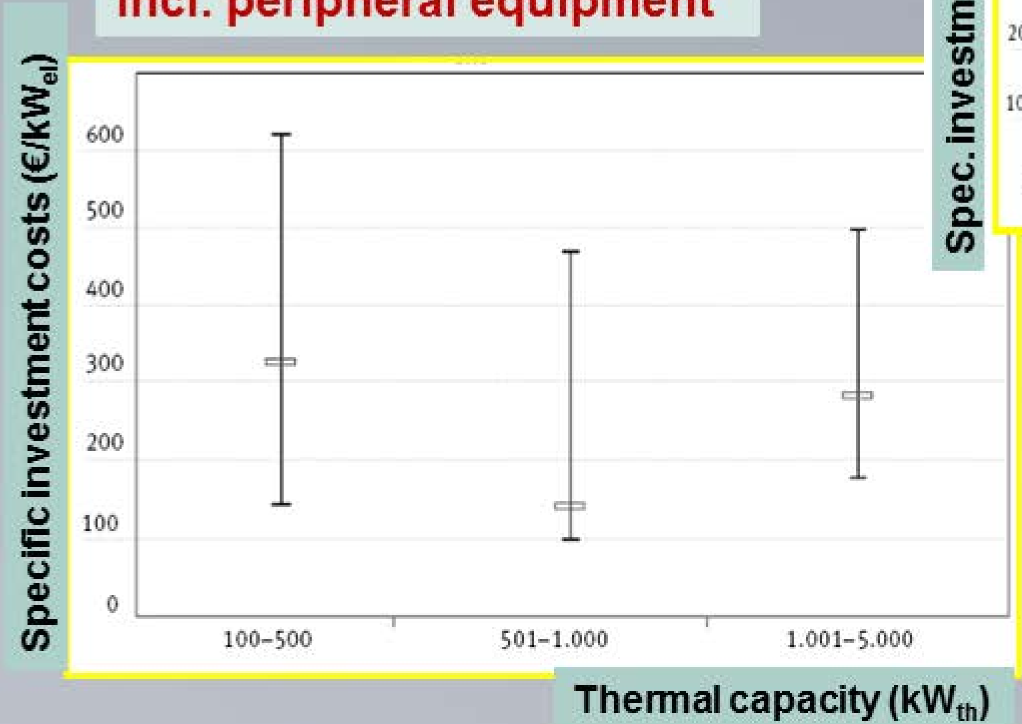
A complete CHP plant:
2000 - 4000 Euro/kW_{el}

1 Euro = 1 € ≈ 2,21 BZD

Steam turbines
incl. peripheral equipment (without condensator)



