Basic Principles of Thermochemical Biomass Energy Conversion Systems

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Presentation Plan

- Short Introduction of Solar Energy Institute
- Biomass fuel characterization
- Thermochemical Biomass Conversion Systems
- Biomass Gasification
- Biomass Combustion
- Conclusions

Ege University Solar Energy Institute

The Solar Energy Institute was established in 1978 for graduate education (Msc and PhD) and research on solar energy and its applications. Along with the solar energy, other renewable energy resources like wind, biomass and geothermal are also being studied.

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e-mail: egegunes@ege.edu.tr

Ege University Solar Energy Institute

SOLAR ENERGY INSTITUTE
Director: Prof. Dr. Gunnur KOCAR

ENERGY

-Solar Photochemistry
-Next Generation PV
-Organic Solar Cells
-Optoelectronics
-Solar Thermal Applications
-Thermodynamics
-Energy Efficiency in Buildings

ENERGY TECHNOLOGY

- Solar Architecture and Solar Thermal Applications
- Photovoltaic
- **Biomass Energy**
- Wind Energy
- Geothermal Energy and Heat Pumps
- Energy Efficiency and Management

Solar Energy Institute/Energy Technology

RESAERCH INTERESTS

- Biogas and Organic Fertilizer Production (Anaerobic Digestion)
- Energy Crops Production
- Biodiesel Production and Testing
- Bioethanol Production
- Geographical Information Systems
- Biorefineries
- **Thermochemical Biomass Conversion)**
  - ✓ **Combustion**
  - ✓ **Gasification**
  - ✓ **Torrefaction**

The usage of biogas in engines and direct combustion systems

Energy crop cultivation with organic fertilizer from biogas system residues.

Biomass Fuel

There are a **wide variety of fuels** currently in the world.

- Agricultural residues (wheat straw, corn stover)
- Energy crops (switchgrass, poplar)
- Wood and wood waste
- Municipal solid waste

- Forestry and Woody waste
- Straw
- Domestic Waste
- Nut shells
- Sewage sludge
- Olive pips
- Leather waste
- Animal litter
- Sugar Cane Bagasse
- Energy crops
- Oil seed rape husks
- Rice and Corn husks
- Chicken Waste, Bone-meal
- Cotton Stalks, Fish waste

Biomass Fuel Characterization

- Proximate Analyze

Moisture (%), Volatile matter (%), Fixed carbon (%), Ash (%)

- Elementel Analyze

C (%), H (%), O (%), N (%), S (%)

- Heating value (MJ/kg)
- Density (kg/m^3)
- Particulate size (mm)
- Ash melting point (^oC)
- Ash analyses (Na, Mg, Si, K, Ca, Na_2O, MgO, SiO_2, K_2O, CaO,
- Alkali metal in ash (Na, K)
- Pollutants (Cl)
- Cellulose/lignin
- TG
- Hardness

- **Moisture** effect into calorific value
- **High volatile matter** can cause high tar content
- Moist fuel is difficult to transport
- **Ash content** is important for combustion and ash handling
- **The ash composition:** affect to combustion and re-use
- **Ash melting behavior:** Important for combustion; slagging and fouling
- **Particle size:** Important for handling and combustion. Aim is to produce homogenous particle size distribution
- **High ash content** (> 3w-%)with **chlorine** can cause problems in boiler.
- **Properties like sulphur, chlorine and heavy metals** are important to know for environmental reasons,
- **High alkali content** like potassium (K), sodium (Na) and chlorine (Cl) can cause corrosion and slagging problems in steam boilers

Eija Alakangas, VTT

Biomass Fuel Characterization

	Anthracite	Bituminous			Sub-Bit.	Lignite	Biomass
	Ruhr	Pitt. #8	Ill #6	Talcher	PRB	Tuncbilek	Range
Fixed Carbon	81.8	51.0	41.5	28.8	33.1	21	<15
Volatile Matter	7.7	36.7	35.3	24.1	31.4	25	>70
Moisture	4.5	5.2	12.2	14.8	30.2	7	10-60
Ash	6.0	7.1	11.0	32.3	5.3	47	<1-5
Total	100.0	100.0	100.0	100.0	100.0	100.0	_
HHV [MJ/kg]		30.99	25.67	16.46	19,49	13.10	15-20

Data in wt% on as received basis except for biomass volatiles

Biomass Energy Conversion Technologies

Biomass can be converted into three main products:

- power/heat generation
- transportation fuels
- chemical feedstock.

Conversion of biomass to energy is undertaken using three main process technologies:

- Thermo-chemical
- Bio-chemical/biological
- Mechanical extraction (with esterification)

For Bio-chemical conversion two process options are available:

- Digestion (production of biogas, a mixture of mainly methane and carbon dioxide)
- Fermentation (production of ethanol).

For thermo-chemical conversion four process options are available:

- Combustion
- Gasification
- Pyrolysis
- Liquefaction

Peter McKendry, Energy production from biomass (Part 2), Bioresource Technology 83 (2002) 47–54

Biomass Energy Conversion Technologies

Fuel Handling →	Conversion →	Cleaning →	End Use
Biomass receiving	Combustion	Hot gas cleaning	Heat and power
First stage screening	Gasification	Cold gas cleaning	Gas biofuels
Storage	Pyrolysis	Tar removal	Liquid biofuels
Feed preparation	Liquefaction	Dust removal	Solid biofuels
Conveying		COS, H_2S removal	
Feeding		Emissions reductions, SO_2, NOx	

Hazard and Safety Issues

Biomass Handling Systems

The Biomass Handling System can be broken into 5 stages.

- Biomass receiving, First stage Screening, Storage, Feed preparation, Conveying, Feeding

Biomass Receiving

Biomass is first transported via truck or rail-car and unloaded at the receiving station

First stage Screening

to remove foreign materials from biomass

Storage

Once received or screened the biomass is transported by conveyor belt to above ground storage for large biomass or to silo or bunker for smaller biomass

Feed Preparation

The feed preparation process consists of

- Screening
- Drying
- Sizing
- etc

Conveying

Once the biomass prepared, it is then transported to the hoper which gravity feeds the feeder.

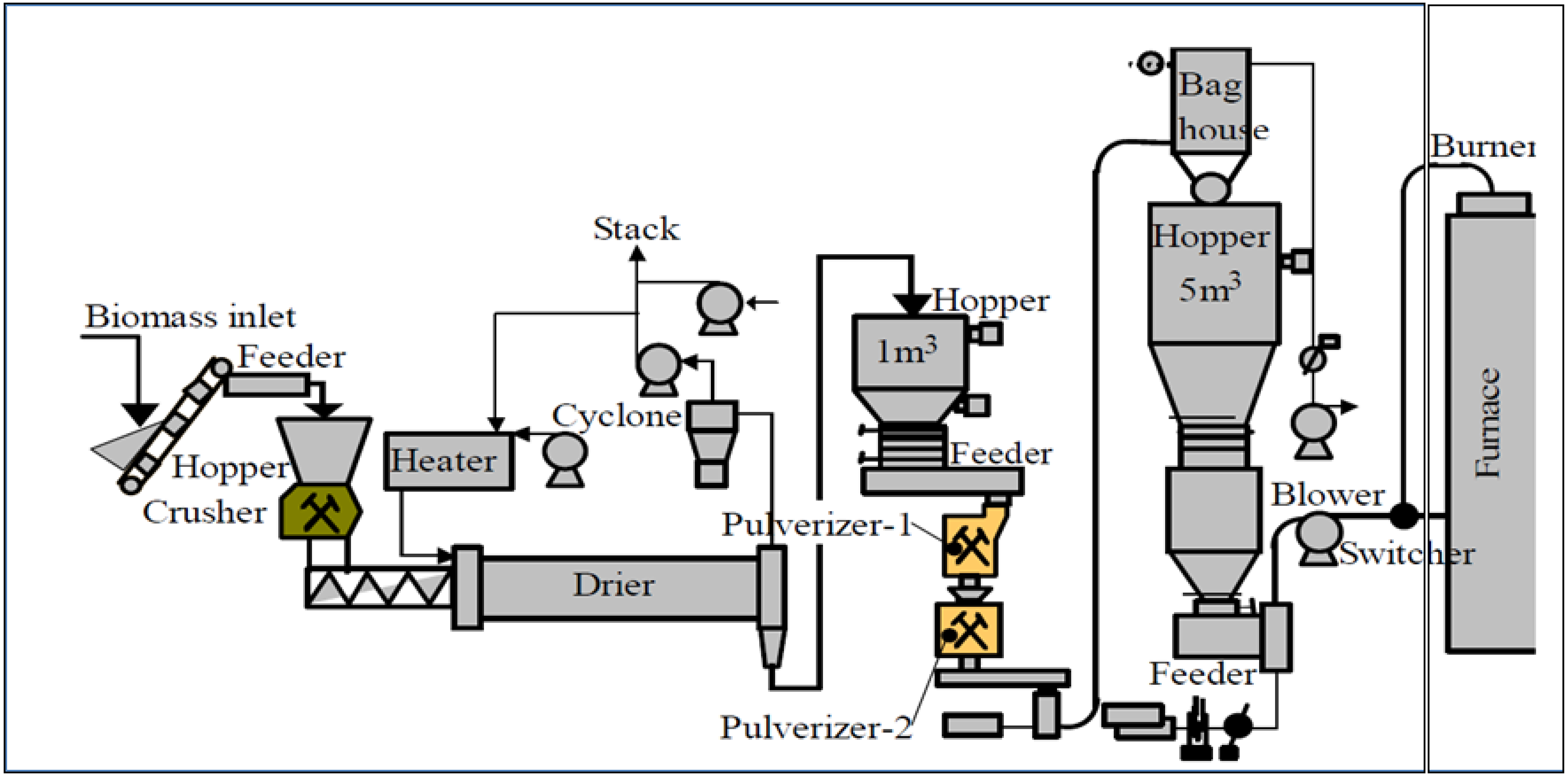
Feedings

6 Main types of feeders are available.

- Gravity chute,
- Screw conveyor,
- Pneumatic injection,
- rotary spreader ,
- Moving hole feeder,
- Belt feeder

