for business
bioenergy

Utilization of straw for mid-scale heat applications

Training material for B4B seminars
Prepared by: Danish Technological Institute
2016

Overview

- Straw as energy resource
- Handling and storage of straw
- In-house heating applications of straw
- Straw for small scale district heating applications
- Straw for large scale heat and power generation (optional)
- Residual products

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Straw as energy resource

Straw production

- Straw is a by product from cereal grain production
- Straw yield depends on the crop
- Usually 35 and 53 kg straw per 100 kg grain
- Yield per ha are ca.
  - 3.5 t/ha for wheat straw
  - 2,75 t/ha for barley straw
  - 1,5 t/ha for rape straw

- Variation due to climatic conditions can be up to 30%
- Variation due to geographic location, soil quality and farming technology
- Only minor part is used for energy production
- Major part of the straw harvest is used in agricultural sector i.e. animal bedding, forage
- Unutilized straw surplus makes out a potential fuel reserve
- Some years ago it was common to burn unutilized straw directly on the field

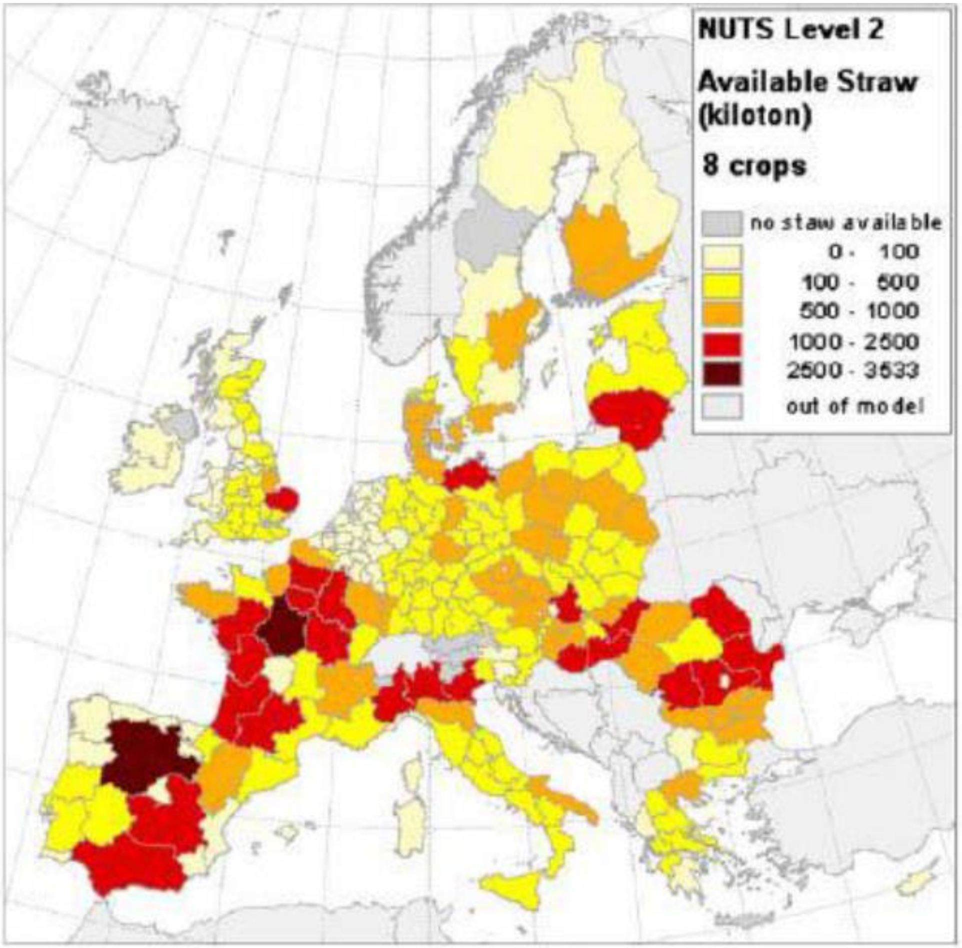
[1]

[1]

[1]

Straw as energy resource

Technical potential of straw residues in Europe



Available straw potential in Europe in 1,000 tons [4]

Country	Available potential PJ/a
Austria	6.4
Belgium	5.2
Bulgaria	12.1
Cyprus	0
Czech Republic	15.8
Denmark	19.3
Estonia	1.8
Finland	8.9
France	111.5
Germany	92.9
Greece	8.7
Hungary	15.7
Ireland	5.1
Italy	40.3
Latvia	3.5
Lithuania	6.6
Luxemburg	0.4
Malta	0
Netherlands	3.6
Poland	39
Portugal	1.5
Romania	18.7
Slovakia	6
Slovenia	0.5
Spain	74.4
Sweden	10.5
United Kingdom	52
EU-27 TOTAL	560.4

Technical potential of straw residues in Europe [5]

Straw as energy resource

Straw as a fuel

- Most important arguments for using straw as a biofuel are lower CO_2 emissions compared to fossil fuels
- Low cost and good availability, especially in agricultural regions

Benchmark of straw to other fuel types:

	Yellow straw	Grey straw	Wood chips	Coal
Water content	10-20%	10-20%	40-50%	12%
Ash	4%	3%	1%	12%
Carbon	42%	43%	50%	59%
Hydrogen	5%	5%	6%	4%
Oxygen	37%	38%	38%	7%
Chloride	0.75%	0.20%	0.02%	0.08%
Nitrogen	0.35%	0.41%	0.30%	1.00%
Sulphur	0.16%	0.13%	0.05%	0.80%
Heating value	14.4 MJ/kg	15.0 MJ/kg	10.4 MJ/kg	25.0 MJ/kg

