Biomass - combustion

- combustion proces
- combustion equipment
- emission
- designing
- economy

Direct combustion of phytomass

- combustion = oxidation

Glucose is a 6-carbon structure
source of energy for every organism
essential to fuel cellular respiration

$C_6H_{12}O_6$

$+ O_2$

$= \mathbf{CO_2}$

$+ \mathbf{H_2O}$

+ **energy released**

$$C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O + \text{energy released}$$

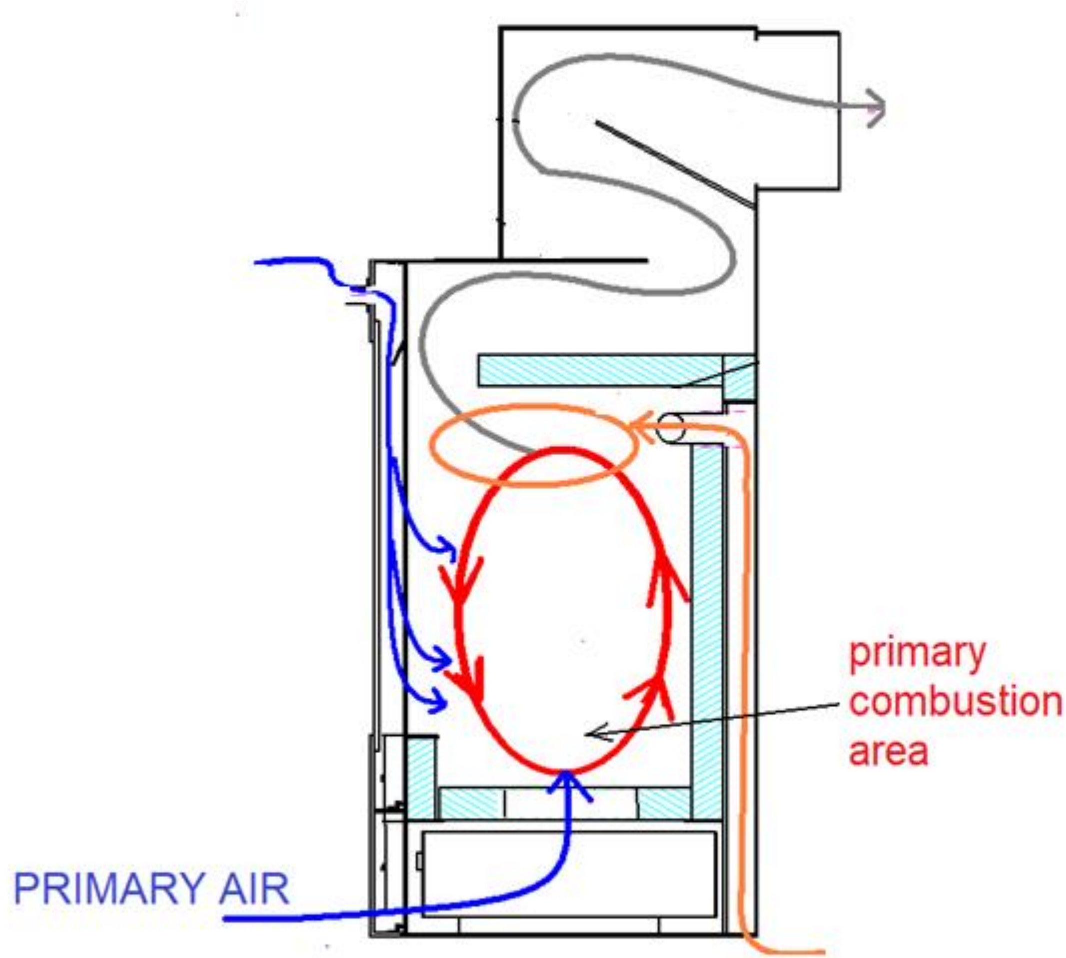
Direct combustion of phytomass

- **Phytomass … high O_2 content**
  - lower calorific value *than fossil fuels* (=carbonization, hydrocarbons, high calorific value), phytomass: **higher fuel consumption, higher fuel volumes**
  - high **volatile*** content (70-80% in dry matter), release at temperatures > 200 ° C **multistage combustion: gasification + combustion of gases**
  - large quantities of combustion **gases** = considerably longer flames, longer burning time: **greater space for burning gases**
  - Difficult **penetration** of combustion **air** into flames, increased need for air supply for combustion: : **Higher combustion air excess ratio λ**

* volatile content is material that can be easily transformed into a vapor.

- **Phytomass … low ash content** (excluding stalks)

Combustion (fireplace stove)



Primary Air

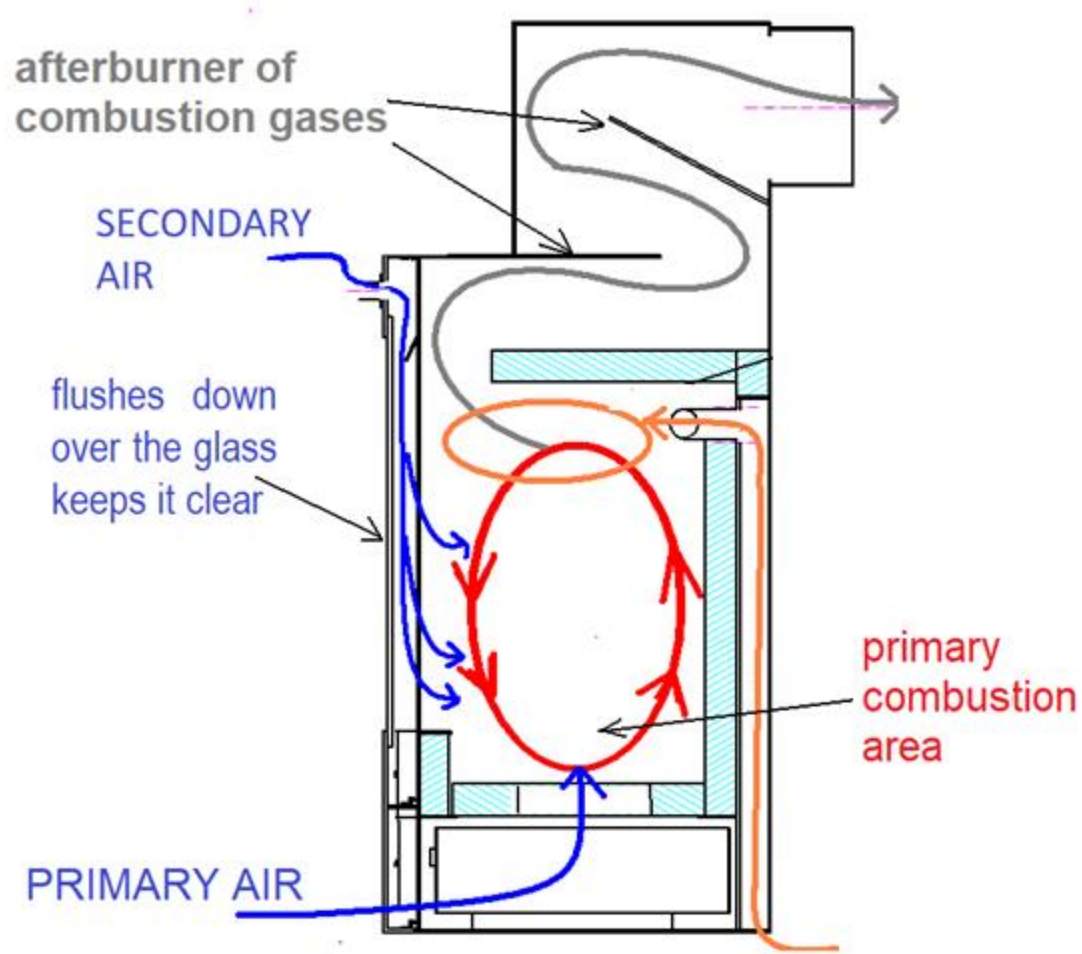
- comes in through the ash pan when you first start the stove
- going and up to operating temperature

Combustion (fireplace stove)

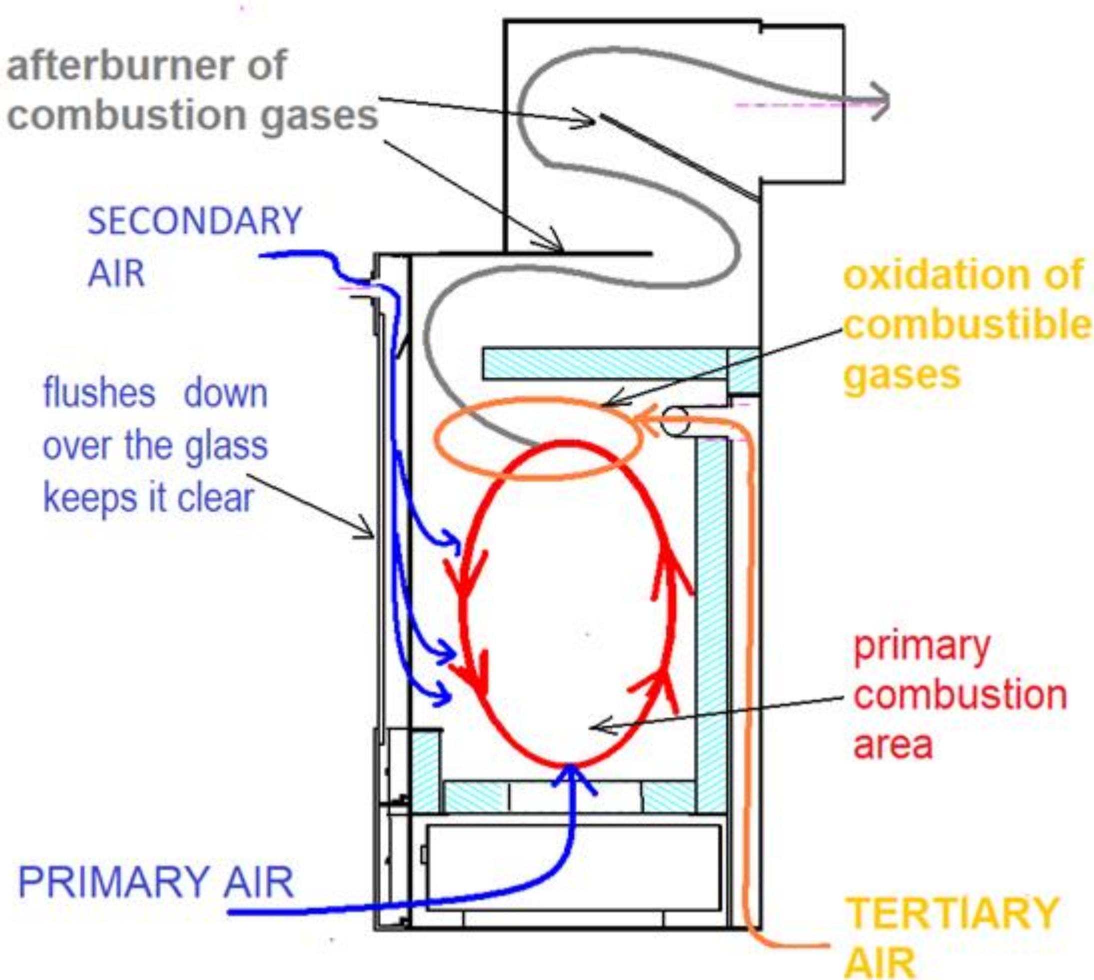
Secondary Air

pre heated air, enters the chamber around the top of door

- after start up to keep the stove operating efficiently
- flushes down over the glass it keeps it clear