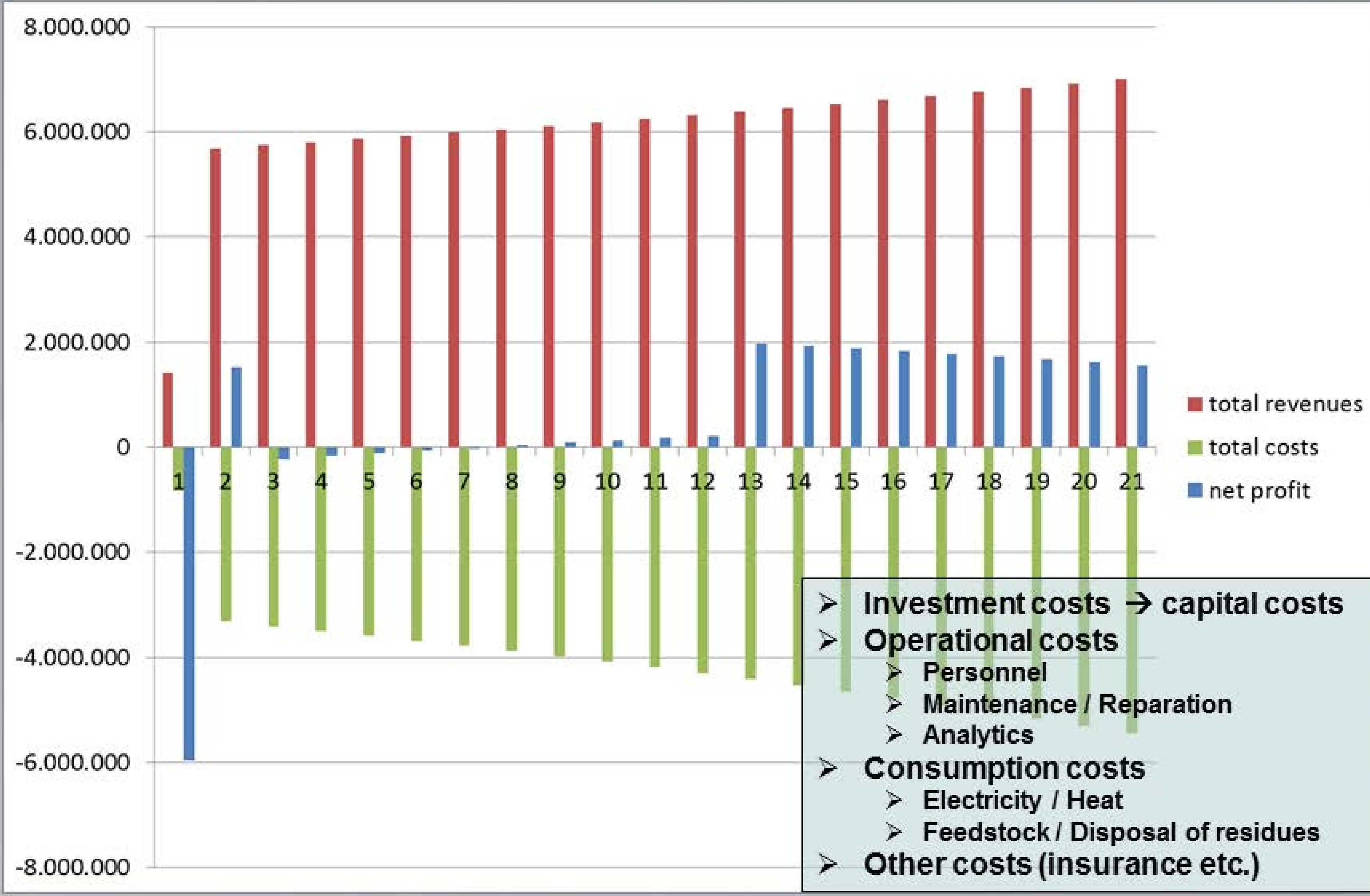
Automatic biomass boilers
incl. peripheral equipment