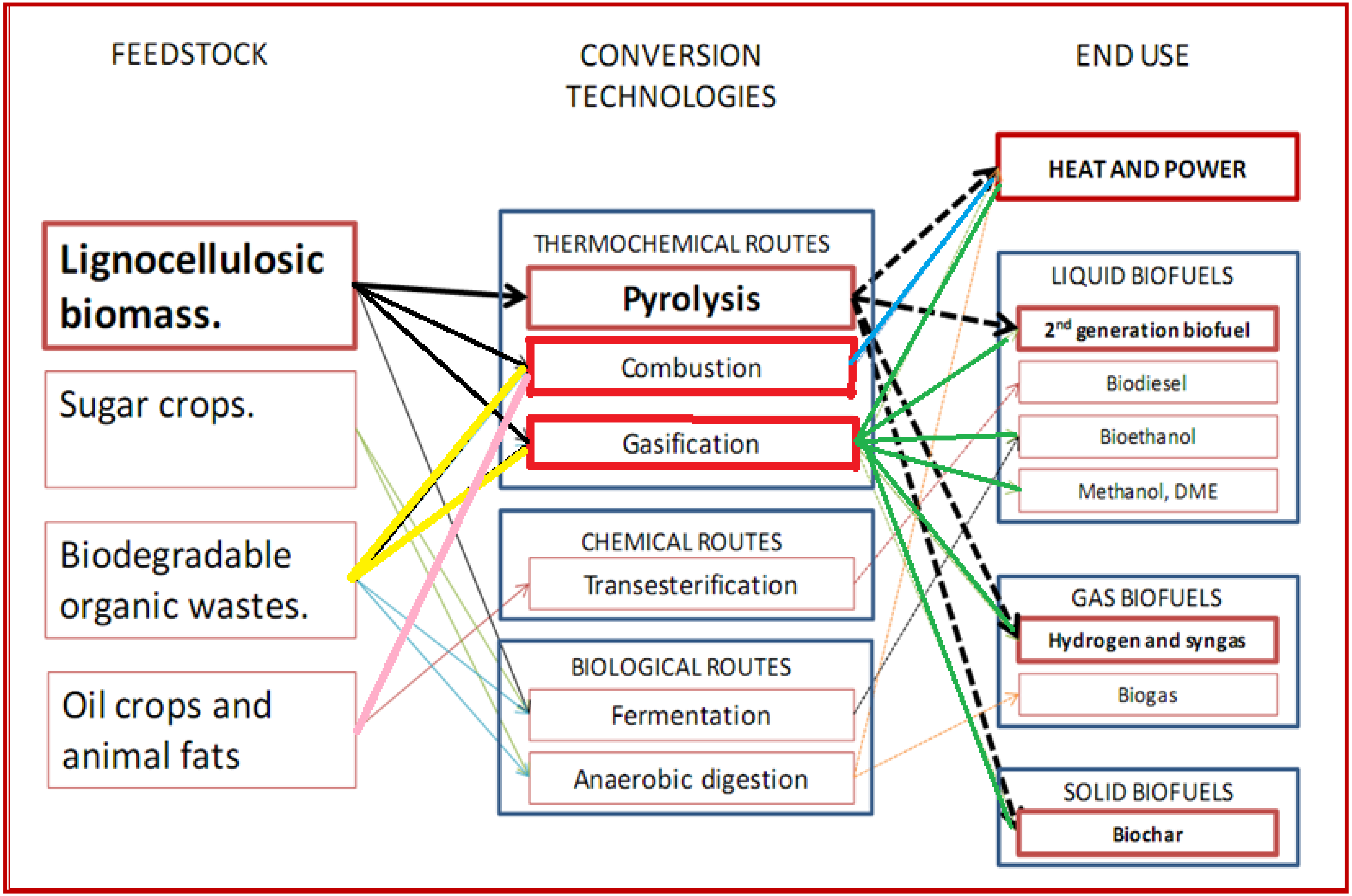
www.scribd.com/.../PPT-CH10-Biomass-Handl.

Biomass Handling Systems



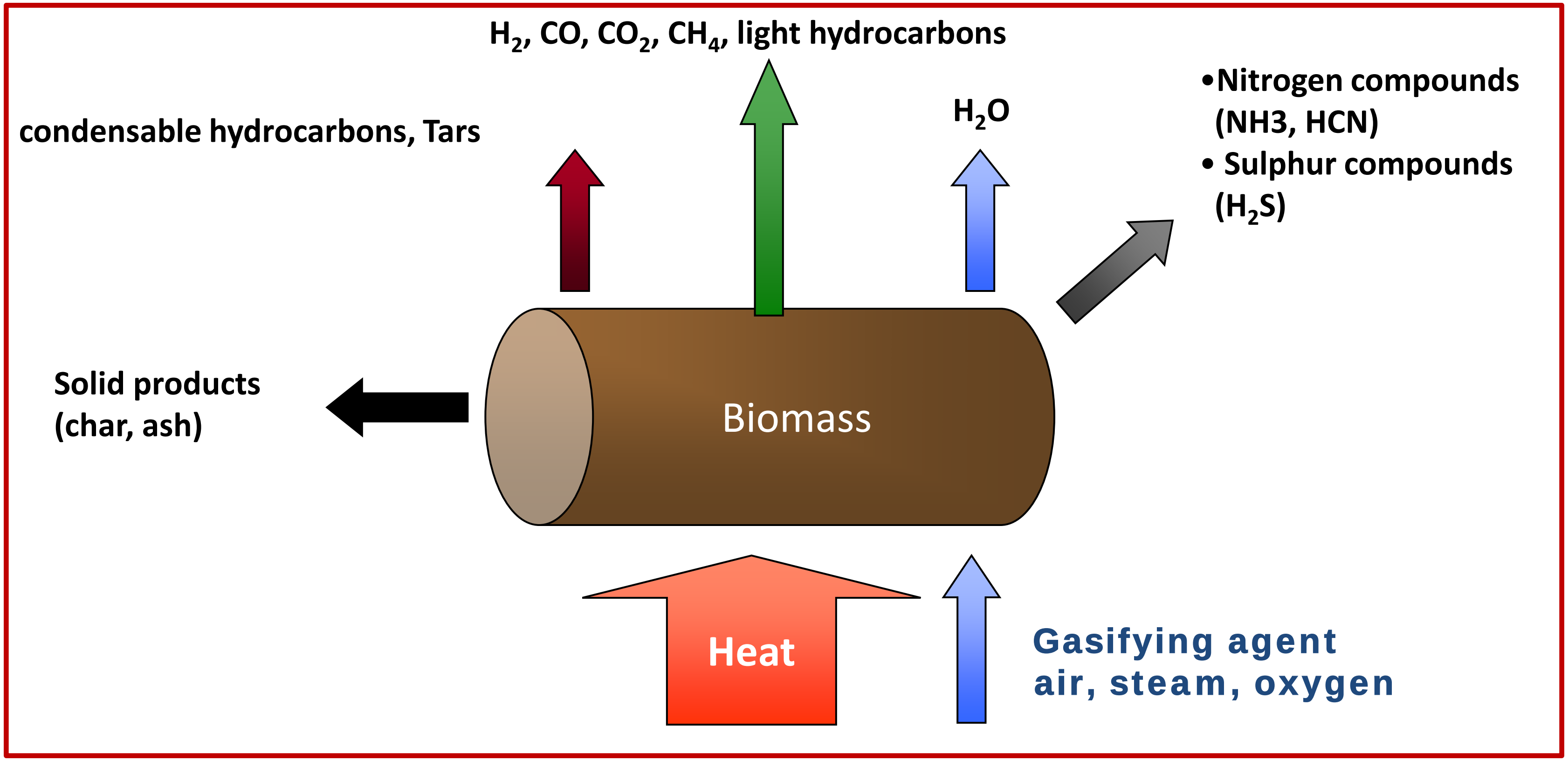
http://www.jie.or.jp/biomass/AsiaBiomassHandbook/English/Part-4_E.pdf

Biomass Energy Conversion Technologies



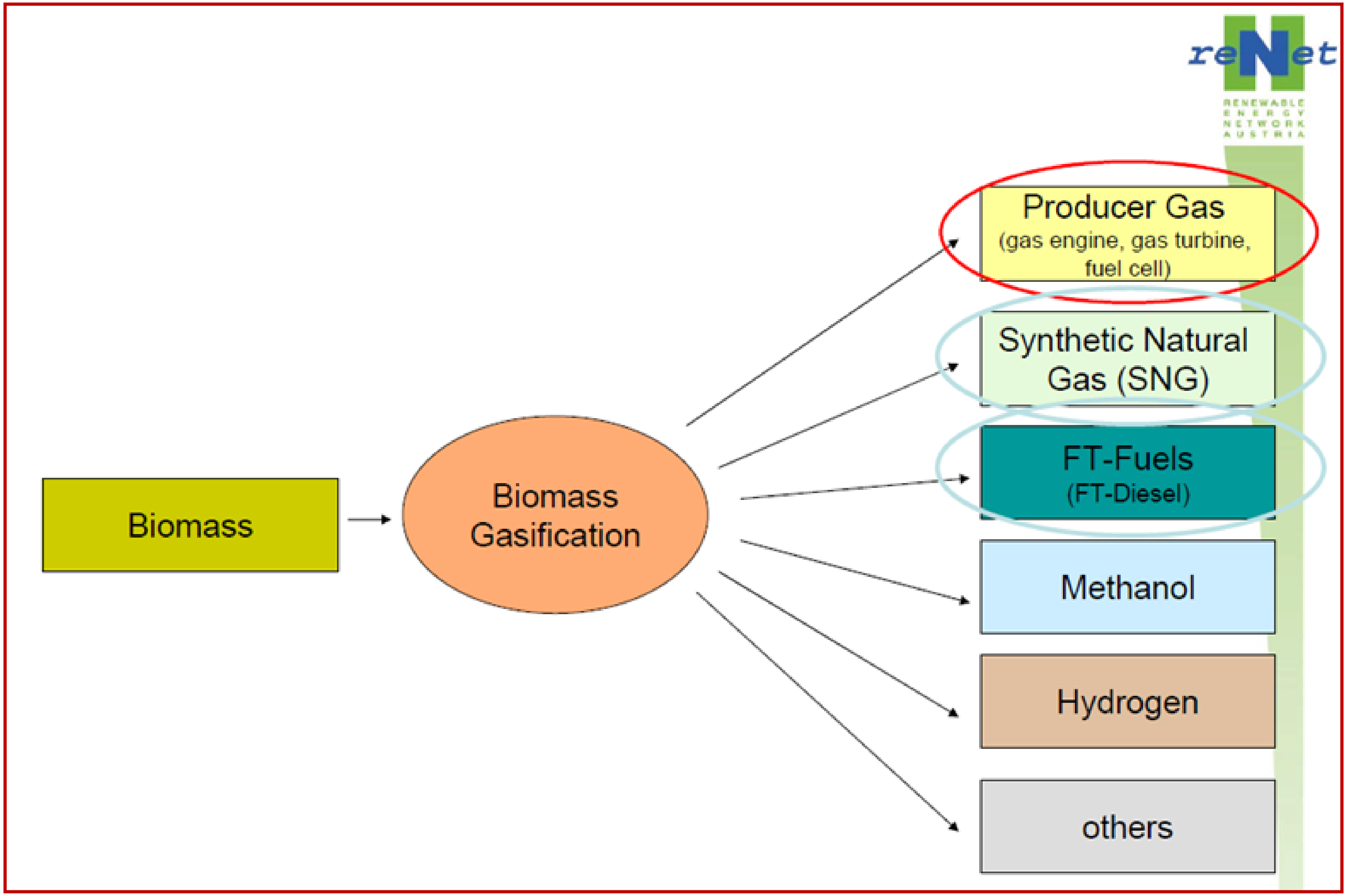
Basics of Gasification

Gasification is the conversion of solid or liquid feedstock into gaseous fuel or chemical feedstock that can be burned to release energy or used for production of value-added chemicals.