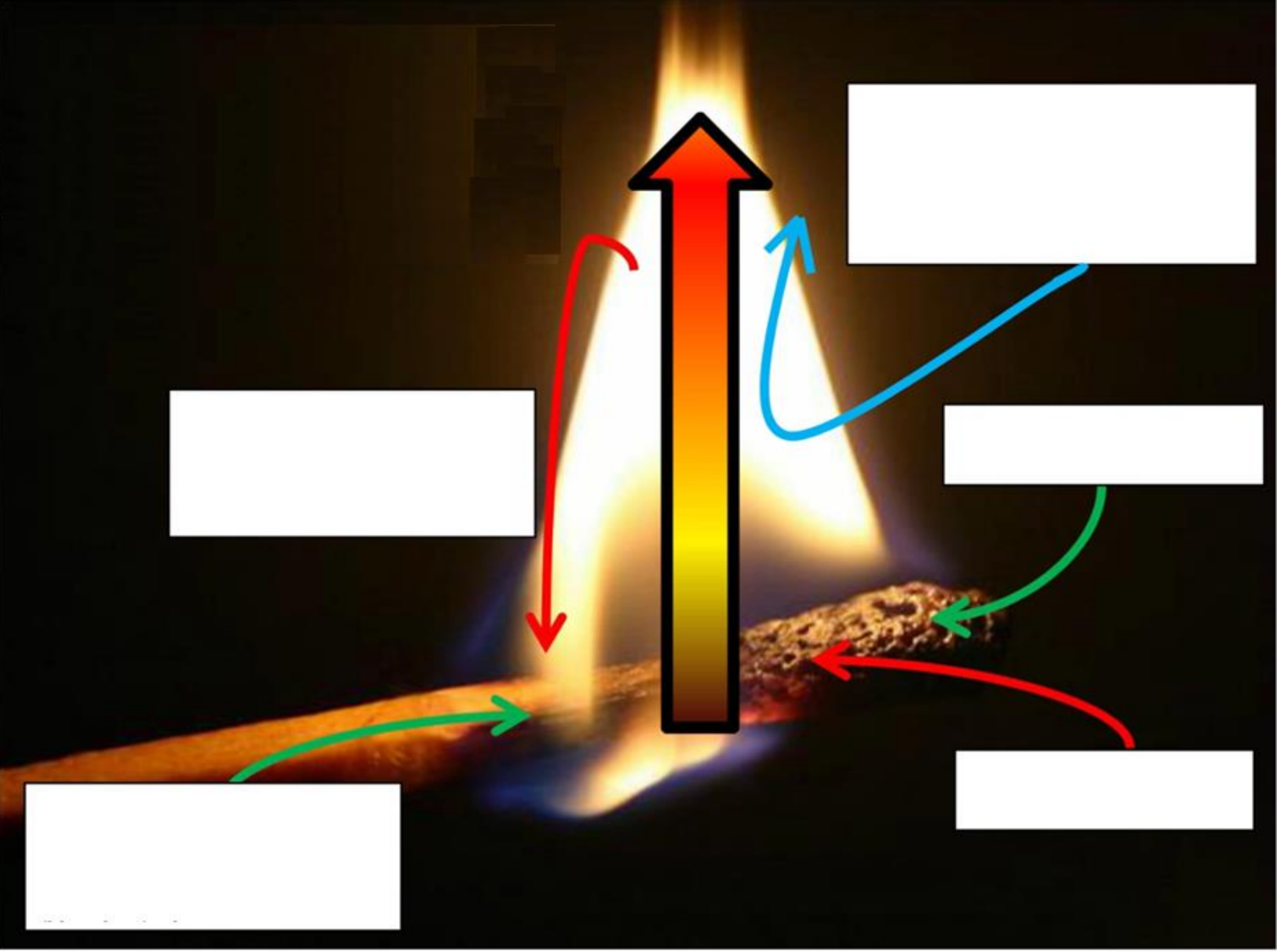


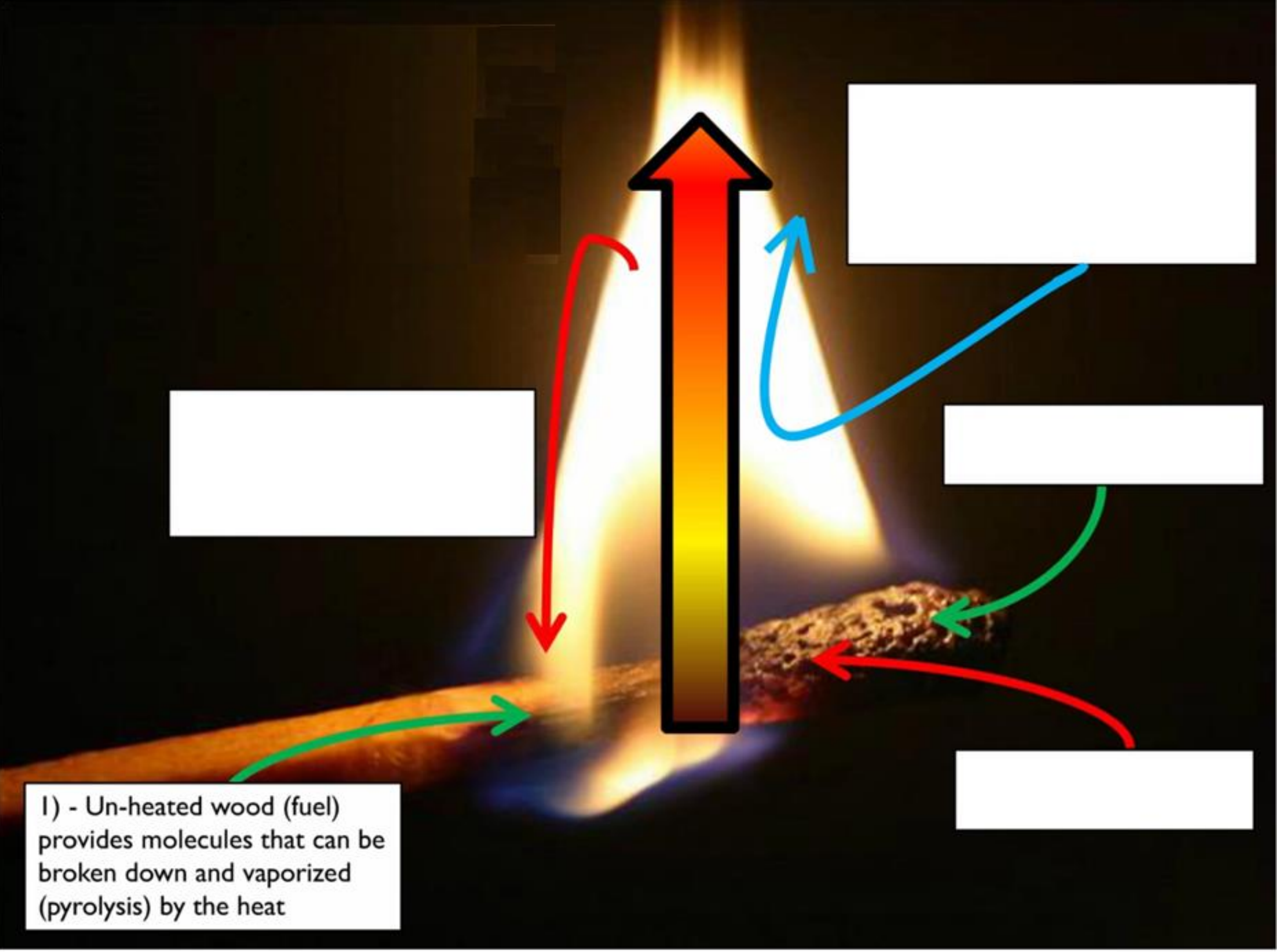
Combustion (fireplace stove)