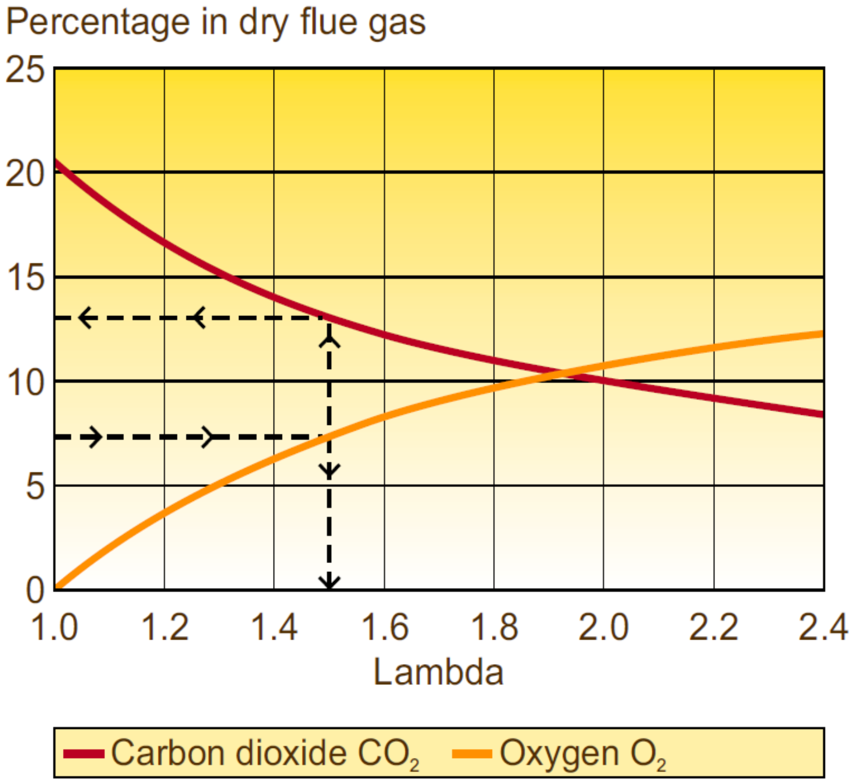
[2]

Straw as energy resource

Straw as a fuel

- Straw is not an easy to use fuel
- High content of alkali and chlorine result in the formation of highly corrosive chloride species during the combustion process
- Corrosion of steel surface in boiler and piping is a serious problem
- The softening temperature of ash is relatively low compared to other fuel types (just 800-850 degrees) in some cases 600 degrees → risk of deposit formation
- Ideal combustion of straw is obtained at excess air ratios of 1.4 to 1.6

[1]



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Straw as energy resource

Pre-treatment of straw and traded forms

- Straw has a very low bulk density after the harvest (just 40-70 kg/m^3)
- Density is increased by baling, briquetting or palletization
    - Bales 100-200 kg/m^3
    - Briquettes 400-500 kg/m^3
    - Pellets 600-680 kg/m^3
- Most common form for energy straw are bales, either round bales or cubes

Curing on the field: Exposure to sun and rain turns fresh “yellow straw” into “gray straw”

- Grey straw has better combustion properties (less ash content)
- Straw has to be dry before bailing (ca. 15% moisture content)

[2]

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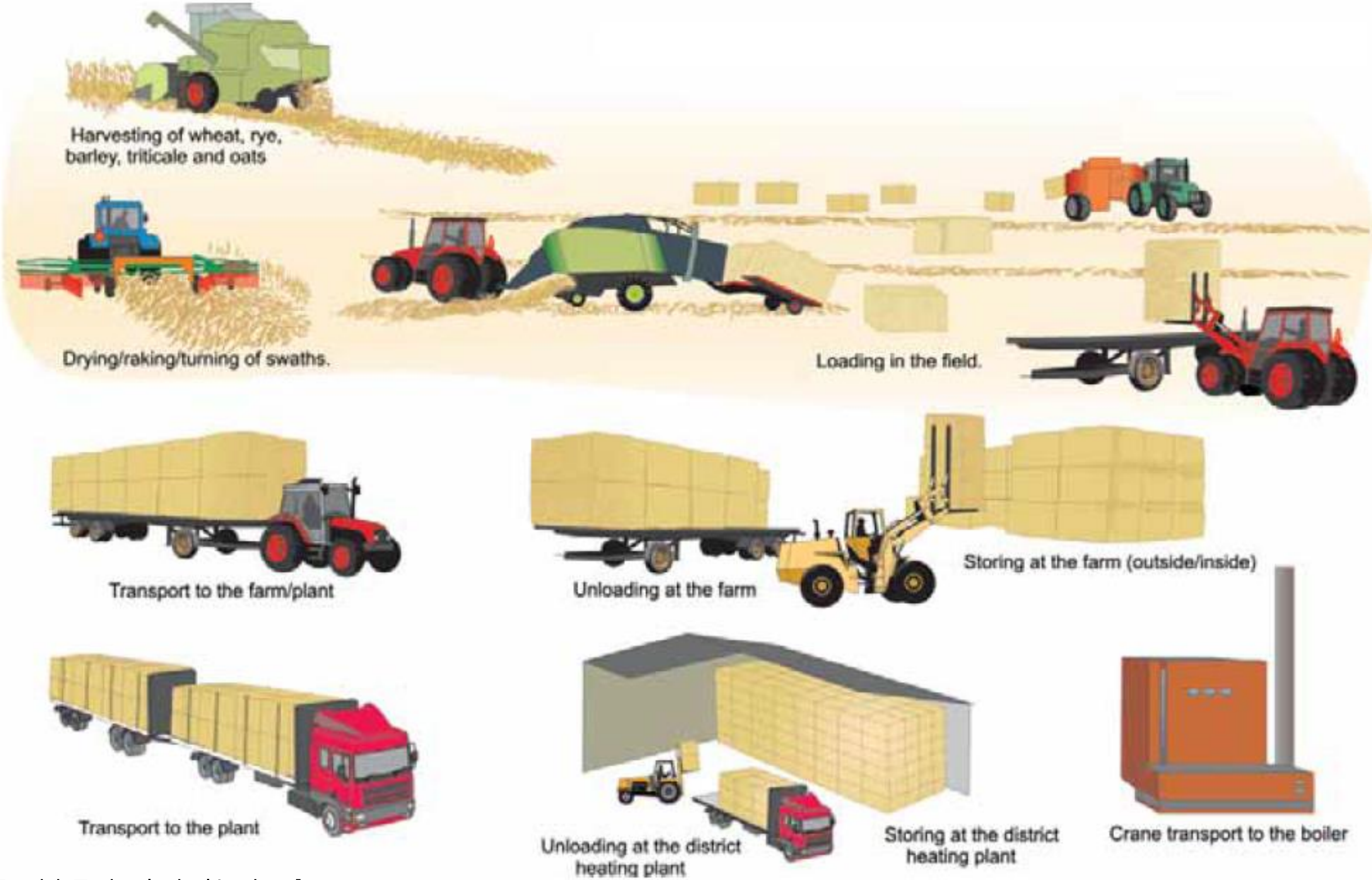
Handling and transport of straw