ORC Module
1300 – 2800 €/kW_{el}

Source: Leitfaden feste Biobrennstofffe. FNR Gülzow 2014

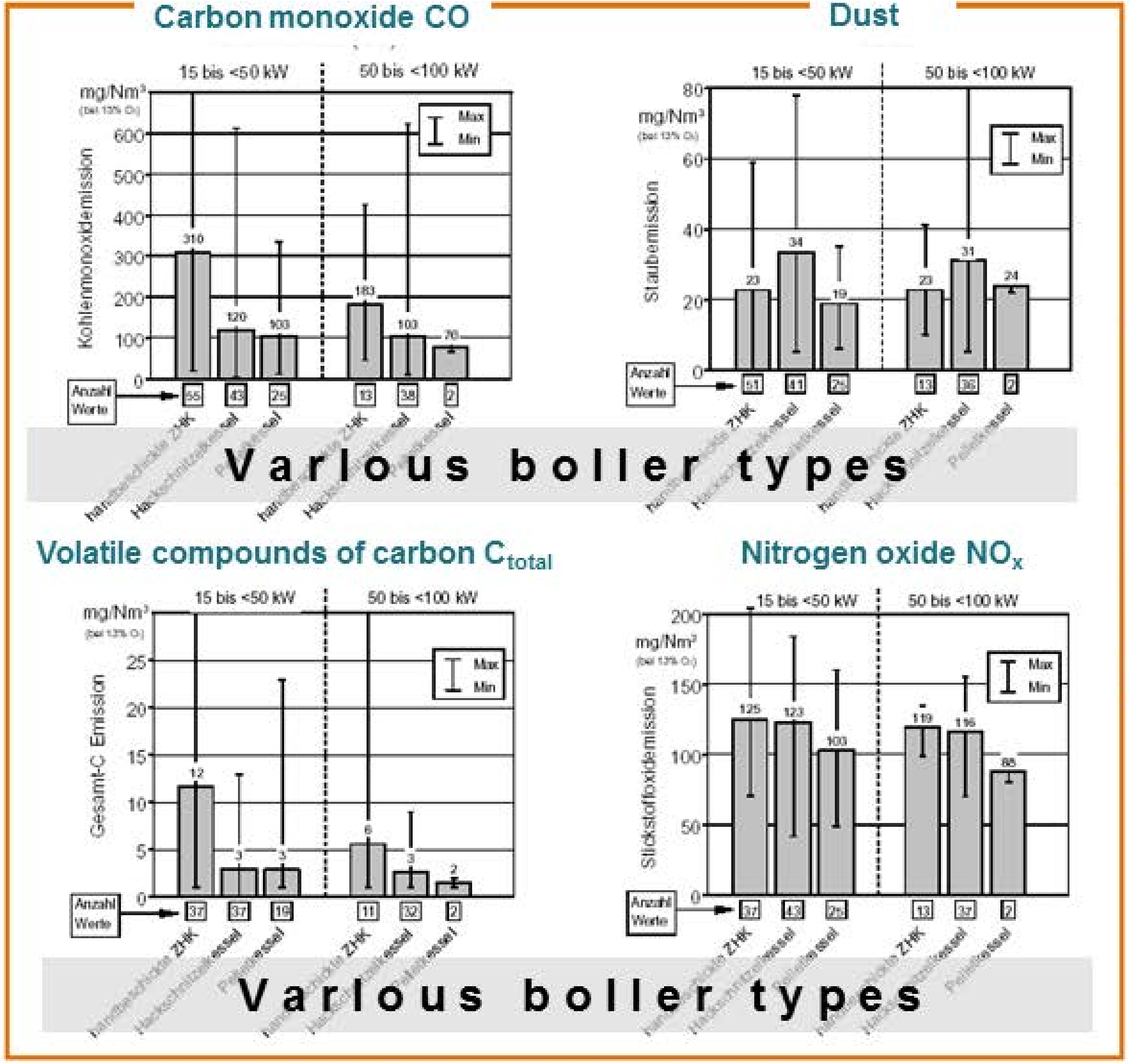
Profit & Loss balance
of a 2 MWel wood CHP plant



- Investment costs → capital costs
- Operational costs
  - Personnel
  - Maintenance / Reparation
  - Analytics
- Consumption costs
  - Electricity / Heat
  - Feedstock / Disposal of residues
- Other costs (insurance etc.)