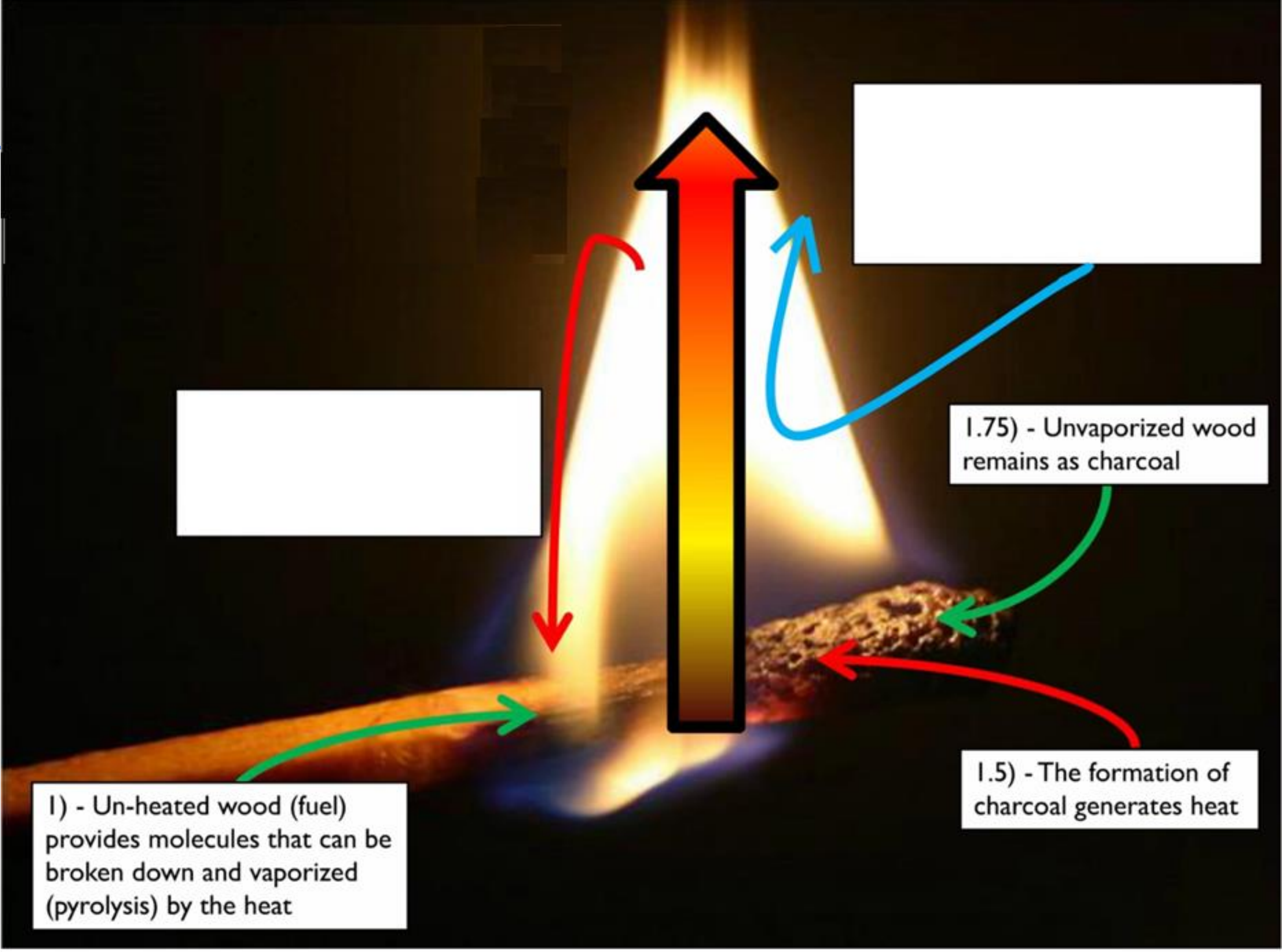


Tertiary Air

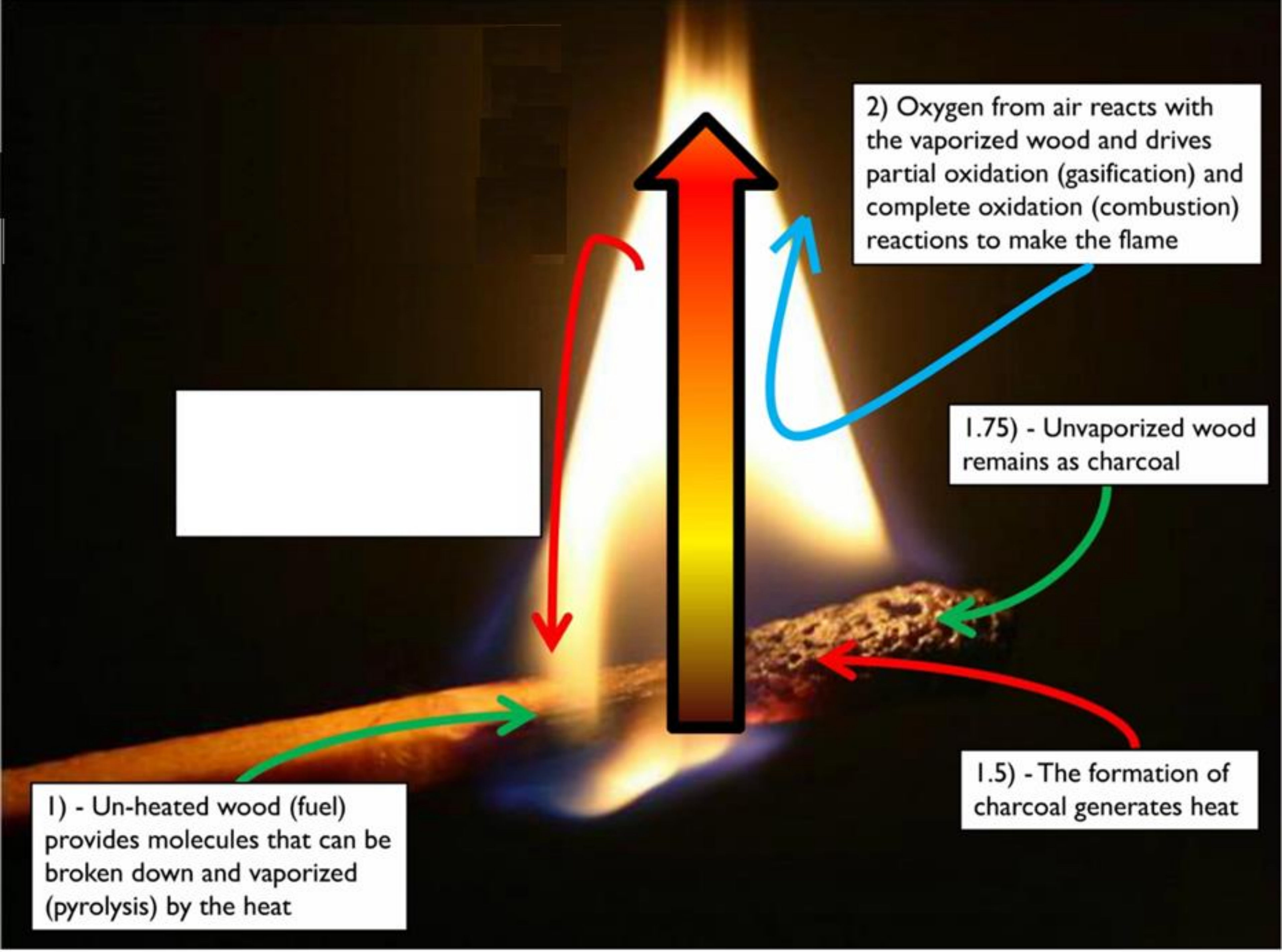
- comes in through air bars on the back of the stove,
- not controllable
- inject more oxygen/air into the chamber
- improve the efficiency … the gases from the primary combustion are re-ignited for a cleaner and more efficient burn




1) - Un-heated wood (fuel) provides molecules that can be broken down and vaporized (pyrolysis) by the heat



1.75) - Unvaporized wood remains as charcoal
1.5) - The formation of charcoal generates heat
1) - Un-heated wood (fuel) provides molecules that can be broken down and vaporized (pyrolysis) by the heat



2) Oxygen from air reacts with the vaporized wood and drives partial oxidation (gasification) and complete oxidation (combustion) reactions to make the flame
1.75) - Unvaporized wood remains as charcoal
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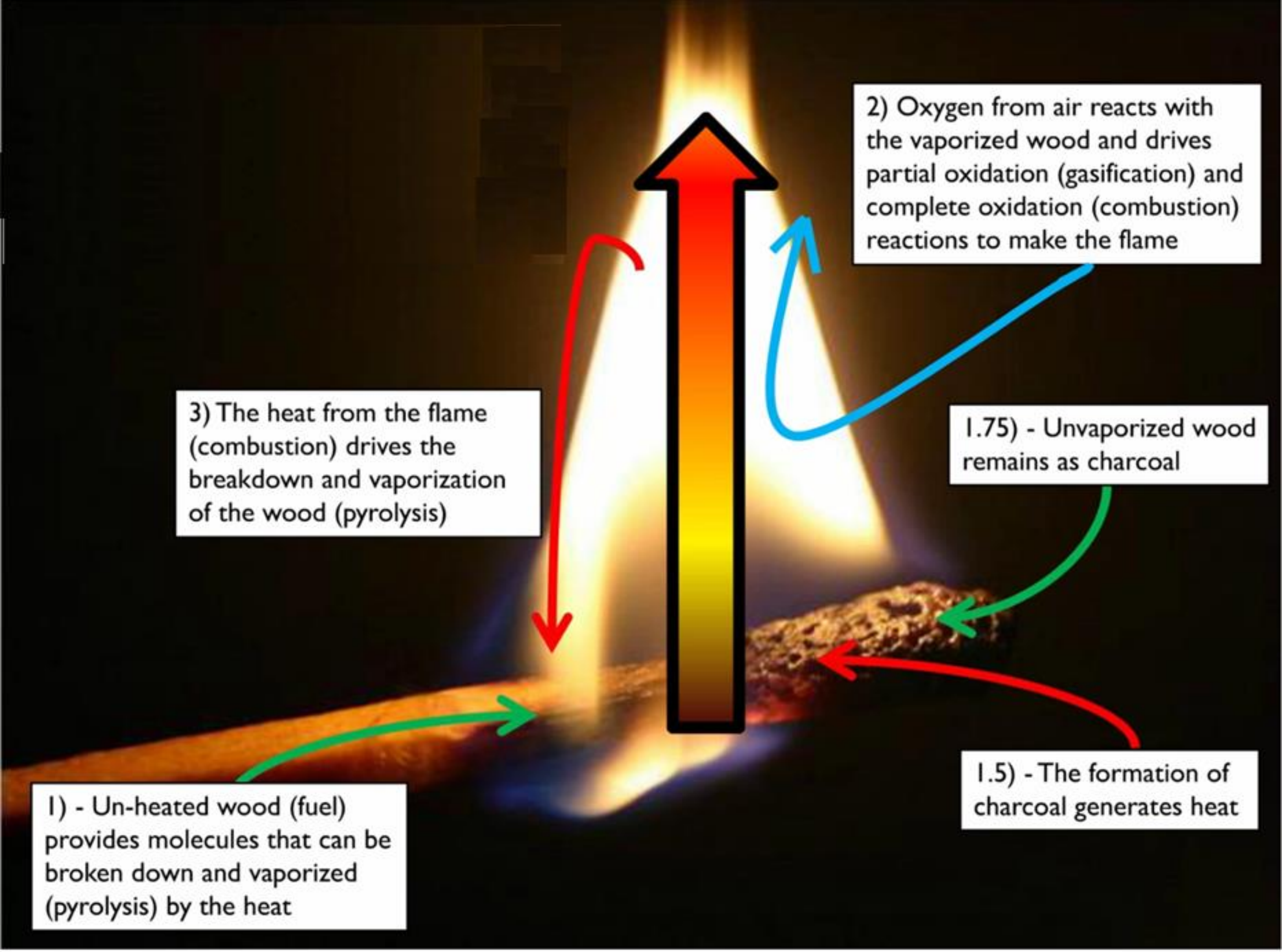
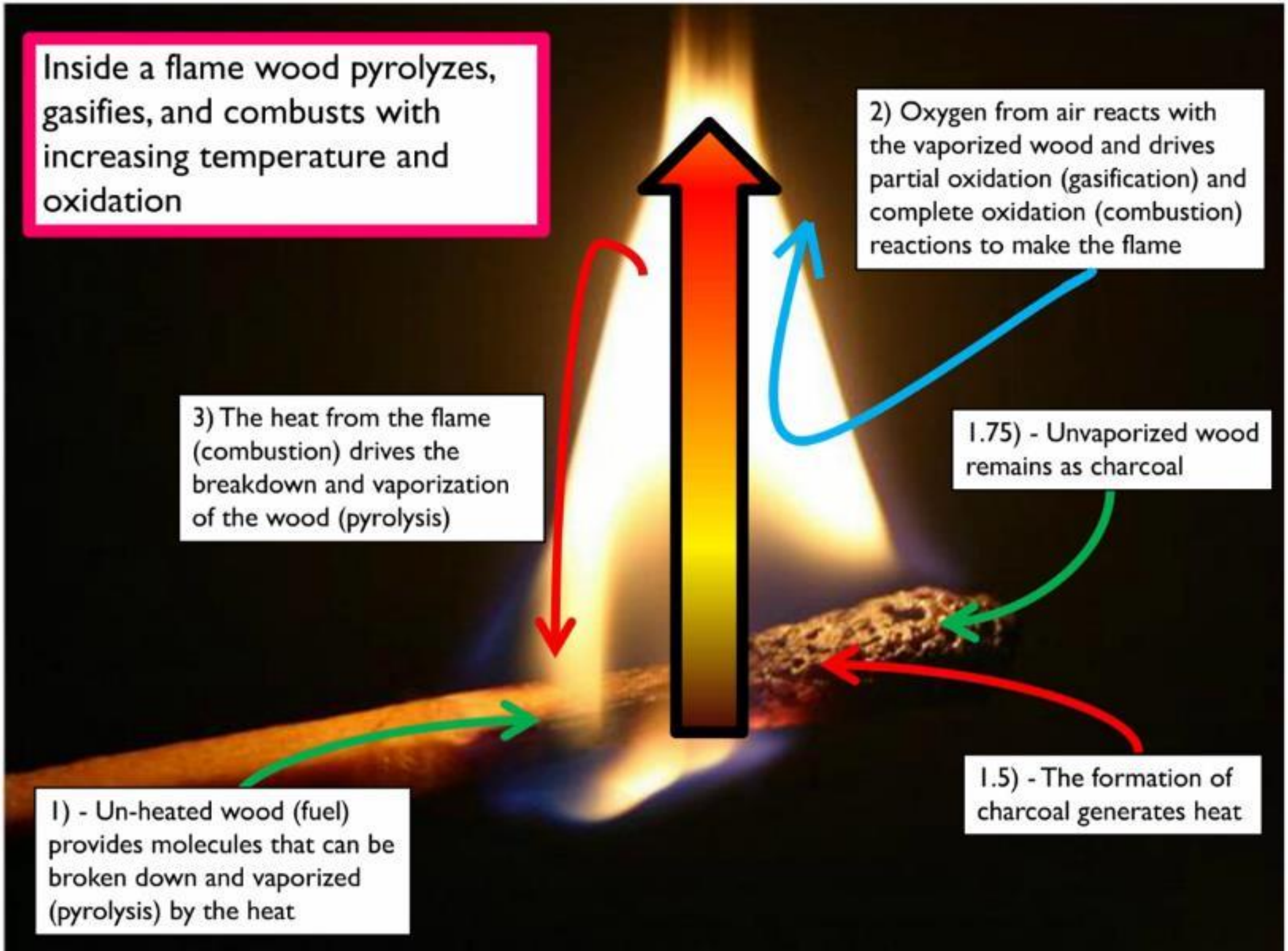
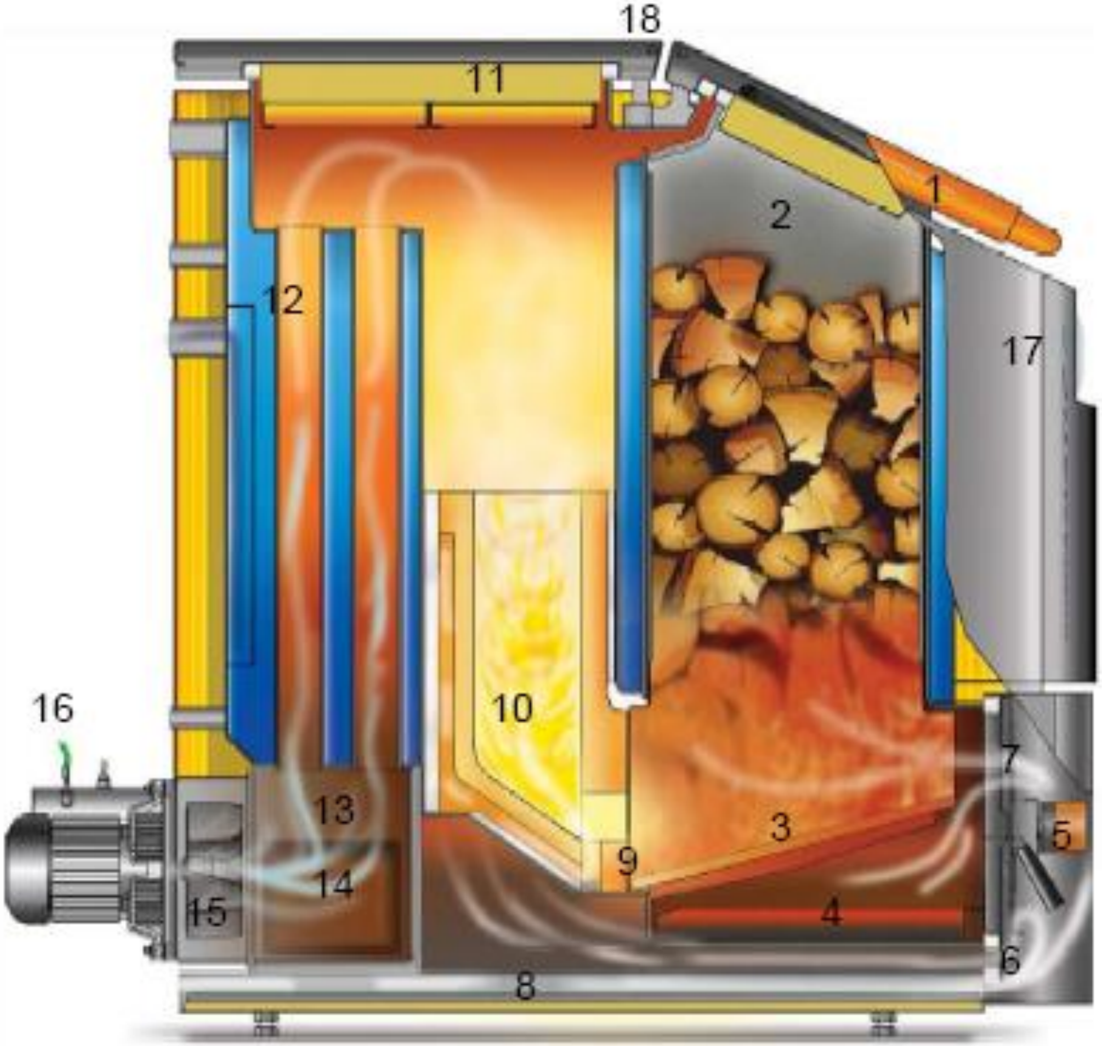