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Handling and transport of straw

Example: cereal straw for biomass boiler

- **Harvesting of cereal straw**
- **Drying / turning of swaths**
- **Baling**
- **Loading on field**
- **Transport to field storage / farm storage**
- **Unloading at storage**
- **Stacking**
- **Loading of truck**
- **Transport to end user**
- **Storage at end user**
- **Internal conveying and combustion**

Handling and transport of straw

Harvesting with a combined harvester chaff cutter

Drying, raking and turning of swaths

Tractor propelled bale press

[1]

Handling and transport of straw

Loading and unloading of transport truck/trailer to storage

Truck/Trailer transport to storage

Plastic covered outside storage

[1]

Handling and transport of straw

Truck transport to end-user

Unloading and storage at end user site

[1]

Handling and transport of straw

Delivery contracts for straw fuels

- The crop delivery contract for straw may include the following terms and conditions:
- Term of contract and notice of termination
- The amount of straw agreed upon, including provisions in the event of increase/decrease in the consumption of straw, non-delivery due to decrease in crop yield etc.
- Terms of delivery, including the type of bale, the dimensions and weight of bales, water content, and other grade determinations
- Basic price and the regulation of price in proportion to water content and time of delivery

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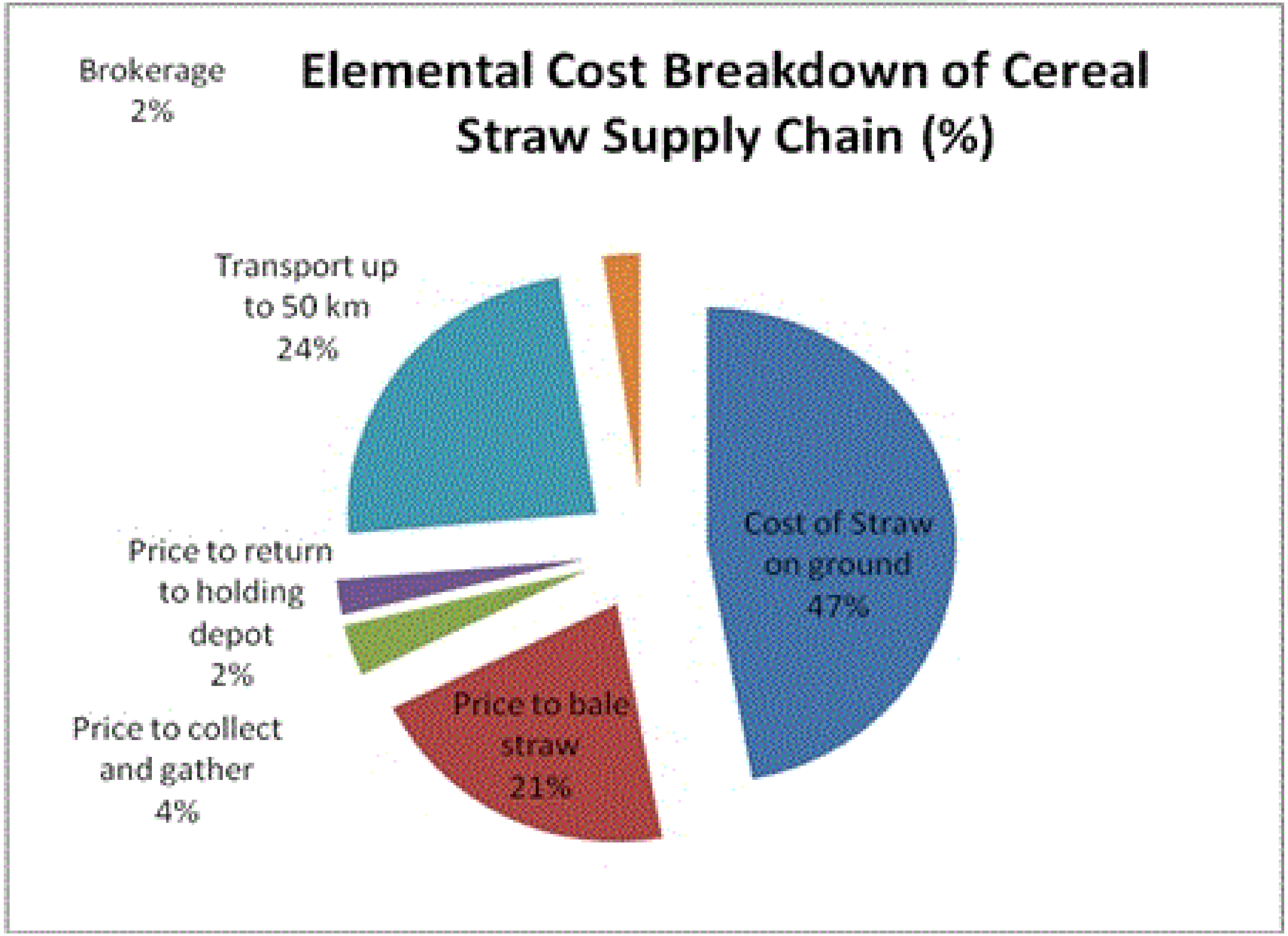
Handling and transport of straw