Christoph Pfeifer, 17.3.2007, Vienna

Basics of Gasification/Products



Success & Visions for Bioenergy ISBN 978-1-872691-28-2

Basics of Gasification/Agents

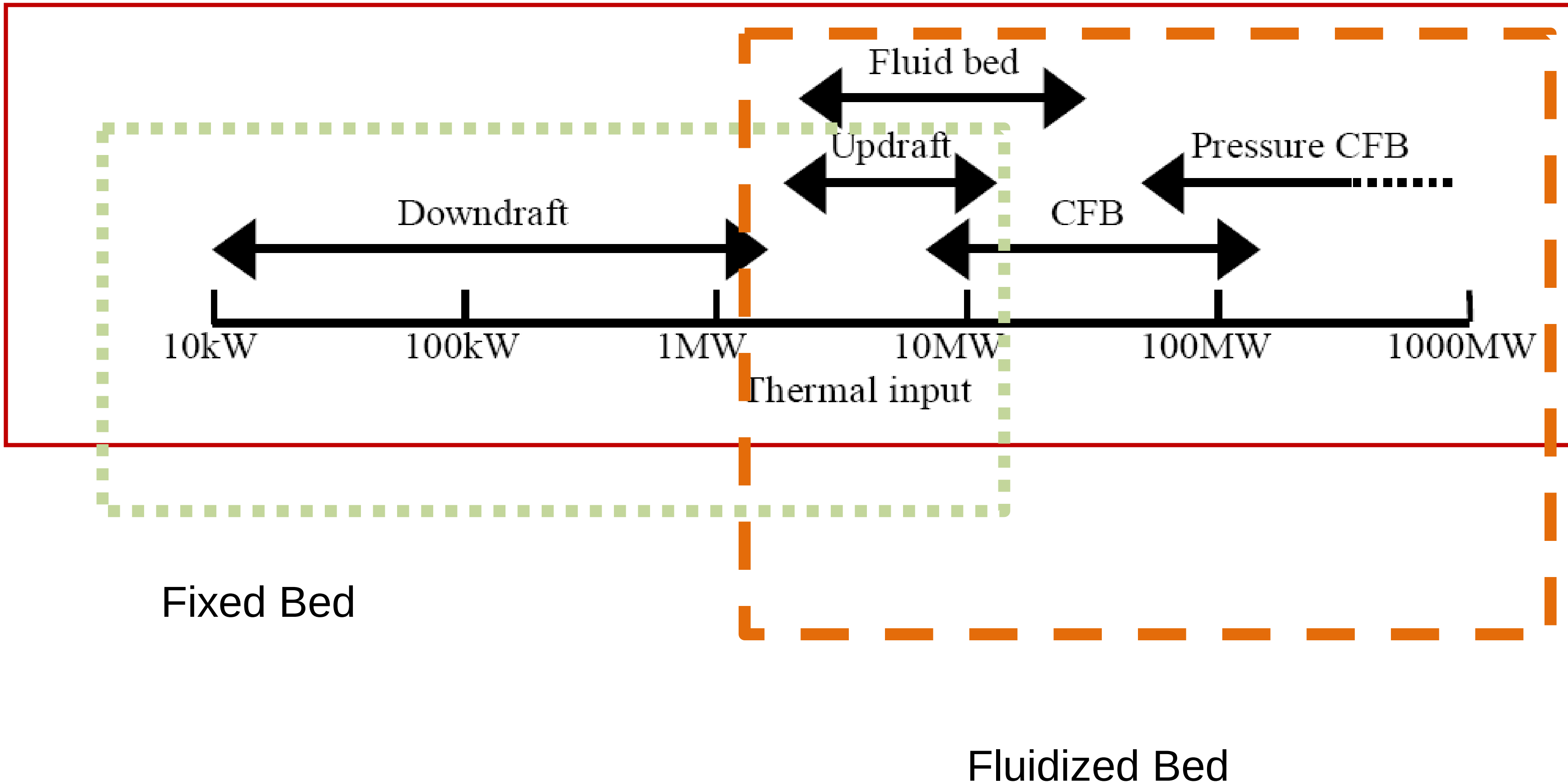
	Main advantages	Main technical challenges
Gasifying Agents		
Air	1. Partial combustion for heat supply of gasification 2. Moderate char and tar content	1. Low heating value (3–6 MJ N/m^3) 2. Large amount of N_2 in syngas (e.g., 450% by volume) 3. Difficult determination of ER (usually 0.2–0.4)
Steam	1. High heating value syngas (10–15 MJ N/m^3) 2. H_2-rich syngas (e.g., 450% by volume)	1. Require indirect or external heat supply for gasification 2. High tar content in syngas 3. Require catalytic tar reforming
Carbon dioxide	1. High heating value syngas 2. High H_2 and CO and low CO_2 in syngas	1. Require indirect or external heat supply 2. Required catalytic tar reforming

Heating Values for Product Gas Based on Gasifying Medium

Medium	Heating Value (MJ/Nm^3)
Air	4–7
Steam	10–18
Oxygen	12–28

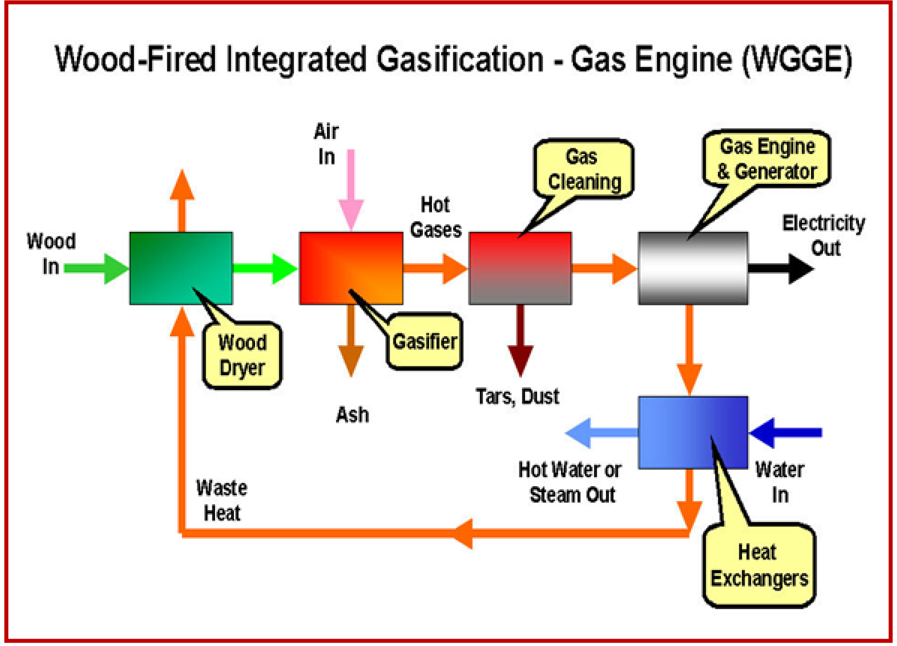
www.eepmekong.org/_.../Biomass_**Gasificatio**...