2) Oxygen from air reacts with the vaporized wood and drives partial oxidation (gasification) and complete oxidation (combustion) reactions to make the flame
3) The heat from the flame (combustion) drives the breakdown and vaporization of the wood (pyrolysis)
1.75) - Unvaporized wood remains as charcoal
1.5) - The formation of charcoal generates heat
1) - Un-heated wood (fuel) provides molecules that can be broken down and vaporized (pyrolysis) by the heat

Direct combustion of phytomass



Burners



fireplace (3)
- drying, gasification

combustion chamber (10)
- combustion of gases

heat exchanger (12)
- heat transfer

air supply
- primary (7)
- secondary (9)

flue gas extraction
- fan (15)

ash extraction (4)

Direct combustion of phytomass (endotermic)

1. **fuel heating (up to 100° C)**
   - heat from the burning fuel, increasing its temperature

2. **drying of fuel (100 to 150 ° C)**
   - evaporation of water bound in fuel, leaves as water vapor

3. **pyrolytic decomposition (150 - 230°C) - no oxygen access**
   - complex hydrocarbon chains degrade to simpler: gaseous hydrocarbons, CO
   - Pyrolytic decomposition **does not require the presence of oxygen**

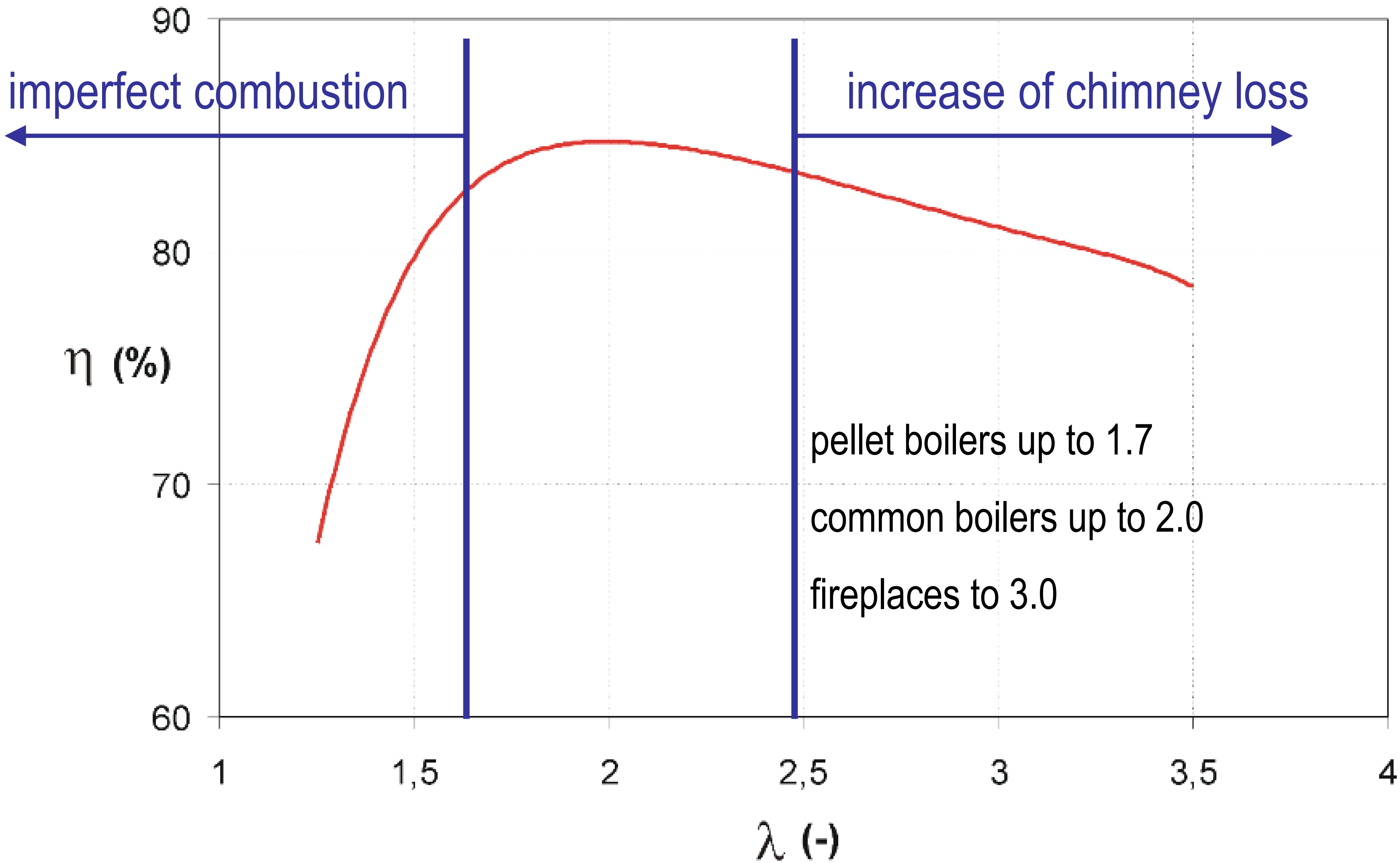
Direct combustion of phytomass (exotermic)

4. **dry gasification (230 to 500°C) - with oxygen access**
   - thermal decomposition of the fuel above the ignition temperature (230 °C) in the furnace, oxygen supplied **in the primary combustion air**, releasing heat
   - effects on solid and liquid products of pyrolysis (carbon, tar) - oxidation
5. **solid carbon gasification (500 to 700°C)**
   - with the contribution of CO_2, H_2O, O_2 , combustible CO is formed: visible flame
6. **oxidation of combustible gases (700 to 1400°C), optimum 900°C**
   - combustion of gases generated in the previous phases - supply **of secondary combustion air** for perfect combustion
   - temperatures above 1200°C: load of the furnace and exchanger structure, NOx formation,

Direct combustion of phytomass

- **combustion air excess ratio λ**
  - for complete wood fuel combustion, the stoichiometric air–fuel ratio is about 6:1. In order to completely burn 1 kg of dry wood, the combustion process needs 6 kg of air for combustion:
  - combustion air excess ratio λ is defined as the percent of total air supplied that is more than what is required for stoichiometric or perfect combustion.
  - difficult penetration of combustion air into flames during the phytomass combustion … increased need for air supply for combustion …. Higher combustion air excess ratio λ

combustion air excess ratio λ



Combustion equipment - requirements

- simple operation and easy maintenance
  - fuel loading, ash removal
- high quality combustion, low emissions
  - CO, C_xH_y, NO_x
- high efficiency
- wide range of performance control while maintaining burning quality
- long life
- traffic safety
- low costs - investment, operational