Major cost factors



Source: The Bioenergy System Planners Handbook - BISYPLAN

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In-house heating applications of straw

Boiler types

Batch fired boilers:

- Always installed in combination with a storage tank that can absorb the heat energy from the firing → Boiler can operate at full load
- Fuel types
  - Small straw bales
  - Medium sized bales
  - Big bales
  - Round bales
- Most widely used boiler size is a boiler for one medum sized bale or 8-10 small bales
- Typical applications are heating of farm buildings, estates building complexes

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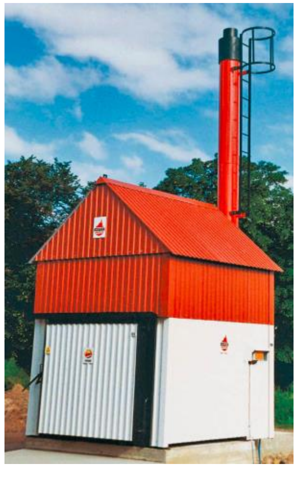

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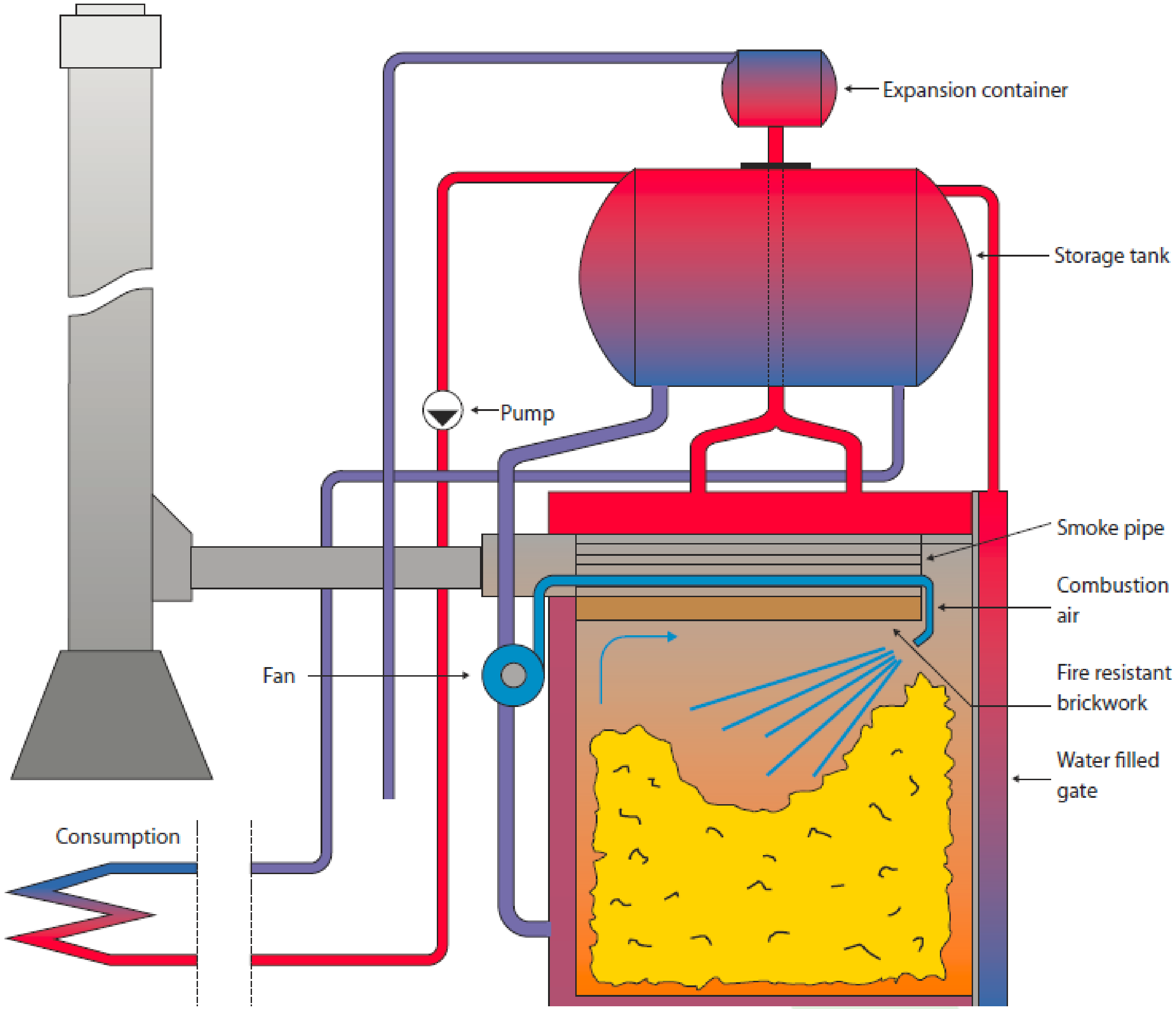
In-house heating applications of straw

Boiler types

Batch fired boilers

The principle in a batch-fired boiler:

The storage tank is big enough to contain the energy generated by combustion of the straw that the combustion chamber will hold



[1]

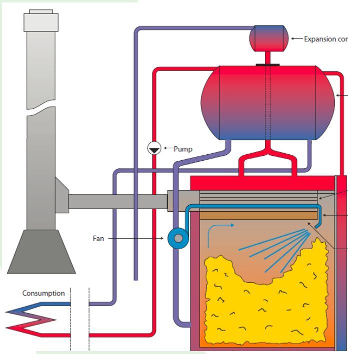
Source: Center for Biomass Technology

In-house heating applications of straw

Boiler types

Batch fired boilers: - Control of firing

- Combustion air fans
- Amount of air and distribution of air between primary and secondary air is controlled electronically by a control unit
- Flue gas temperature and oxygen content are used as control parameter
  - Lambda probe
  - Oxygen concentration of 6-7 % in flue gas (Lambda 1.5)
  - Electronic control unit steers primary/secondary air to keep oxygen level constant
- Air nozzles designed and positioned to maintain a proper turbulence in the combustion zone
- Storage tank (60-80 liters of water per kg of straw) to maintain maximum boiler load throughout all combustion stages