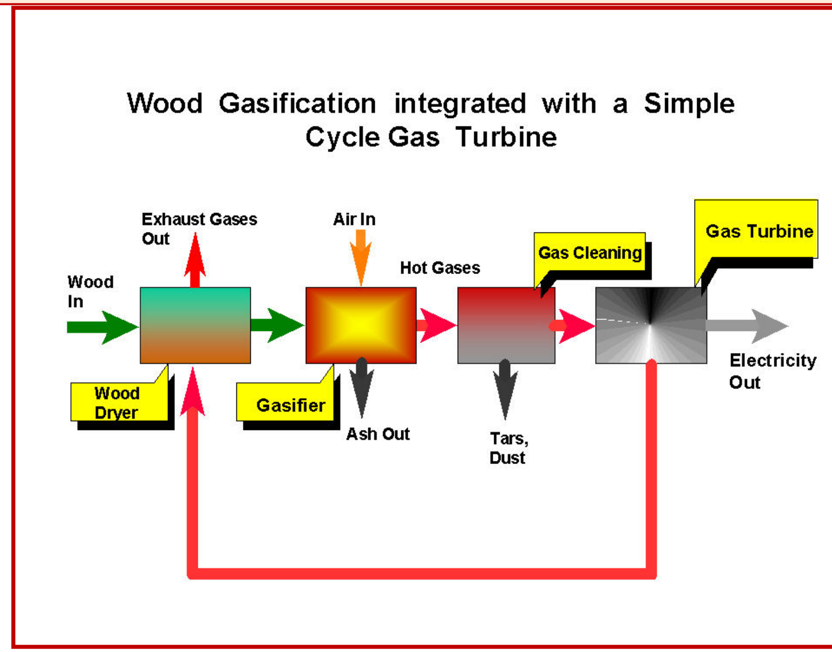
Gasification Systems/Size

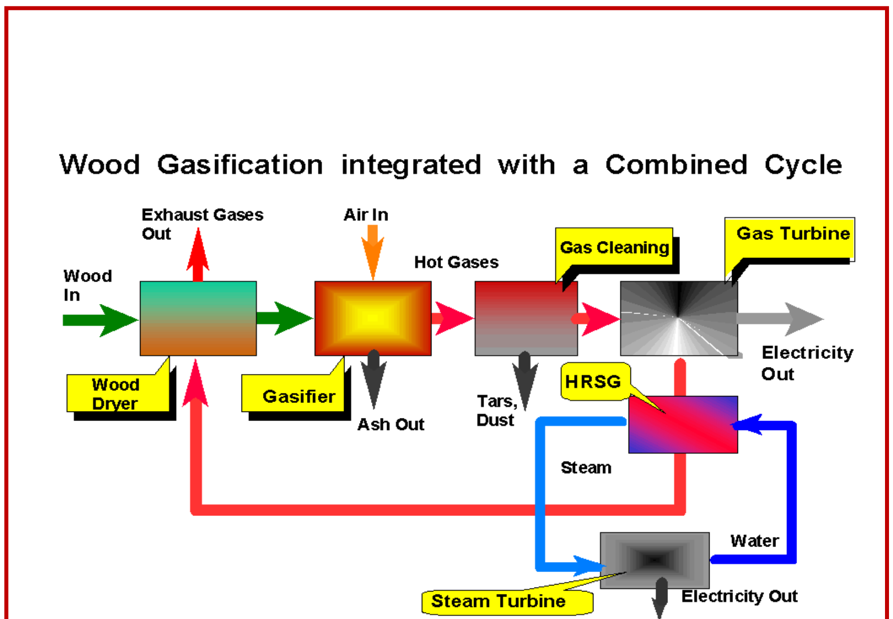


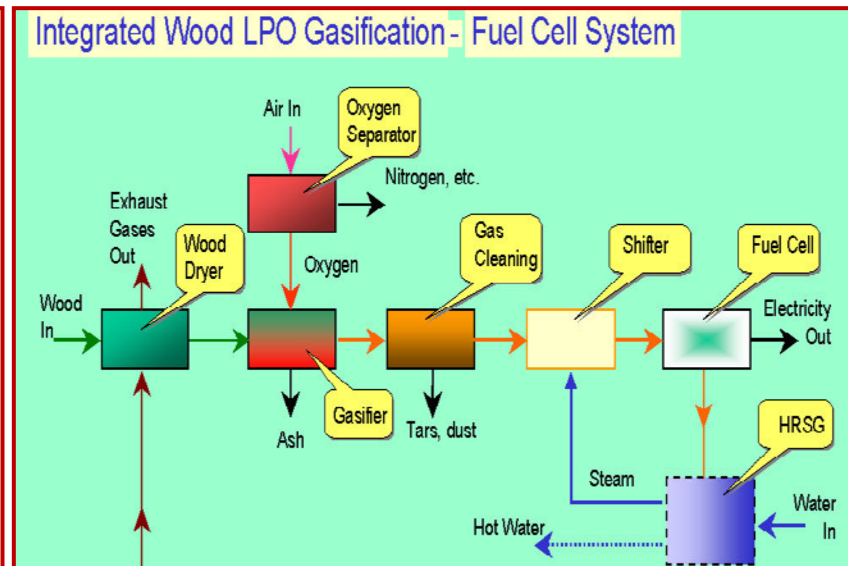
P. Basu, University of Calgary, November, 2010

Gasification Systems/ Applications

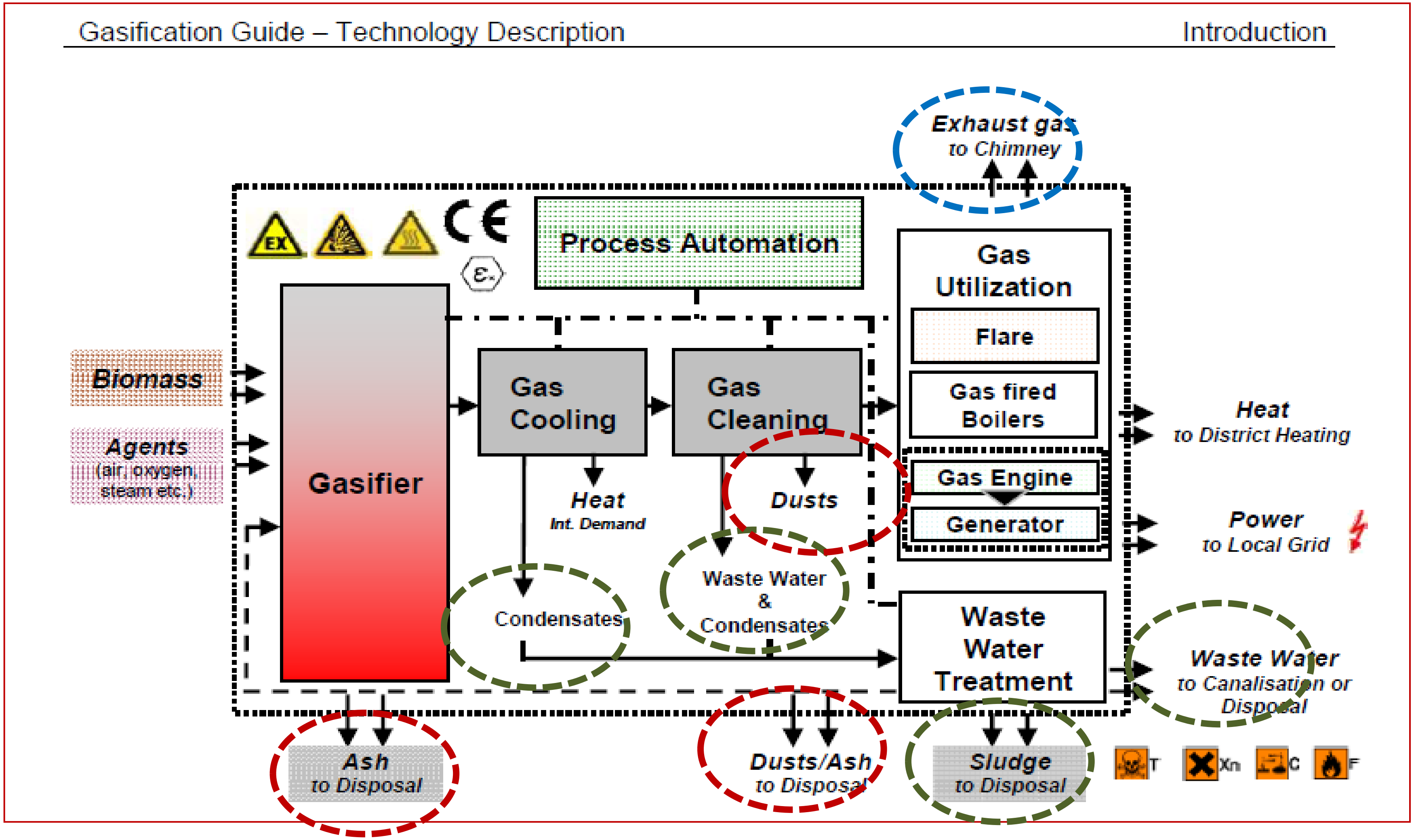








Gasification Guide

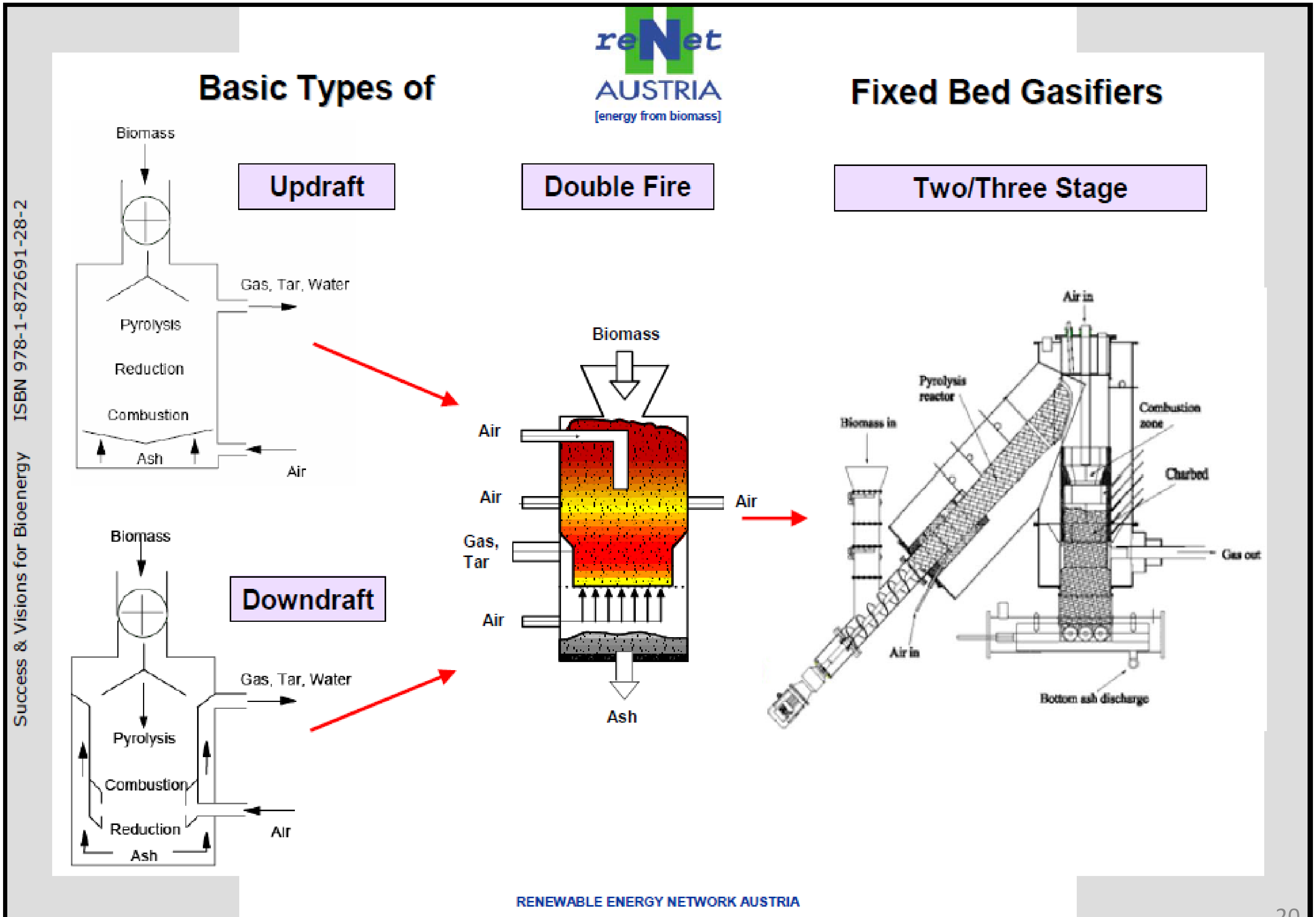


Project acronym: **Gasification Guide**

Full title of the action: Guideline for safe and eco-friendly biomass gasification

Intelligent Energy – Europe (IEE)

Fixed Bed Gasifiers



Fixed Bed Gasifiers/Comparison

Gasifier type	Downdraft	Updraft	Open core	Cross draft	Cross draft heat
Start up time (min)	10-20	15-60	15-60	10-20	15-60
Sensitivity to fuel Characteristics	Sensitive	Not sensitive	Very sensitive+	Sensitive	Not sensitive
Tar production full load (g/Nm^3 gas)	< 0.5	1-15	10-15	< 0.1 †	N.A.
Size & volume gas cleaning section	Small	Big	Big	Small	N.A.
Quantity residual tars	Small	Big	Big	Very small	None
Sensitivity to load fluctuations	Sensitive	Not sensitive	Not sensitive	Sensitive	Not sensitive
Turn down ratio	3-4	5-10	5-10	2-3	8-10
Cold gas heating value full load (MJ/Nm^3)	4.5-5.0	5.0-6.0	5.5-6.0	4.0-4.5	N.A.