Source: renac

Emissions of small wood boilers
< 100 kW

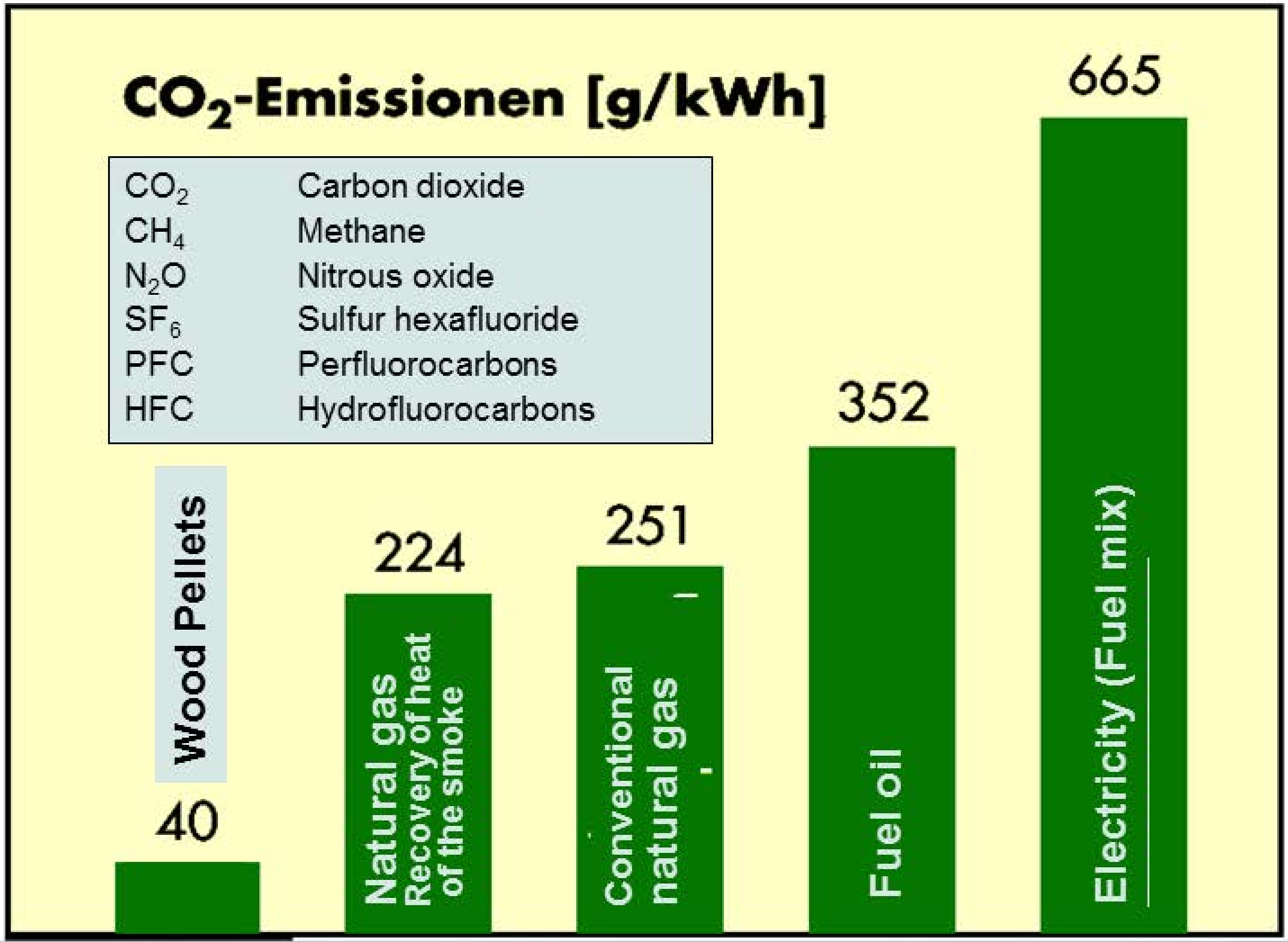


Source: Hartmann, H. et al: Handbuch Bioenergie-Kleinanlagen. FNR Gülzow, 2003

Compare:

Parameter	Fuel oil	Natural gas
	in mg/Nm³ (bei 13 % O_2)	
CO	ca. 8,6	ca. 8,6
flücht org. C	< 2,2	< 2,2
NO_x	43 - 65	22 - 39
Dust (soot)	bis ca. 0,2	-

Legal limits of flue gas emissions
of solid biofuels combustion in Germany



GHG … GreenHouse Gas

Wood logs and wood chips are even better than pellets!

Source: Energieagentur NRW, 2005

Source: renac

Thank you

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