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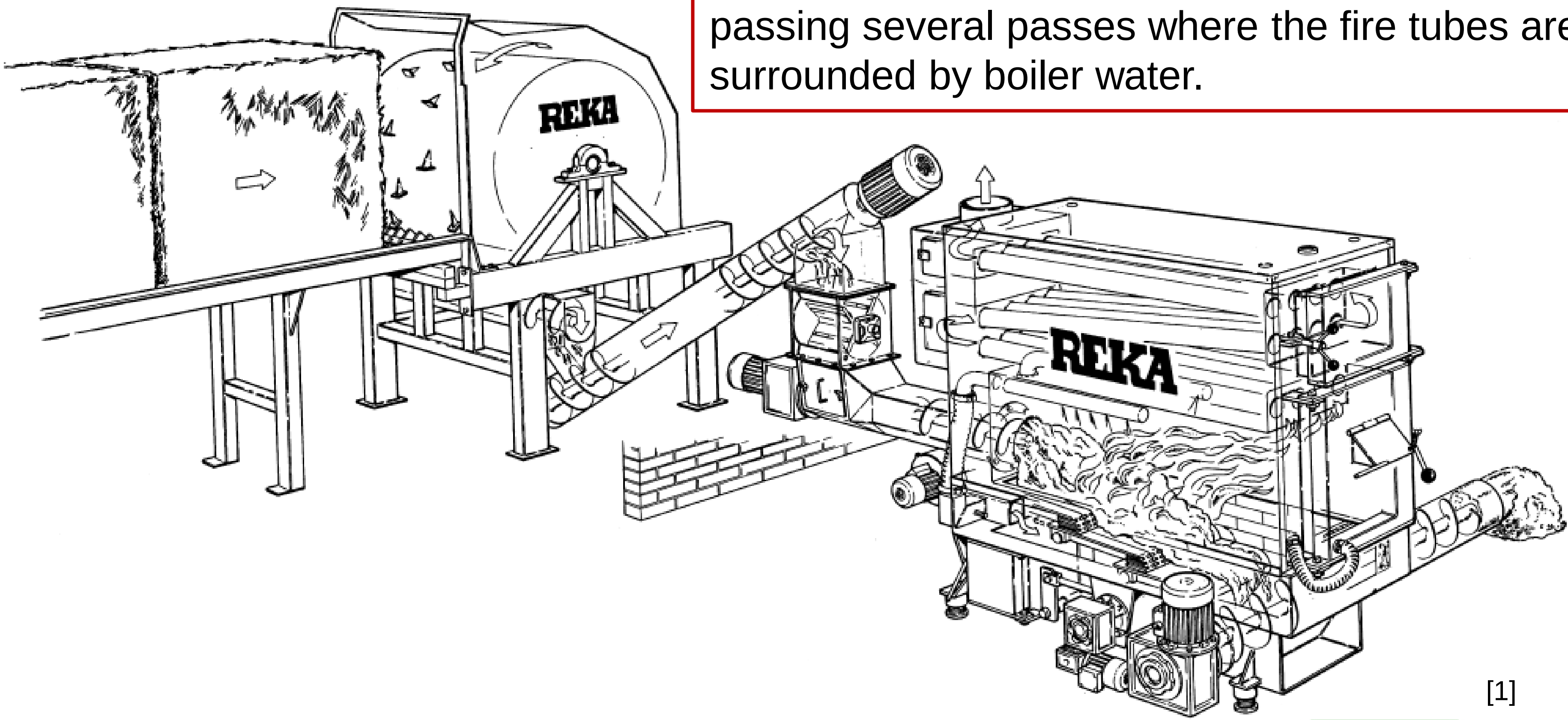
In-house heating applications of straw

Boiler types

Automatic boiler: The straw is being shredded by a slow-speed shredder and fed via screw stoker on to the grate where the combustion takes place. The forward and backward movements of the grate pushes the ash towards the ash chute and further out with the ash conveyor. The flue gases are cooled by passing several passes where the fire tubes are surrounded by boiler water.

Automated boiler

- Ease the work of firing with straw
- Mainly designed for small bales



[1]

Source: Center for Biomass Technology

In-house heating applications of straw

Boiler types

Automated boiler

- Bale conveyor: 10-20 meter length is filled with straw bales once every 24 hours
- Before firing straw is disintegrated by a shredder/cutter
- Worm conveyor or blower transports straw into the boiler
- Blower is most common systems (high security against backfire/burn back
- Continues firing results in a more stable combustion and thus a higher efficiency and reduced emissions
- The boiler heat transmission is adjusted by on/off operation, controlled by a thermostat that controls the boiler water temperature

An automatic boiler. The chaffed straw is sucked into the lower, bright tube of the cyclone. The upper tube is the cyclone exit air. The straw is separated from the transport air in the cyclone and is dosed via a rotary valve under the cyclone down on to the screw stoker that passes the straw into the boiler. The flue gas fan is seen on the back of the boiler

Source: Center for Biomass Technology [1]

In-house heating applications of straw

Boiler types

Automated boiler – combustion control

- Amount of straw fired is adapted to amount of combustion air
- Constant straw fed is applied by an oxygen controlled screw stoker
- Oxygen content in flue gas is recorded by a lambda probe and straw amount is controlled by turning on/off the screw stoker
- Aim is to maintain the oxygen content at approximately 7%

[1]

The gate is open to the combustion chamber of an automatically fed fire tube boiler. The straw is fed by screw stoker behind the flames, and the flue gas passes though the four tubes and further through the boiler vessel. Below on the right, the gear motor of the ash conveyor is seen.