Source: Stassen and Knoef, 1995

Notes:

+	Only rice husk
†	Low volatile content (< 10 %wgt) charcoal
N.A.	Not applicable

ASIAN INSTITUTE OF TECHNOLOGY

October 2010

www.eepmekong.org/_.../Biomass_**Gasificatio**...

Fluidized bed Gasifier

Success & Visions for Bioenergy   ISBN 978-1-872691-28-2

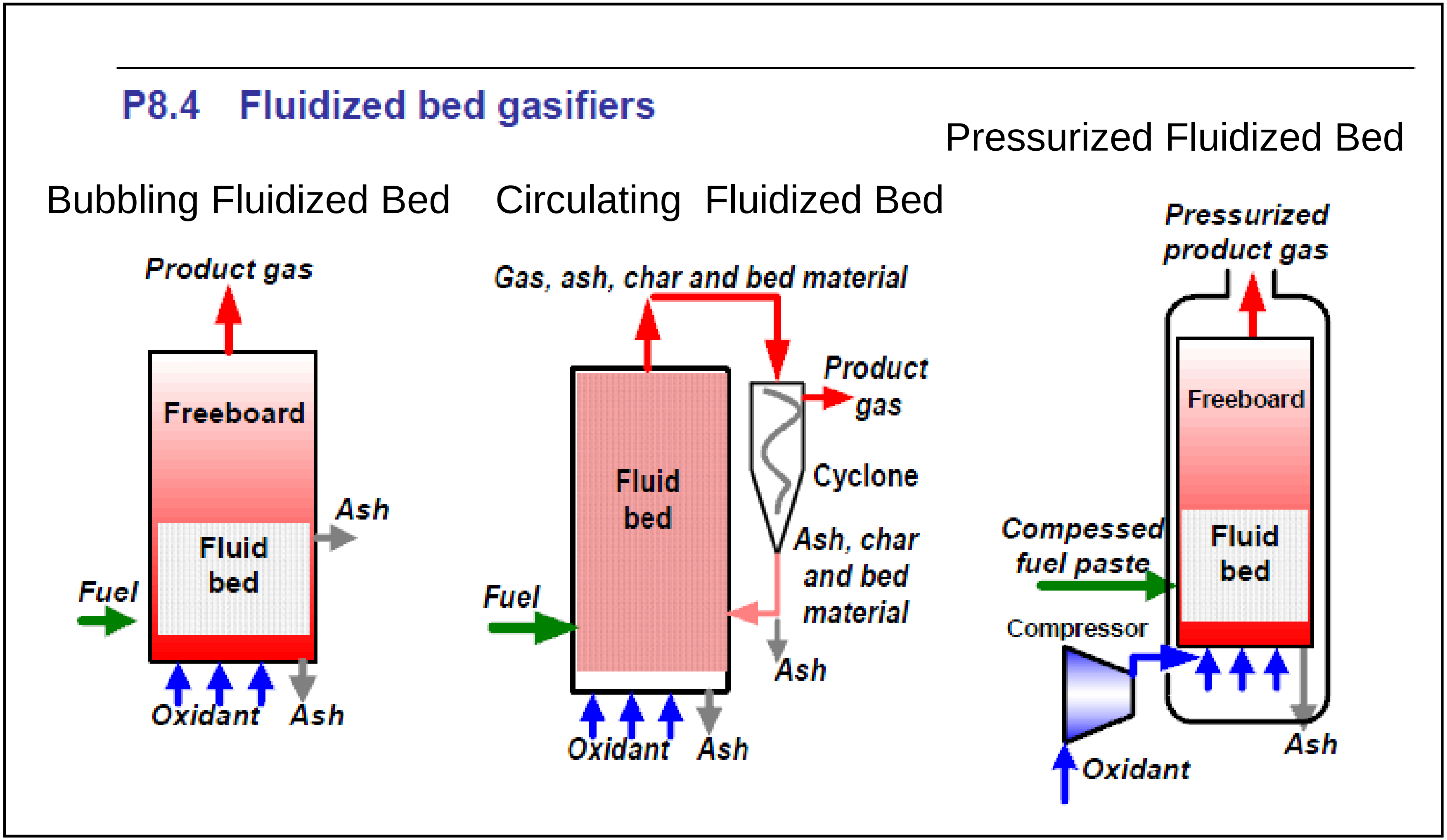
reNet AUSTRIA [energy from biomass]

State of the art fluidized bed gasification

- Temperatures: 750 -900 °C
- Capacities: Medium to large size (2 – 100 MW fuel power)
- High fuel flexibility
  - Kind of fuel, particles size (1 – 50 (100) mm), ash content, water content
  - Restrictions: very fine particles, low ash melting
- Medium tar and dust content
  - Without measures: 1-20 g/Nm³ dry gas
  - With measures: < 1 g/Nm³ dry gas
- Specific investment costs: 2 – 4 Mill € / MWel
- Electricity production costs: 10 -14 cents/kWh (100 – 140 €/MWh)
- Status: A lot of experience available (several plants with 20.000 – 50.000 hours of op.) Commercial for co-firing, CHP and IGCC

RENEWABLE ENERGY NETWORK AUSTRIA

Fluidized Bed Gasifiers

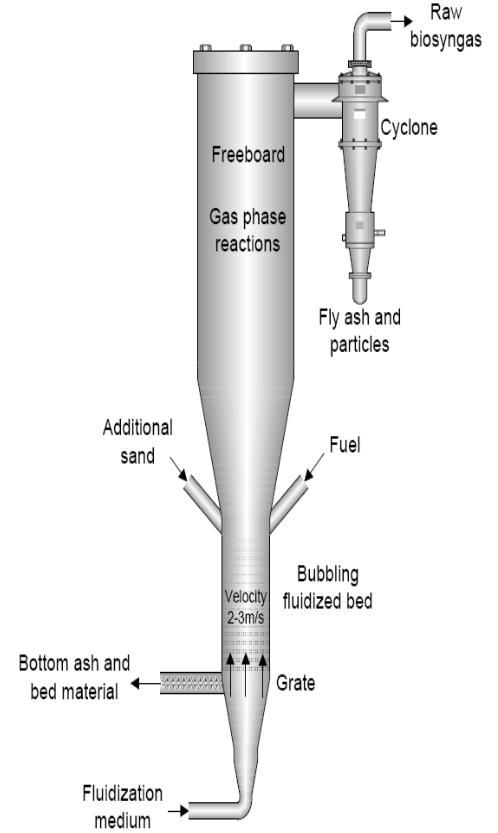


Fluidized bed Gasifier/Bubbling

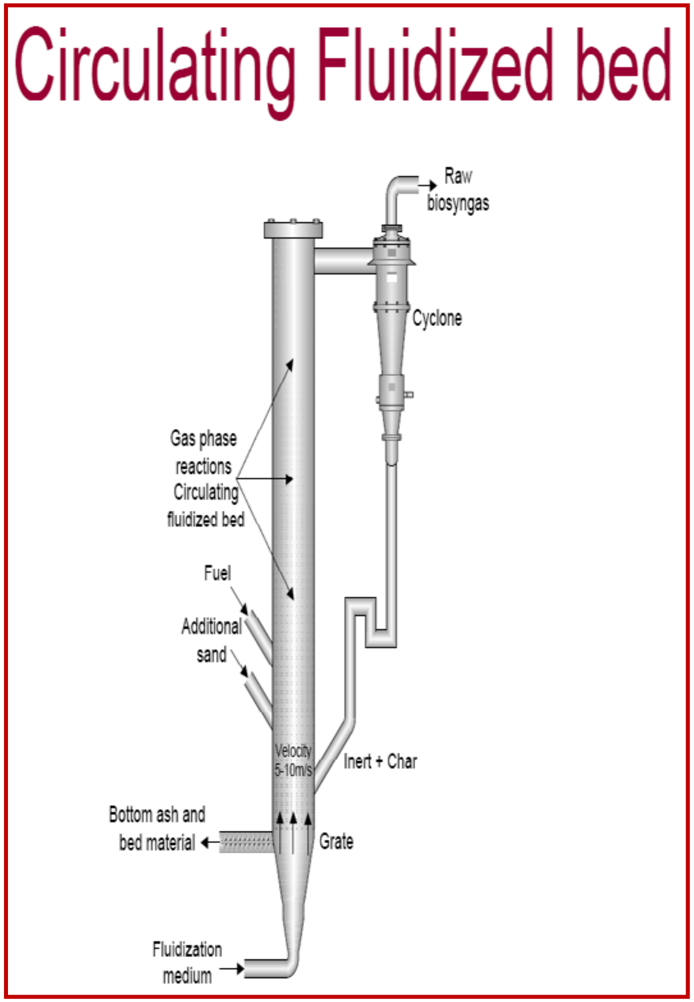
- Higher efficiency
- Higher gasification rate
- Suitable for large system
- Heavy tar content

Bubbling fluidised bed (BFB)	• good gas-solid contact & mixing • high specific heat capacity • good temperature control • can accommodate variations in fuel quality • good turndown • easy start up and shutdown
	• carbon loss with ash • feed pre-processing required • limitation of scale