Combustion equipment - types

- **small family-run facilities**
  - piece wood, briquettes - fireplaces, stoves, gasification boilers
  - pellets - automatic operation

- **middle appliances (schools, retirement homes, ...)**
  - necessary individual assessment: pellets x chips

- **large appliances (heating plants)**
  - hot water, steam boilers
  - possibility of combustion of lower quality fuels with a humidity above 30%, bulk materiál
  - the low price x the heat losses in the distribution system

Local Biomass Combustion (family houses)

- **open fireplaces**
  - high combustion air consumption, low efficiency <20%
- **fireplace inserts**
  - closed furnace, low temperature in the furnace
  - low efficiency <40%

- **stoves**
  - stand-alone interior heaters
  - fans, storage pads, pellet burners
  - efficiency (for pellet stoves) up to 80%

- **tiled stove**
  - accumulation mass in flue gas path, delayed heat transfer

Local Biomass Combustion (family houses)

wood
fireplace stove

pellet
fireplace stove

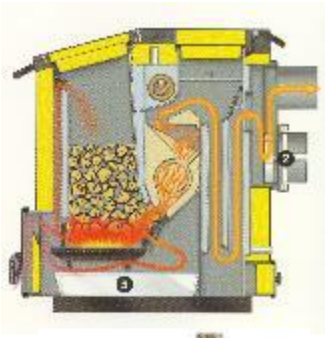
ceramic glazed tile accumulating
(ceramic glazed tile) stoves

Central biomass combustion device

(family houses)

- classic solid fuel boilers (wood)

- gasifying boilers for piece wood



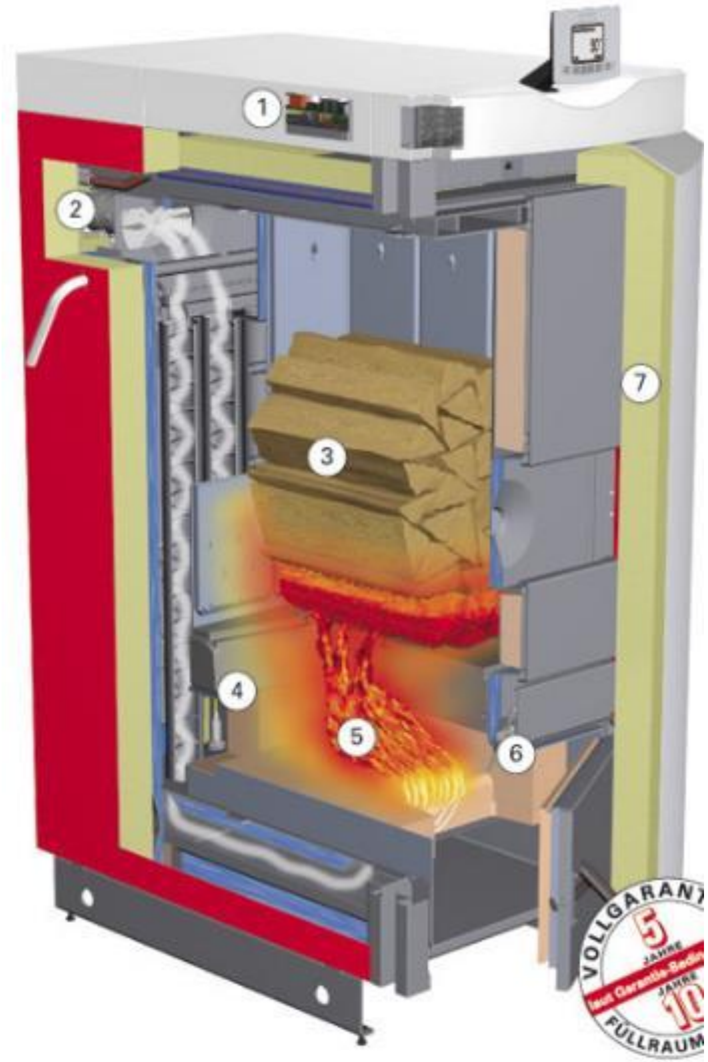
- automatic pellet boilers (chips)

Central biomass combustion device

(family houses)

- **classic solid fuel boilers (wood)**
  - fuel burned directly in the furnace - burning on the grate
  - regulation with limited air supply, limited power control, efficiency 65 - 70%

classic solid fuel boilers (wood)

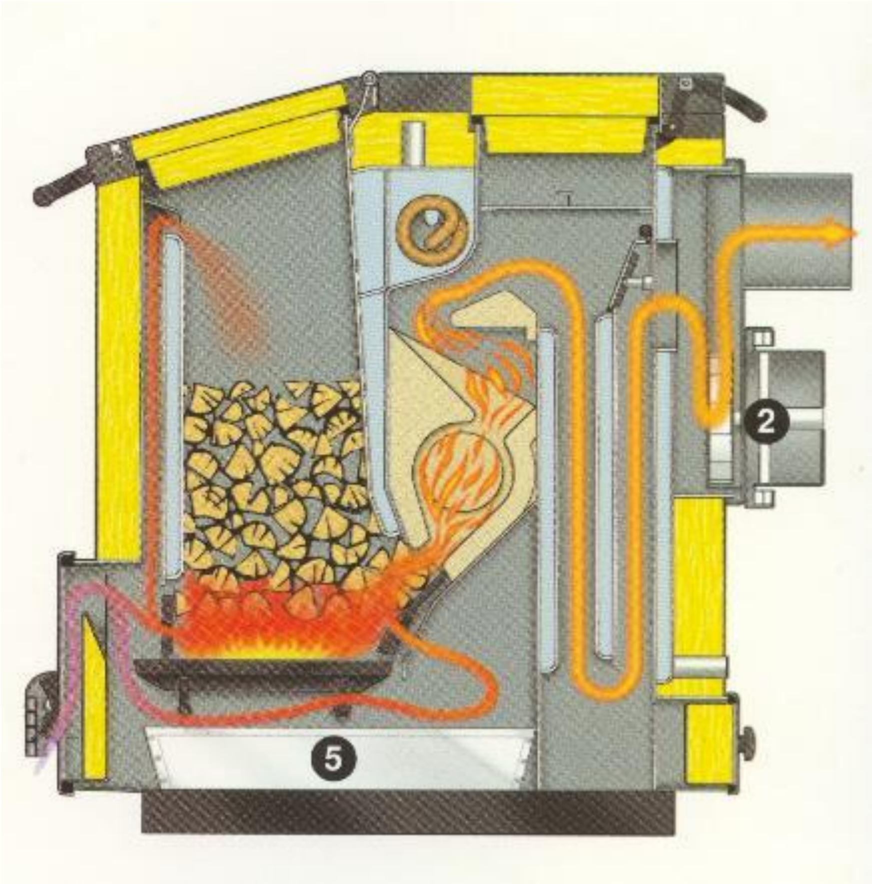


storage requirement
difficult regulation, emissions

Central biomass combustion device

(family houses)

- **gasifying boilers for piece wood**
  - gasification in the furnace, then combustion of gases in the combustion chamber
  - power regulation 50 - 100% (primary air supply), efficiency 80 - 90% (at nominal power)



Central biomass combustion device

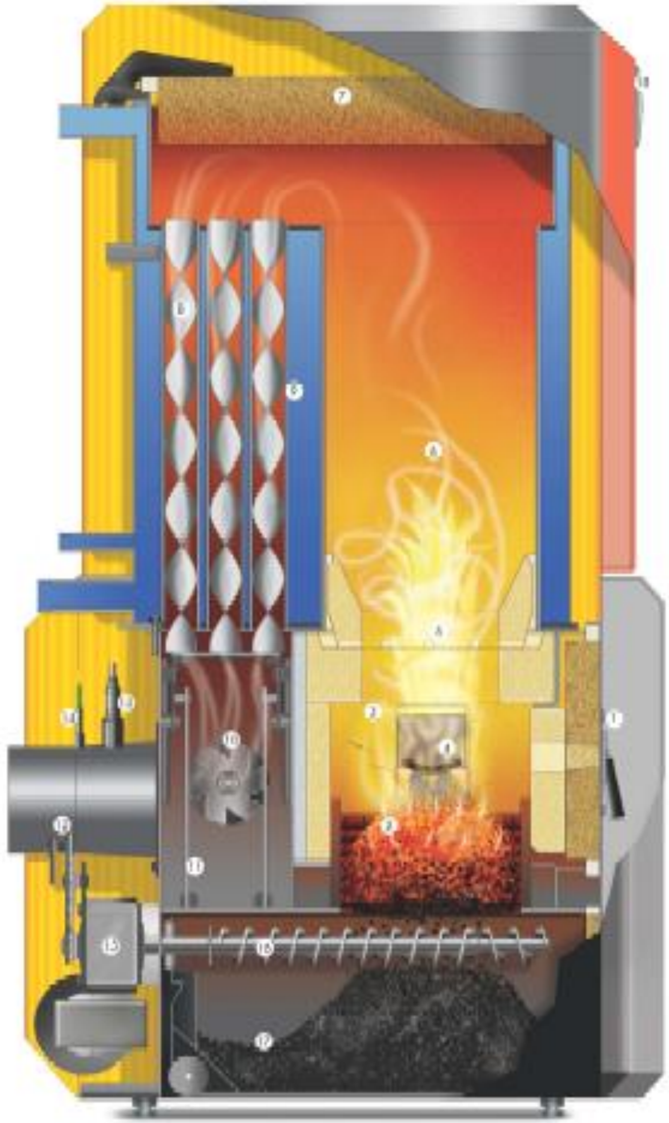
(family houses)