Source: Center for Biomass Technology

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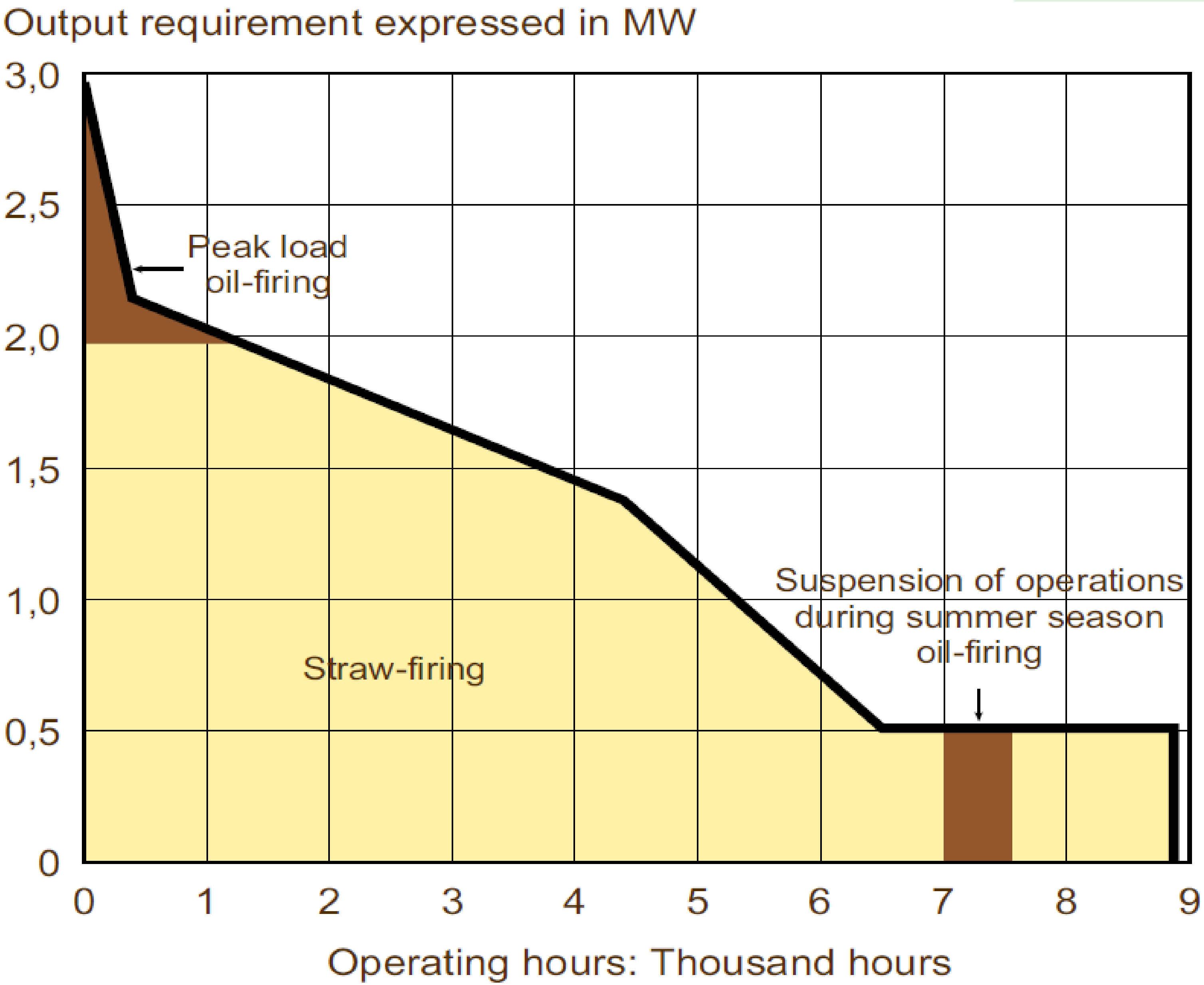
Small scale district heating

- Small heating plant without power production
- 1-9 MW (usually around 3 MW)
- Maximum boiler temperature of 120 C and 6 bar pressure
- Most common type of straw utilization for energy production
- Designed for big bales

Design

- The boiler rating is fixed on the basis of the maximum heat amount to be supplied to the distribution net on the coldest day of the year
- Distribution loss 16-42 %
- Straw boiler with back-up boiler
- See B4B dimensioning tool for further info

Small scale district heating



The duration curve for a 3 MW boiler plant with a 2 MW straw-fired boiler. Peak load and stand-by load by a 3 MW oil-fired boiler

Source: Center for Biomass Technology [1]

Small scale district heating

Handling & Storage

- Space consuming
- 8 days full operation is minimum requirement
- 400 big bales for a 3,7 MW plant (600 m2)
- Weighing of the bales upon arrival
- Reject if more than 20% moisture content
- Crane for moving the bales
- Chaff cutting and shredding before firing

Source: Center for Biomass Technology [1]

Small scale district heating

Boiler

- Boiler for sliced bales
  - Bale is sliced by hydraulic knife
  - Pushed into boiler by a ram stoker
- Boiler for continues firing
  - Instead of cutting the bale is pressed continuously into the boiler
  - Burning from the end
  - Cigar burner principle
- Boiler for firing of whole bales
  - Whole bale is placed into the boilers pre-heating chamber by crane
  - Bale is ignited by the buring fuel already present in the chamber
  - Burns partly from the from and top
  - Air inlet is controlled by flue gas temperature