Bubbling Fluidized bed



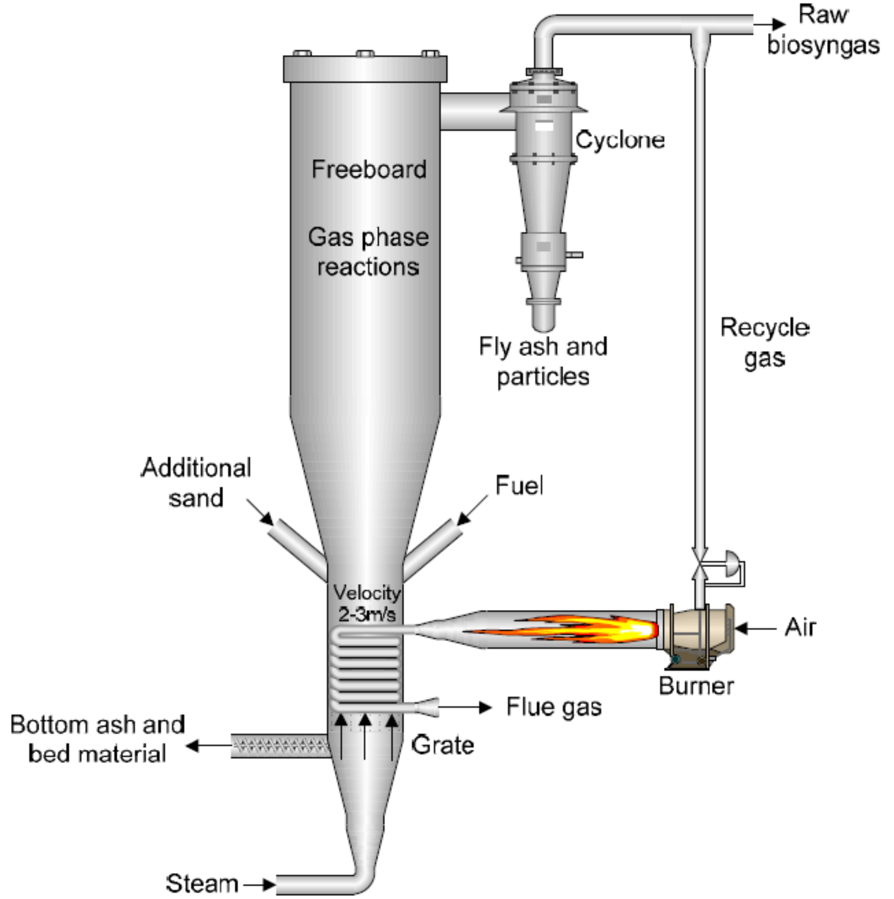
Fluidized bed Gasifier/Circulating



Circulating fluidised bed (CFB)	• as for the BFB • can be designed for very large scale

Fluidized bed Gasifier/Indirect

Gas Indirect, single stage with steam reforming



Fluidized Bed Gasifiers

Some advantages of fluidized bed gasification are:

- Compact construction because of high heat exchange and high reaction rates due to intensive mixing in the bed.
- Dolomite can be added to the bed collecting sulfur from the biomass.
- Good control of temperatures.
- Can be done large scale.

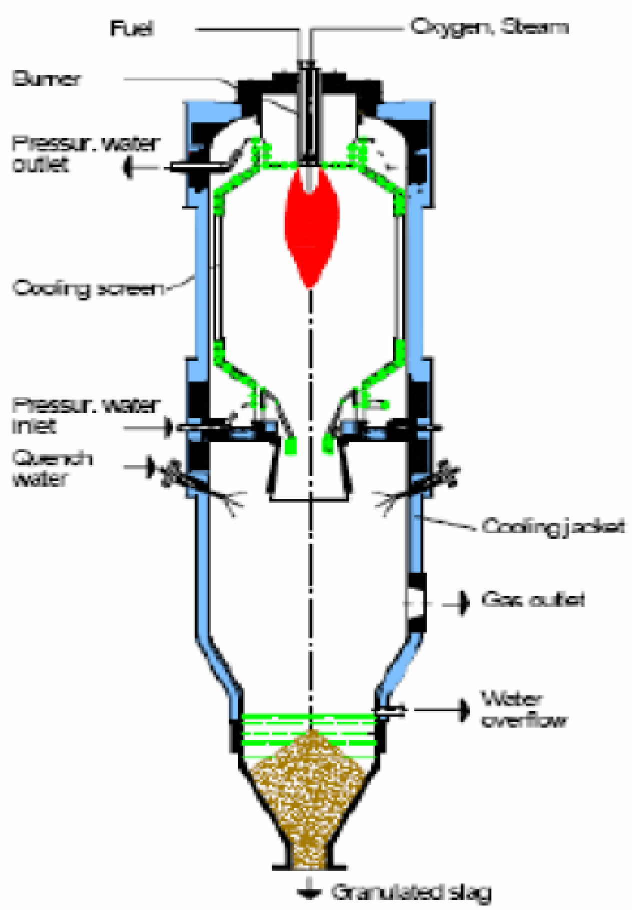
Some disadvantages:

- High tar and dust content - Needs extensive gas cleaning.
- Incomplete carbon burnout.
- High producer gas temperature with alkali metals in vapor state.
- Complex operation because of the need to control air and solid fuel.
- High internal power consumption.
- Not suitable for fuels having the ash melting point at low temperature. Ash melting can cause bed agglomeration. Straw, for example, has ash melting point at around 600°C.

Entrained Flow Gasifier

Success & Visions for Bioenergy ISBN 978-1-872691-28-2

reNet AUSTRIA
[energy from biomass]



State of the Art of Entrained Flow Gasification

- High temperatures (>1200 °C)
- Low particle diameter necessary
- Pressurized operation easy possible
- Very low tar contents
- Low methane content
- High availability
- Currently for large scale and especially for liquid fuel production
- Much experience from coal gasification

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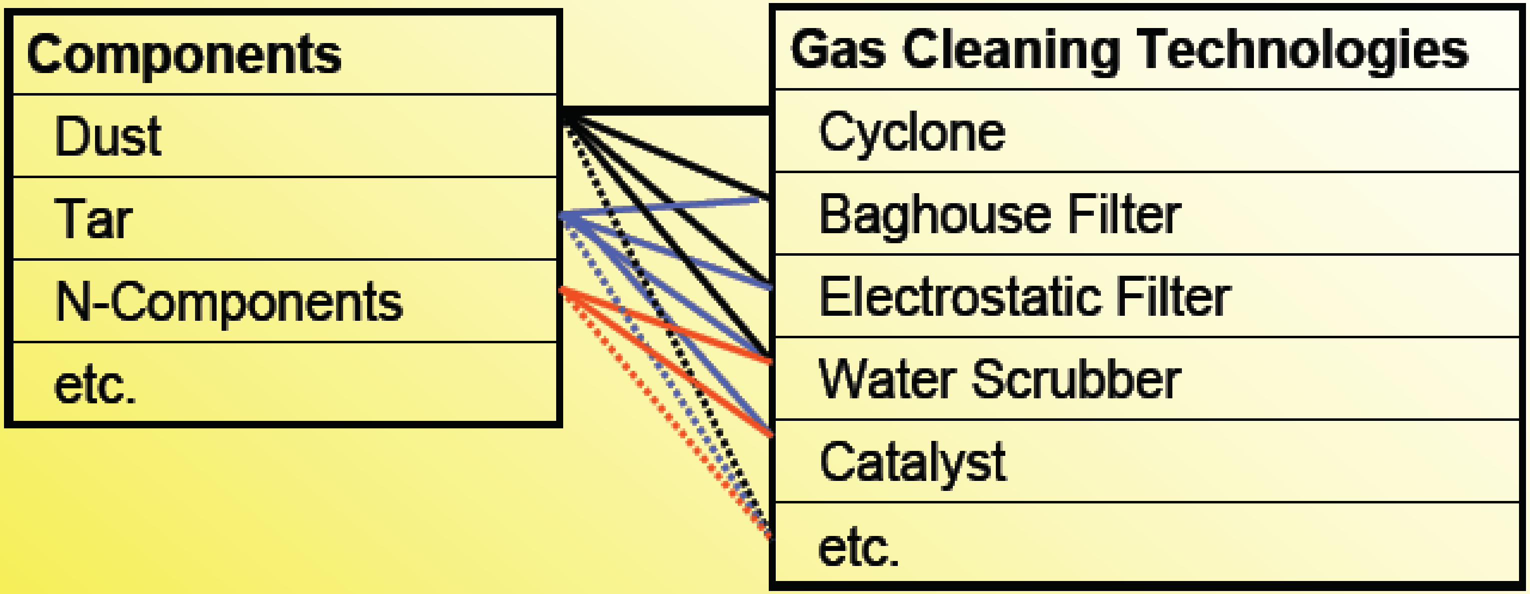
Gas Cleaning

Compound	Combustion Engine	Combustion Turbine	Fuel Cells
Tar	<50 [mg.m^{-3}]	<5 [mg.m^{-3}]	<1 [mg.m^{-3}]
Dust	<5 [mg.m^{-3}]	<1 [mg.m^{-3}]	<0.1 [ppmw]
H_2S	No definition	<1 [ppmw]	<60 [ppbv]
HCl	No definition	<0,5 [ppmw]	<10 [ppbv]
NH_3	No limit	No limit	No definition

Gas Cleaning

- Producer Gas Components & Cleaning Technologies I -



- There are lots of gas cleaning technologies available.
- Only some of them allow for the provision of a clean gas; often several technologies are used in a combined way.
- The process technology is partly well developed.