- **automatic pellet boilers (chips)**
  - gasification in the furnace, combustion of gases in the combustion chamber
  - free operation, feeder, burner
  - power regulation 25 - 100%, efficiency 85 - 92% in the control range

automatic pellet boilers

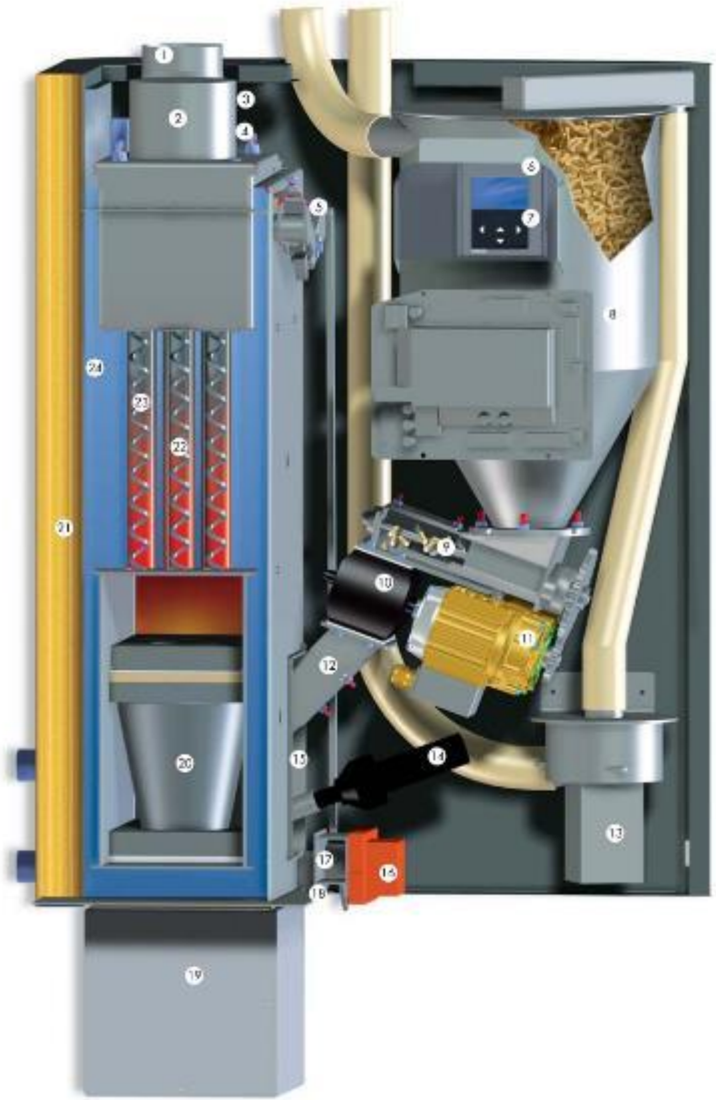
fuel tank
supply pellets from the top

automatic chip boilers



automatic fuel supply
automatic ash extraction

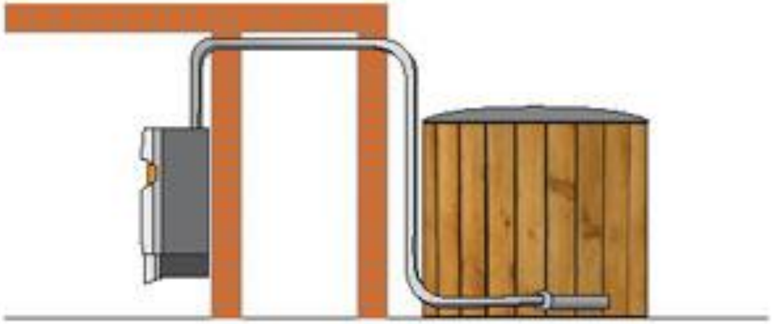
automatic pellet boilers



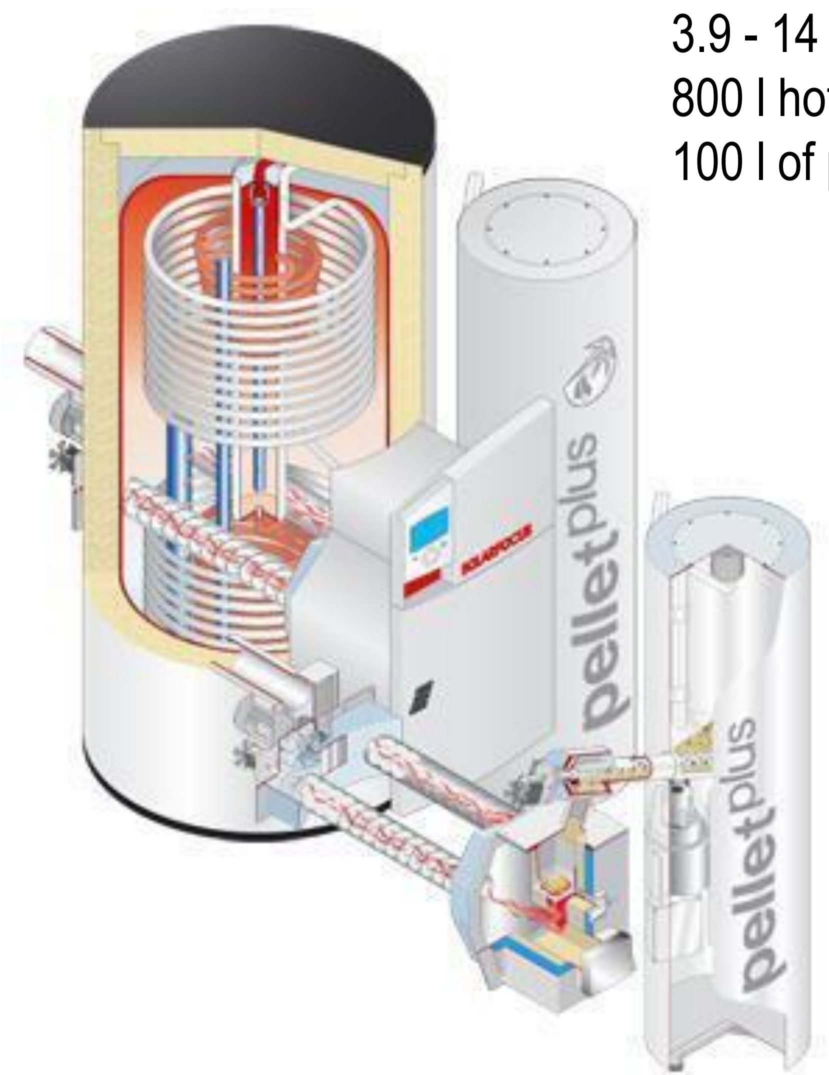
wall pellet boiler

2 - 7 kW

(lowenergy houses)



Integration of pellet burner in boiler



3.9 - 14 kW
800 l hot water container
100 l of pellets

Combustion equipment for chips

not suitable for small performances

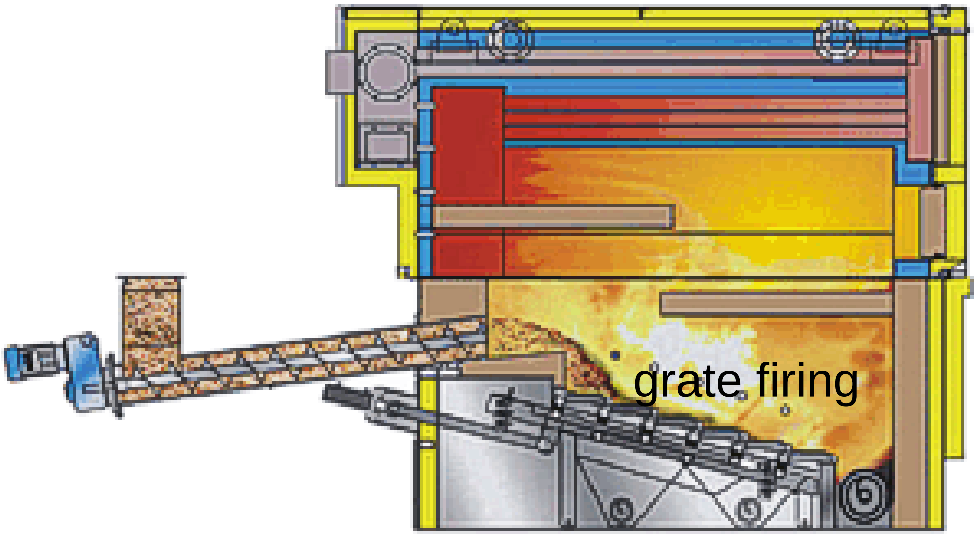
storage,

drying

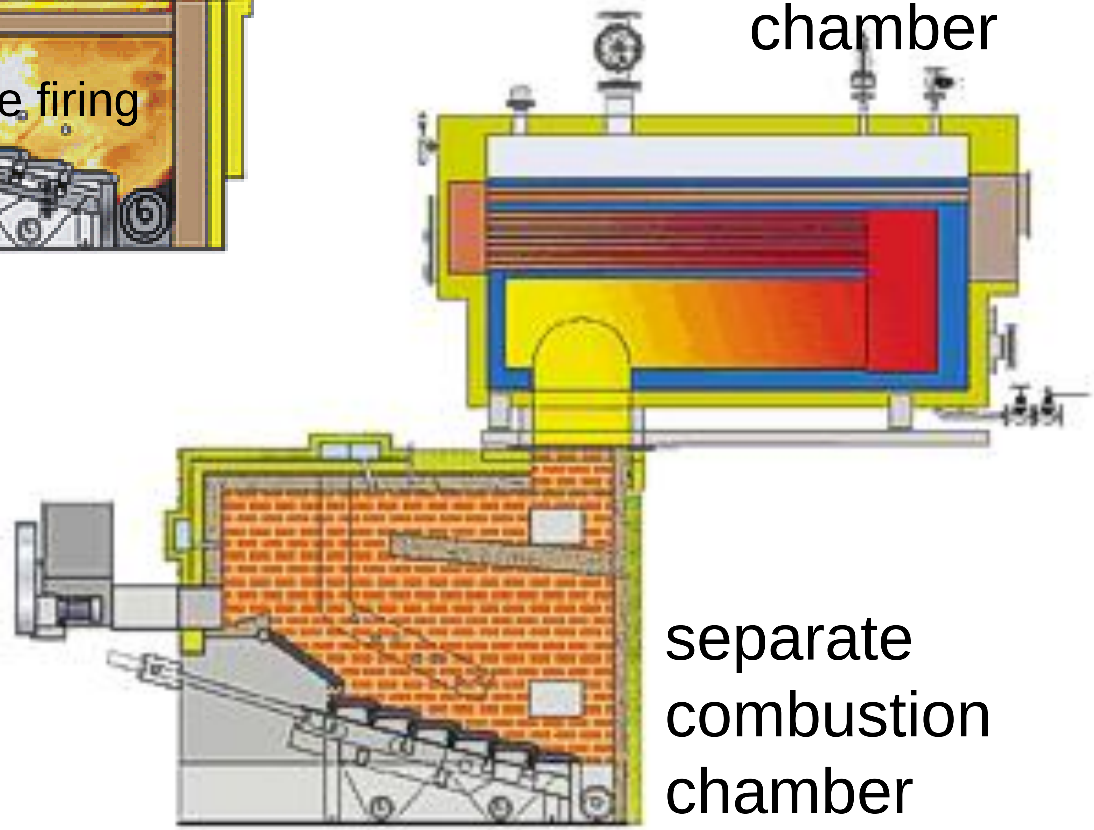
Biomass combustion devices (large appliances)

- **combustion on the grate (in the layer)** spalování na roštu (ve vrstvě)
  - fuel with high humidity> 40%, outputs up to 50 MW, efficiency up to 85%
  - multiple air supply (optimization), multistage combustion