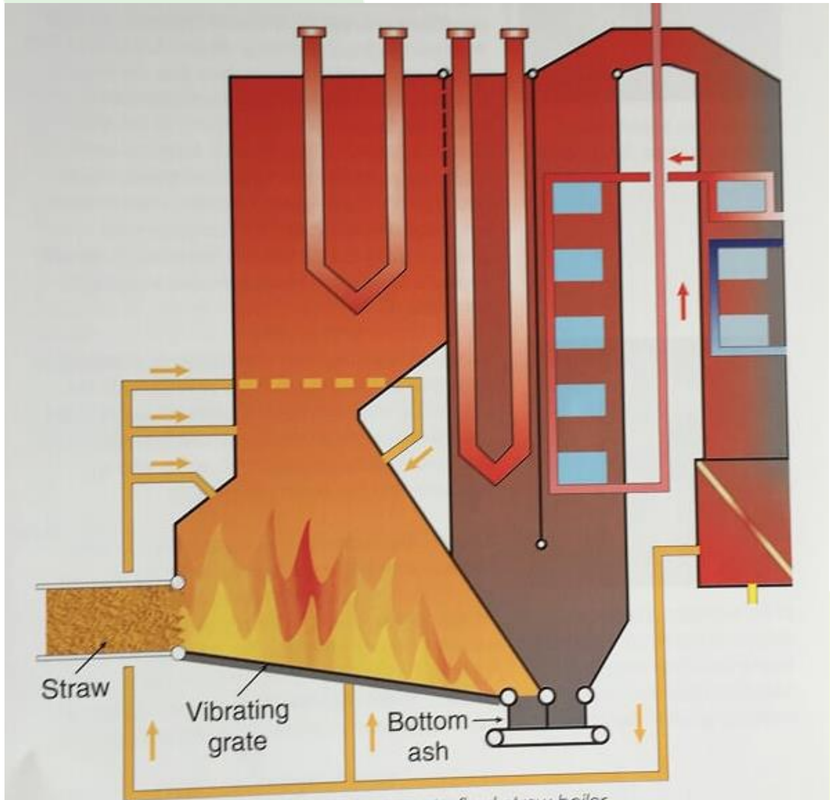


Figure 5.2. Cross section of a modern grate-fired straw boiler.

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Flue gas cleaning

- Multi-cyclone
- Bag filter
- Electrostatic filter
- Flue gas scrubber
- Flue gas condensation

Small scale district heating

Storage tank

The advantages of installing a tank are the following:

- Peak load morning and evening during the winter season can be smoothed out, thereby avoiding oil firing.
- During suspension of operations, the heat consumption can be drawn from the storage tank, thereby avoiding oil firing.
- A 400 m3 tank can supply heat for 7 hours at full load at an average plant.
- At off-peak load during summer, the boiler can operate at full load for a short period while the storage tank is filled, and then boiler is closed. The result is improved efficiency and lower emissions compared to continuous operating at off-peak load.
- The personnel's roster becomes more flexible, since, e.g., the boiler can be closed over the week-end during summer.

Drawbacks are increased expenses for investments and maintanance of the tank

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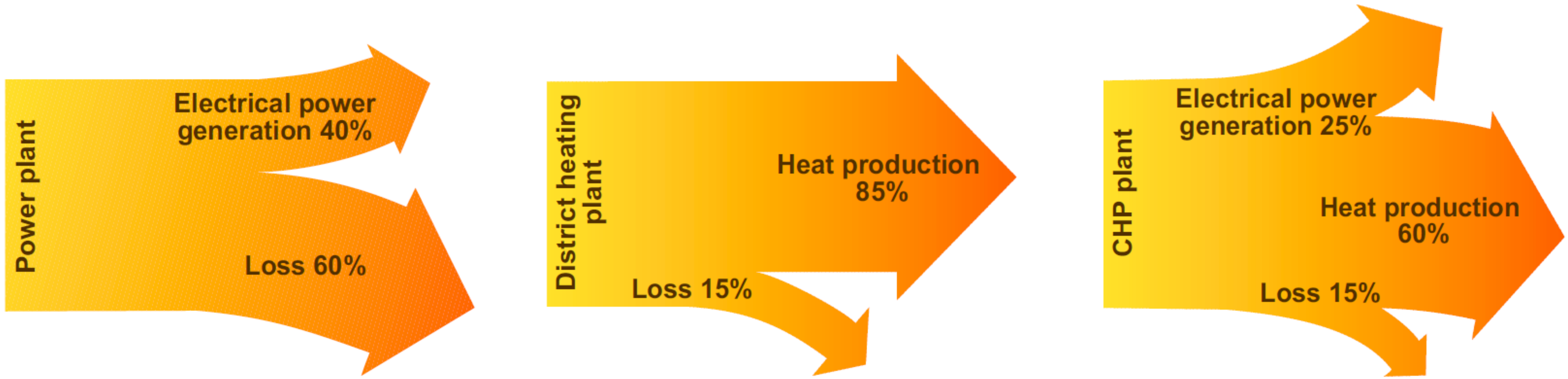
Straw use in CHP and powerplants

CHP plant principle and advantages

- Higher efficiency: 85-90 % of the fuel energy are used for heat and power production
- Ratio between heat production and power production can be changed



Source: Center for Biomass Technology [1]

By separate electrical power generation and heat production at a power plant and a district heating plant, the losses are much larger than by combined heat and power production at a CHP plant. Losses include own consumption at the plant