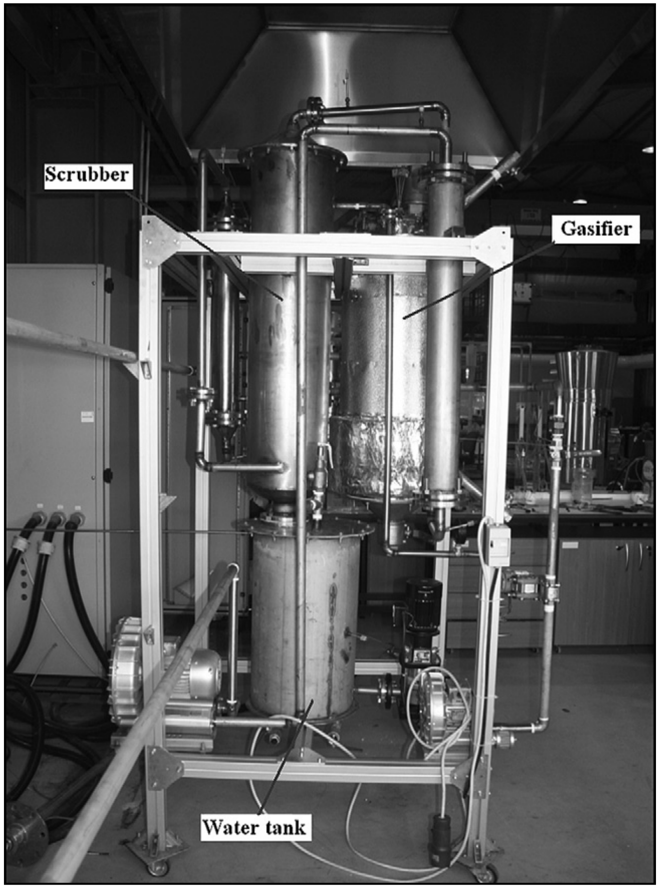
Primary Technical Barriers

Gasification

- **Feed Pretreatment**
  - ✓ **Feeder reliability**
  - ✓ **Feed modification**
- **Gasification**
  - ✓ **Tar & Heteroatom chemistry**
  - ✓ **Gasifier Design**
  - ✓ **Catalysis**
- **Gas Cleanup & Conditioning**
  - ✓ **Catalytic Conversion**
  - ✓ **Condensing Cleanup**
  - ✓ **Non-condensing Cleanup**
- **Syngas Utilization**
  - ✓ **Cleanliness requirements**
  - ✓ **Gas composition**
- **Process Integration**
- **Sensors and Controls.**

An Introduction to Biomass Thermochemical Conversion, Richard L. Bain, DOE/NASLUGC August, 3-4 2004

TUBITAK MAM



Results with a bench scale downdraft biomass gasifier for agricultural and forestry residues

Hayati Olgun[a,], Sibel Ozdogan[b], Guzide Yinesor[b]*

BIOMASS AND BIOENERGY 35 (2011) 572–580

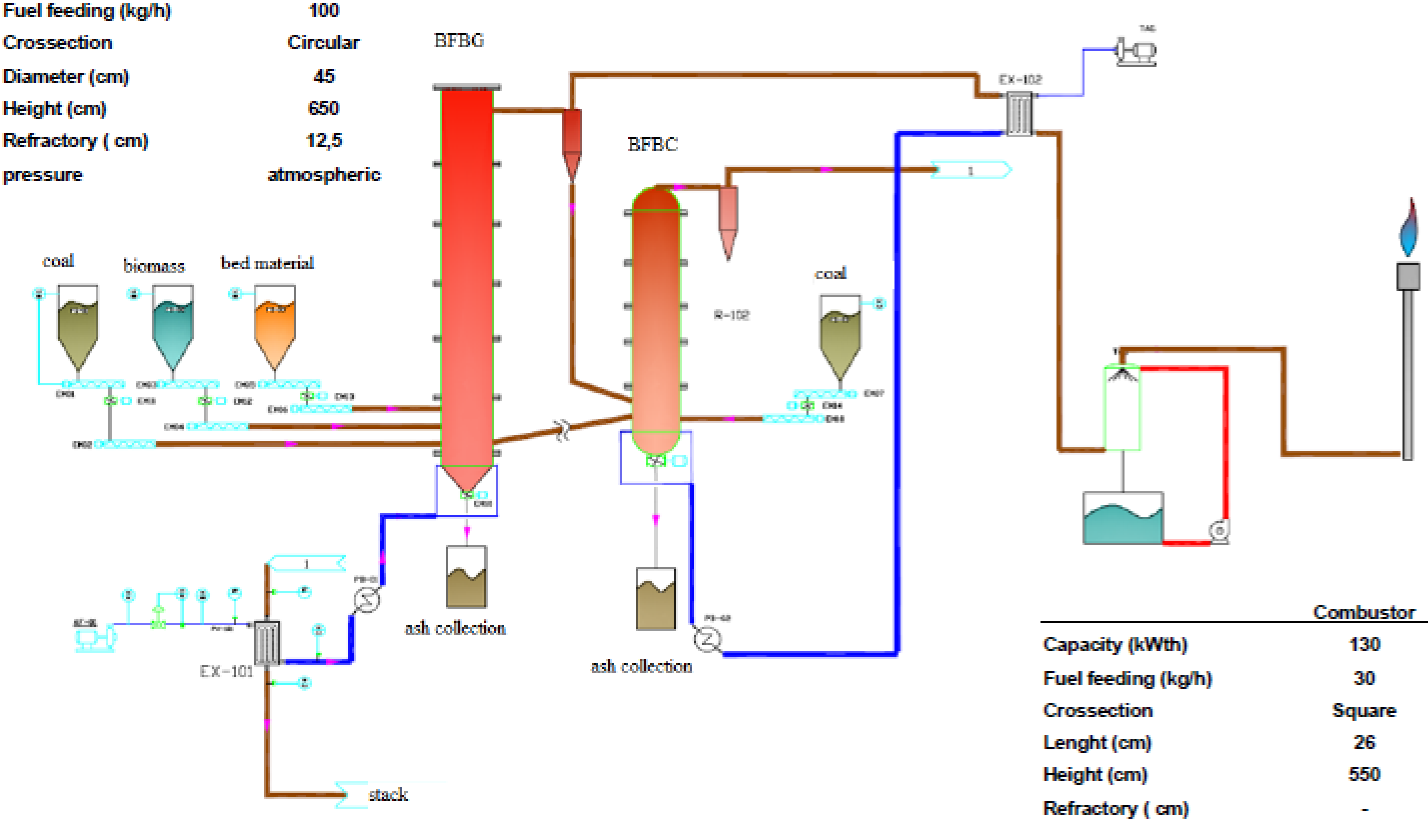
The Tenth international conference on combustion and energy utilisation 10th ICCEU May 4-8 2010 Mugla

Preliminary Results with a Laboratory Scale Bubbling Fluidised Bed Gasifier

TUBITAK MAM

System concept according to multipurpose design;

	Gasifier
Capacity (kWth)	450
Fuel feeding (kg/h)	100
Crossection	Circular
Diameter (cm)	45
Height (cm)	650
Refractory (cm)	12,5
pressure	atmospheric



	Combustor
Capacity (kWth)	130
Fuel feeding (kg/h)	30
Crossection	Square
Lenght (cm)	26
Height (cm)	550
Refractory (cm)	-
pressure	athmospheric

TUBITAK MAM

- BFB Gasifier 450 kWth)
- Downdraft Gasifier (70 kg/h)

TUBITAK MAM (TRIJEN)

CFB Gasifier (150 kWth)

Coal Gasification Plant (TKI-Tuncbilek, Turkey)

Entrained Flow Gasifier (250 kg/h)

Basics of Combustion

- Combustion is a chemical reaction that occurs between a fuel and an oxidizing agent that produces energy, usually in the form of heat and light.
- Biomass combustion is a complex process consisting of consecutive homogeneous and heterogeneous reactions.
- The essential process steps include drying, devolatilization, gasification, char combustion, and gas phase reactions.

A global reaction for the combustion of biomass fuel in air might take the following form:

$$C_{x1}H_{x2}O_{x3}N_{x4}S_{x5}Cl_{x6}Si_{x7}K_{x8}Ca_{x9}Mg_{x10}Na_{x11}P_{x12}Fe_{x13}Al_{x14}Ti_{x15} + n_1H_2O$$
$$+ n_2(1+e)(O_2 + 3.76N_2) = n_3CO_2 + n_4H_2O + n_5O_2 + n_6N_2 + n_7CO$$
$$+ n_8CH_4 + n_9NO + n_{10}NO_2 + n_{11}SO_2$$
$$+ n_{12}HCl + n_{13}KCl + n_{14}K_2SO_4 + n_{15}C + \ldots$$

B.M. Jenkins et al. / Fuel Processing Technology 54 (1998) 17–46

Biomass Combustion and Applications

- **Small-scale biomass combustion systems**
  capacity range: <100 kW_{th}

- **Medium-scale combustion systems**
  capacity range: 100 kW_{th} to 20 MW_{th}

- **Large-scale combustion systems**
  capacity range: >20 MW_{th}

- **Co-firing of biomass in coal fired power stations**
  capacity range: some 100 MW_{th}