Grate boilers for wood chips, sawdust up to 10 MW



separate afterburner chamber



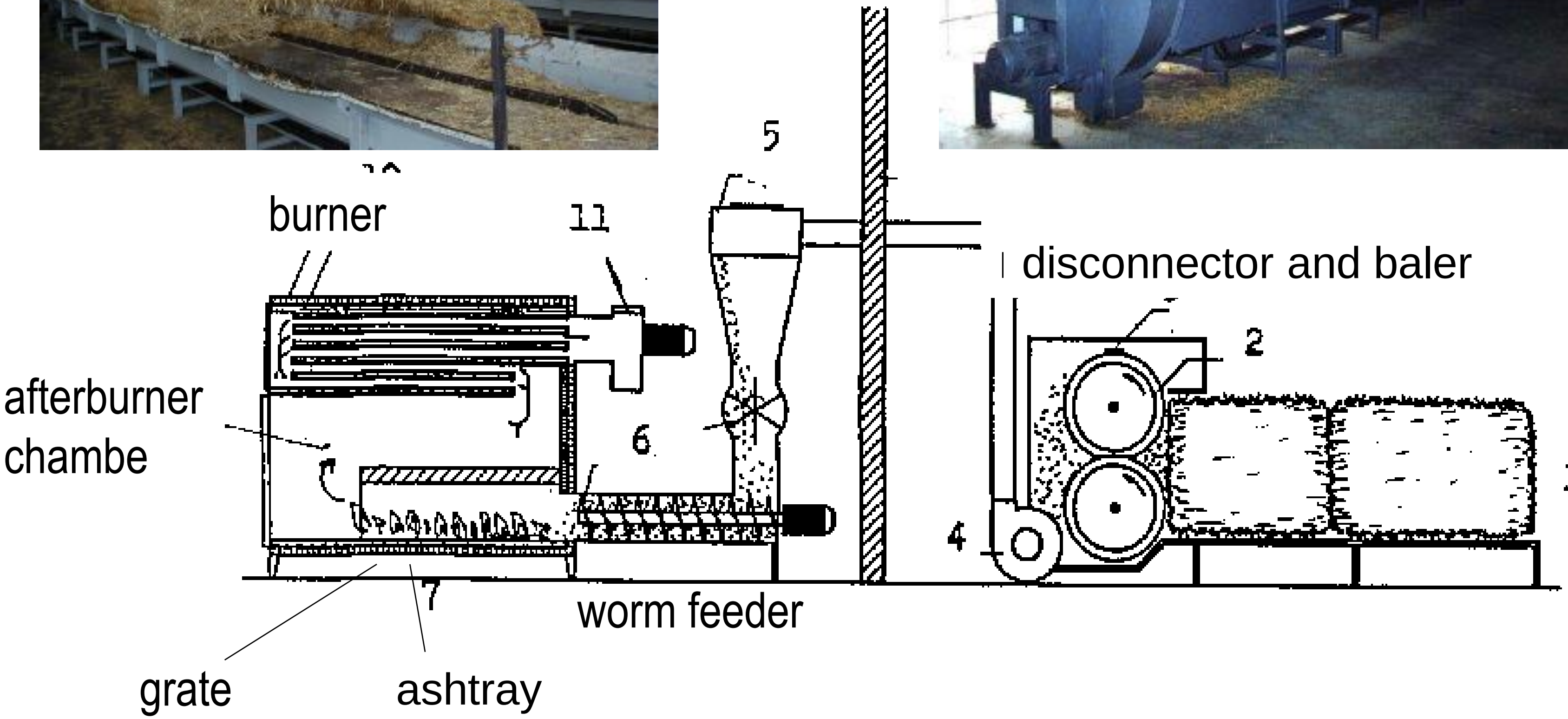
separate combustion chamber

Big combustion and afterburner chamber

big accumulation – fireclay

tertiary air

Straw burning equipment

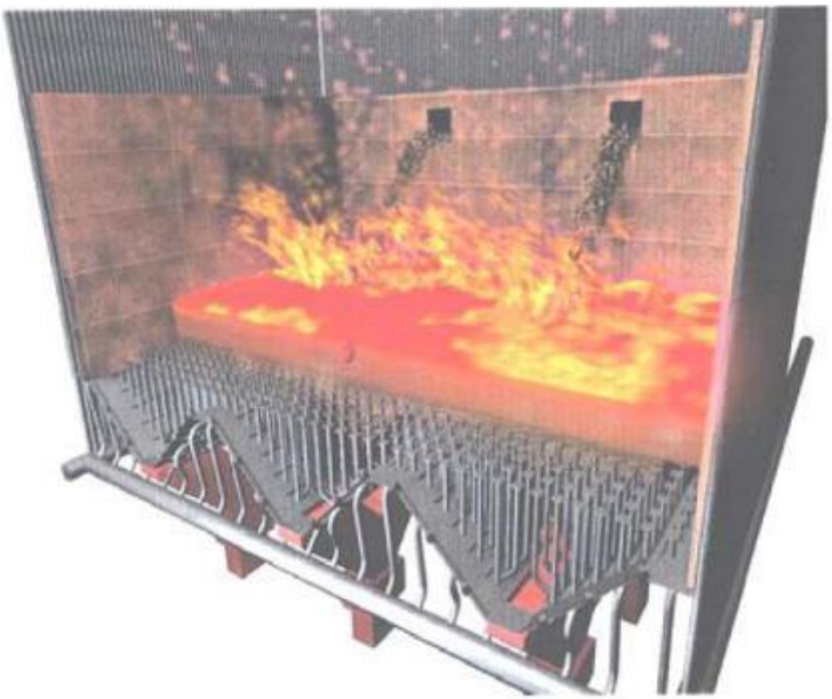


Biomass combustion devices (large appliances)

- **fluidized bed combustion**
  - uptake of fuel particles by flue gas and air, high heat transfer and substance, circulation layer, efficiency 85-88%
  - only 700 to 900 ° C, lower NOx production, rapid combustion, wet biomass
  - cyclone separators

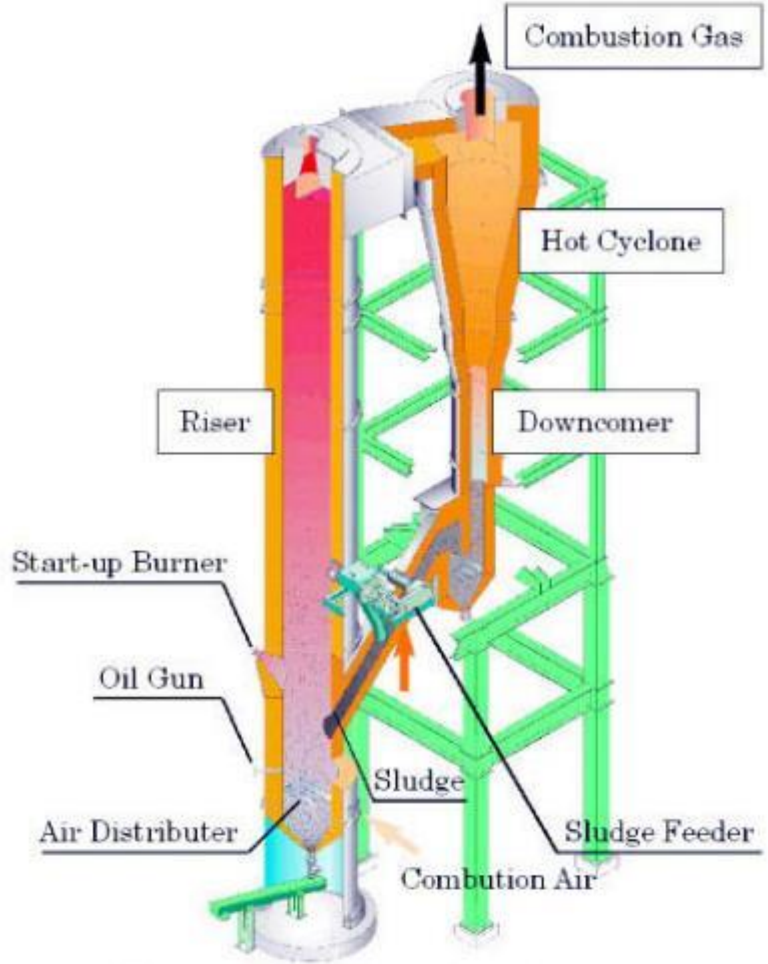
Fluidized bed boilers - fluidized bed combustion

stationary fluidized bed grate



smaller output boilers

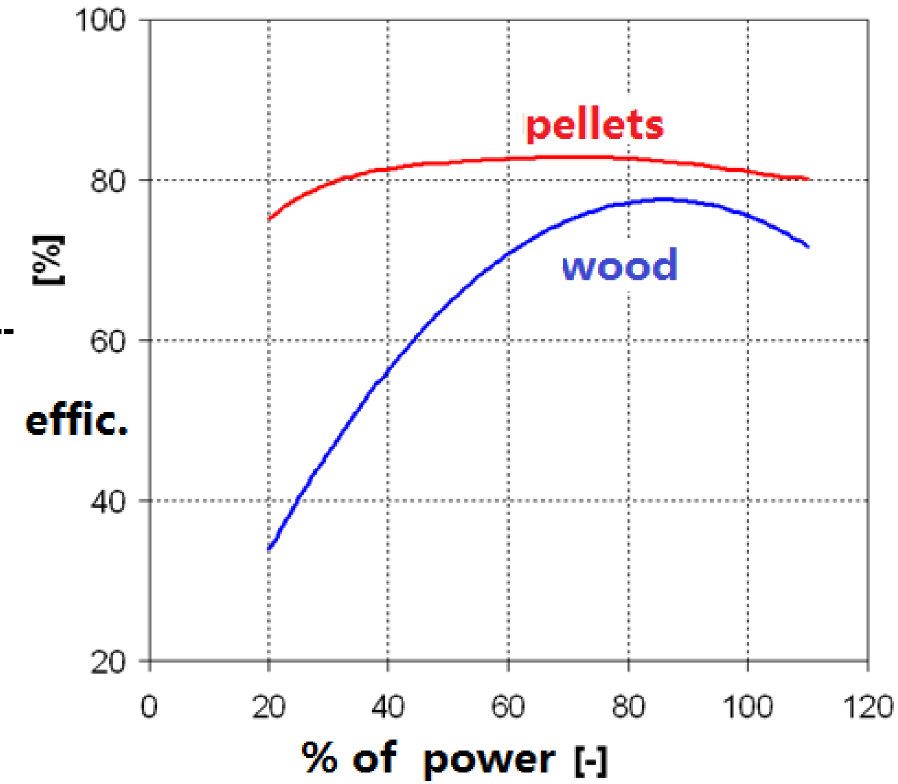
circulating fluidized bed, cyclone



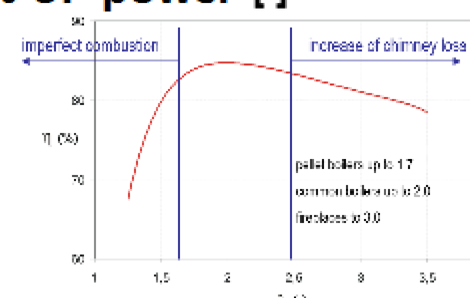
burning less valuable fuels

Efficiency x Power Regulation

- **Power regulation** by limiting the combustion air supply
  - manual stoking the boilers
  - incomplete combustion
  - CO emissions
  - reduction in efficiency -------------------



- **Power regulation** by limiting fuel supply
  - automatic boilers on pellets, chips



Principles of proper combustion of biomass

- **wood burning**
  - 2-3 degree: wood gasification + combustion of generated gases (wood gas)
  - furnace **gasification**, partial air supply (primary air),> 200°C
  - **combustion** in post-combustion (afterburner) chamber, air supply (secondary, eventually tertiary)
  - heat transfer for further use (exchanger), flue gas temperature 150°C (chimney loss x chimney draft)
- **requirements for efficient combustion**
  - sufficient air supply (excess air l = 1.5 to 2.5)
  - low fuel humidity (10 to 20%)
  - sufficiently high combustion temperatures (800 to 900 ° C)
  - stability of temperature conditions in boiler (accumulation lining, low heat loss)
  - stability of pressure conditions in boiler (suitable dimensioning of flue gas path)
  - constant operating conditions

Poor combustion

- **non-compliance with proper combustion principles**
  - biofuel with inappropriate properties (high humidity)
  - inappropriate device (eg coal-fired boiler used for wood burning) without power control
- **result**
  - low efficiency
  - short boiler life
  - high pollutant emissions