Straw use in CHP and powerplants

Examples of straw fired CHP boilers in DK

Plant	Technology	Biomass consumption/ year	Steam temper-ature	Steam pressure	Commis-sioned
Haslev Kraftvarmeværk	Grate-firing of straw	26,000 tonnes	455°C	67 bar	1989
Rudkøbing Kraftvarmeværk	Grate-firing of straw	14,000 tonnes	450°C	60 bar	1990
Slagelse Kraftvarmeværk	Grate-firing of straw	30,000 tonnes	450°C	67 bar	1990
Maribo-Sakskøbing Kraftvarmeværk	Grate-firing of straw	45,000 tonnes	540°C	93 bar	2000
Fynsværket	Grate-firing of straw	150,000 tonnes	540°C	110 bar	2009
Køge Kraftvarmeværk unit 7	Grate-firing of wood	80,000 tonnes	525°C	93 bar	1987
Køge Kraftvarmeværk unit 8	Grate-firing of wood	120,000 tonnes	525°C	93 bar	1999
Herningværket	Grate-firing of wood	250,000 tonnes	525°C	115 bar	2002
Assens Kraftvarmeværk	Grate-firing of wood	45,000 tonnes	525°C	77 bar	1999
Randers	Grate-firing of coal and dry biomass	74,000 tonnes	525°C	111 bar	2002*
Måbjerg bio-boiler	Grate-firing of wood and straw	65,000 tonnes	520°C	67 bar	1993
Masnedø Kraftvarmeværk	Grate-firing of wood and straw	45,000 tonnes	522°C	92 bar	1996
Ensted bio-boiler	Grate-firing of wood and straw	150,000 tonnes	510°C	210 bar	1998
Avedøre 2 bioboiler	Grate-firing of straw	150,000 tonnes	545°C	310 bar	2001
Studstrupværket unit 4	Co-firing, straw to coal	100,000 tonnes	540°C	270 bar	2002*
Studstrupværket unit 3	Co-firing, straw to coal	30,000 tonnes	540°C	270 bar	2005*
Avedøre 2 main boiler	Biodust-firing in power plant boiler	300,000 tonnes	542°C	310 bar	2001
Amagerværket	Biodust-firing	130,000 tonnes	480°C	120 bar	2003
Grenaa	CFB combustion of straw and coal	40,000 tonnes	505°C	92 bar	1992

*able 5.1. Overview of biomass-fired CHP plants in Denmark. * Converted to biomass.*

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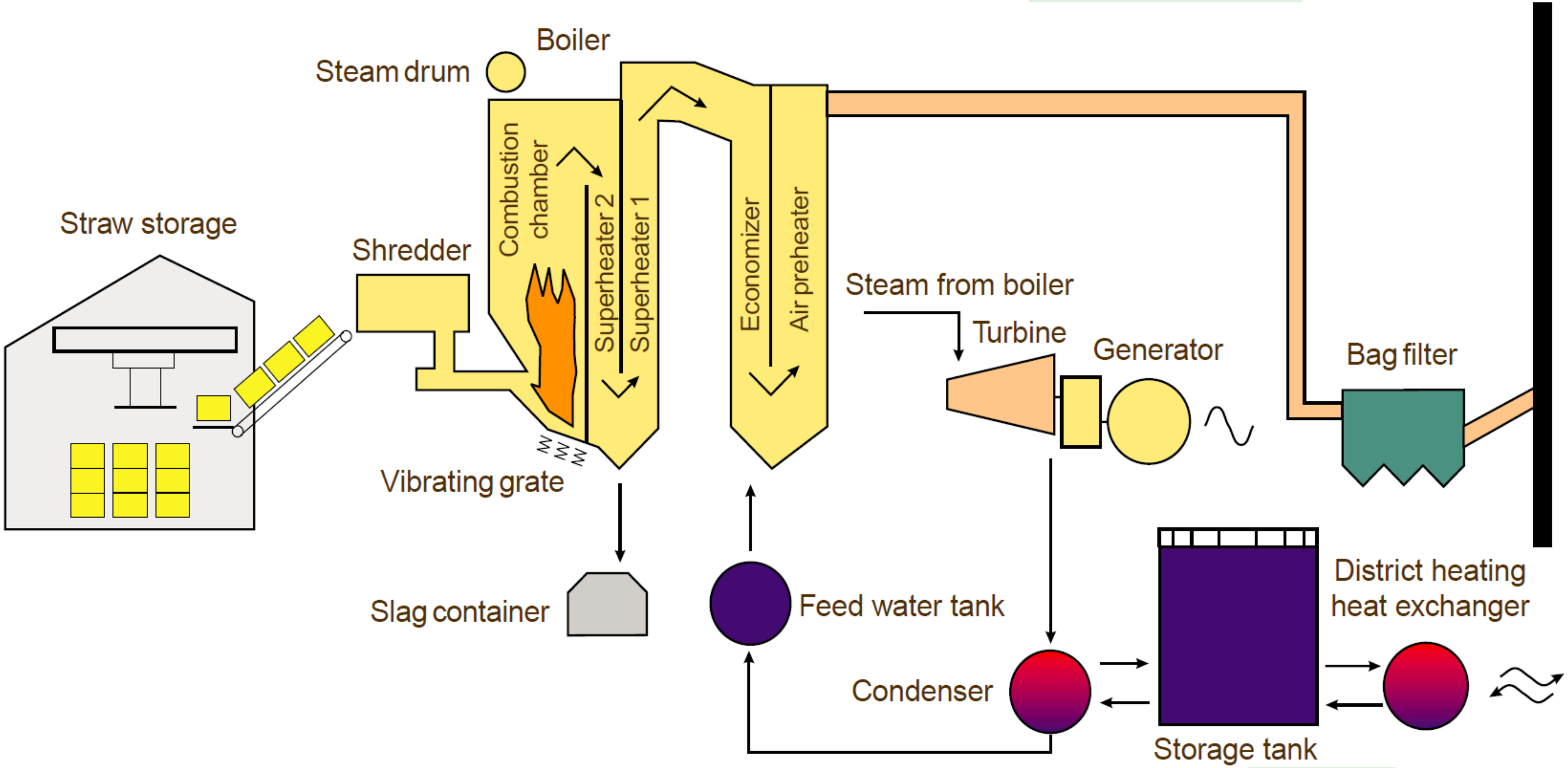
Straw use in CHP and powerplants

Examples of straw fired CHP boilers in DK



Source: Center for Biomass Technology [1]

Residual products

Ash

- Ash is rich in nutrients, primarily potassium, magnesium and phosphorous and can therefore be used as fertilizer
- Bottom ash can in a number of regulated countries be used as soil improvement or fertilizer directly on farmland in other countries. Limits determined by trace elements.
- Another option is the use in composting together with other plant materials.
- Some bottom ashes may even be used for engineering purposes, e.g. certain road constructions, especially far from major cities.

[6]

References and further reading

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