Phytomass combustion emissions

- **carbon dioxide (CO_2)**
  - neutral balance, optimal combustion: CO_2 content about 12%
- **nitrogen oxides (NO_x)**
  - nitrogen content in phytomass 0.1 to 0.5% (coal 1.4%)
  - oxidation of nitrogen in combustion air dependent on combustion temperature (keep up to 1200°C !)
- **solid particles (dust)**
  - ash, unburned soot - depends mainly on fuel humidity
  - the ash: content of wood is a small,

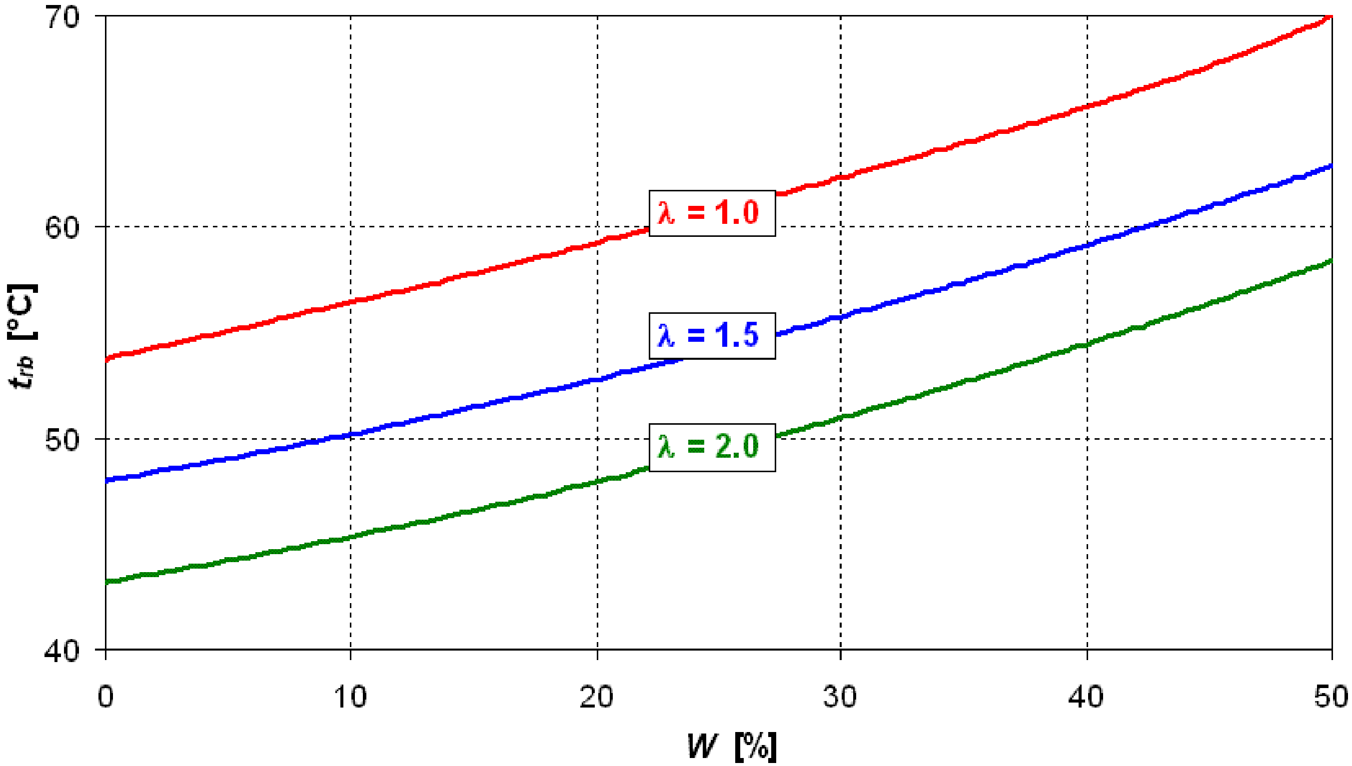
    significant component in straw

Phytomass combustion emissions

- **carbon monoxide (CO)**
  - product of incomplete combustion, wet fuel, insufficient air supply
  - CO is rich in energy … high CO content in flue gas = low efficiency
  - combustion quality indicator, recommended: concentration below 0.1%
- **hydrocarbons (C_xH_y)**
  - due to pyrolytic decomposition
  - especially when start firing (below 600 ° C), smoke
- **sulfur oxides (SO_x)**
  - very small amount in straw 0.1% (1% brown coal)

Principles of connection of boilers to systems

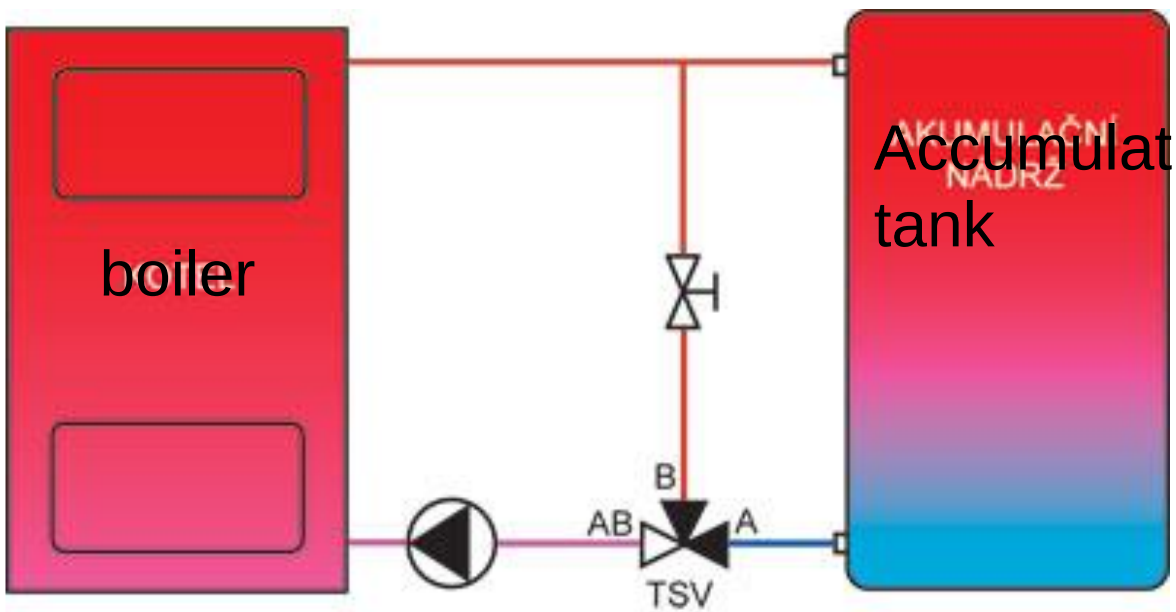
- **flue gas dew point (condensation)**
  - flue gas condensation, flue gas dew point temperature t_{rb} = 50 to 60 ° C
  - aggressive condensate, **corrosion**



zdroj: Trnobranský

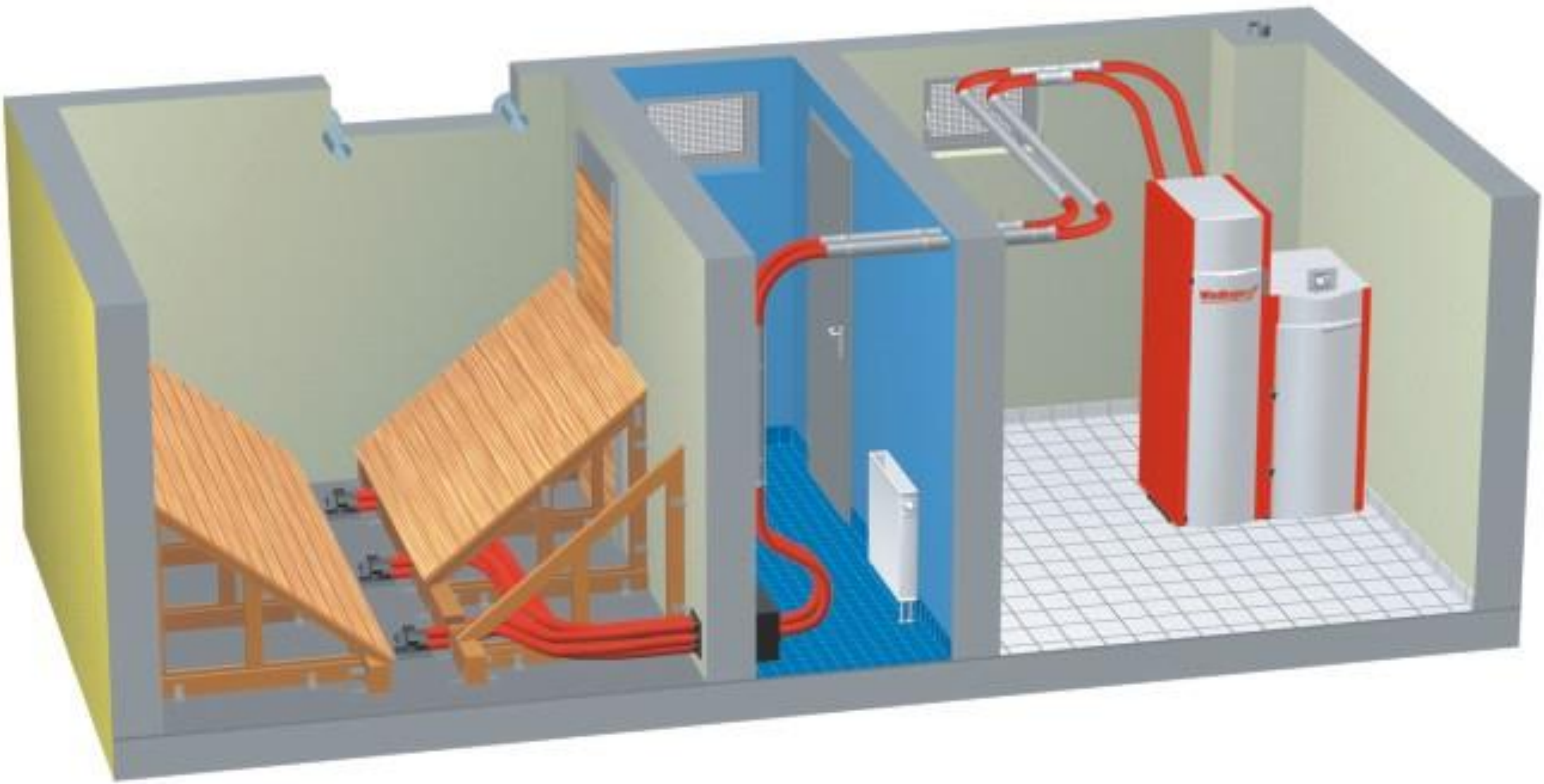
Principles of connection of boilers to systems

- **three-way thermostatic mixing valve**
  - boiler inlet water temperature **> 65 ° C**
  - preheating the return water to the boiler
  - fireplace (high combustion air excess): no protection required, low dew point



Fuel tank

Pellet storage facilities



pneumatic fuel transport, suction head in the warehouse, emergency tank at the boiler with filling sensor

Pellet storage facilities

Chips storage facilities

worm feeder from stock

Chips storage facilities

worm feeder from the cointainer

Chips storage facilities