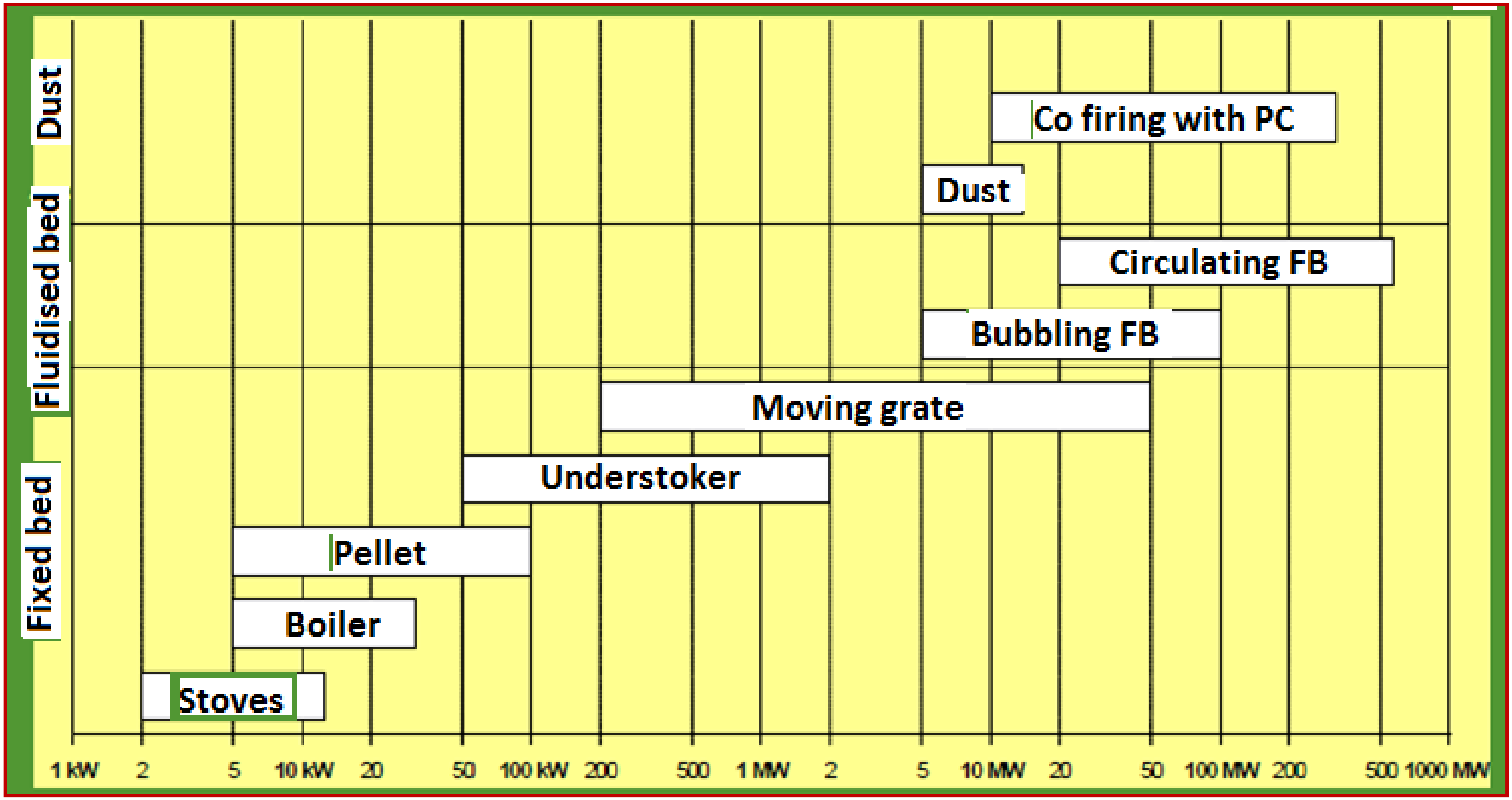
Biomass Combustion

- most advanced conversion technology
- market proven applications for a broad range of fuels and plant capacities

http://www.bios-bioenergy.at/uploads/media/Paper-Obernberger-Industrial-combustion-of-solid-bimass-fuels-2008-10-15.pdf

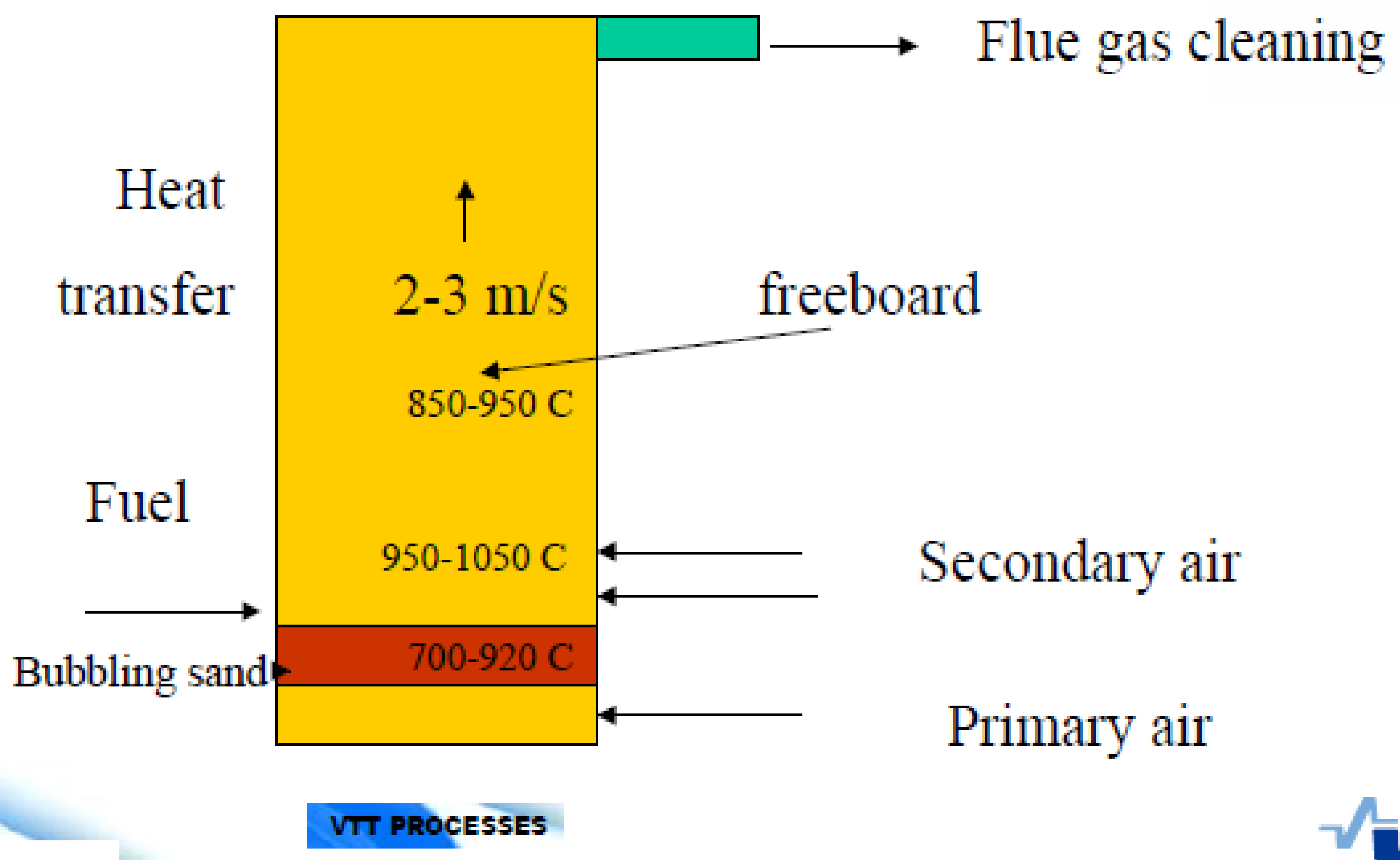
Biomass Combustion and Applications

Modern biomass technology is commercially available from 2 kWth to 550 MWth

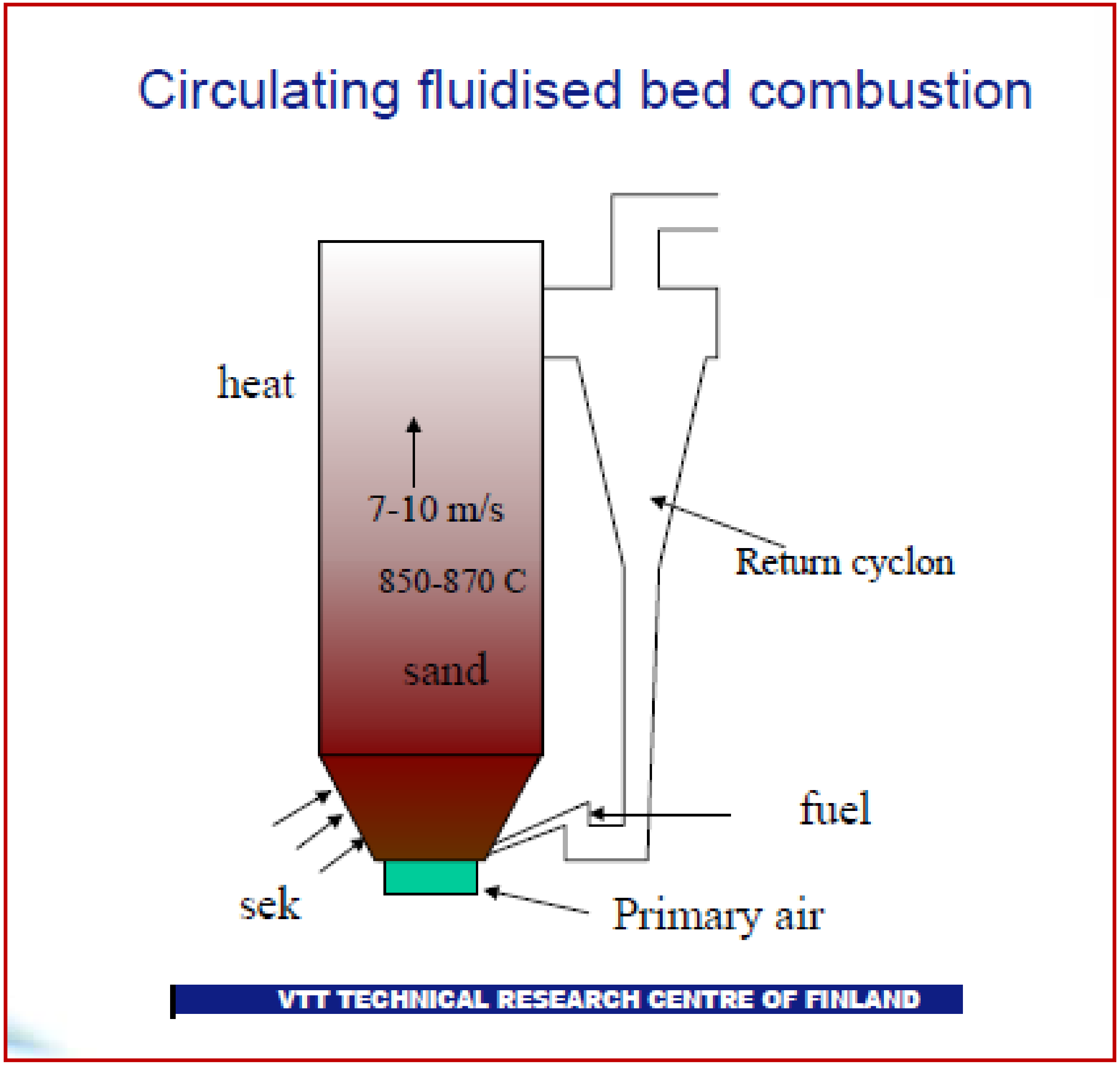


Biomass Combustion and Applications

Bubbling Fluidized Bed Combustion (Large Scale)



Biomass Combustion and Applications



Biomass CFBC

- Circulating fluidized bed combustion (CFBC) is considered a Fuel flexible technology. Different fuels including
  - ✓high sulphur coals
  - ✓high ash coals,
  - ✓low grade fuels
  - ✓various types of biomass
  - ✓waste derived fuels

have become feed stocks for CFBC.

- High heat transfer rate is one of the other advantages.
- In situ SO_2 removal in the combustor is possible by using limestone.
- The thermal NOx formation is minimized due to lower combustion temperature (850-870^{o}C) in the combustor column.

Biomass Combustion in TUBITAK MRC

Project Title: Combustion of Biomass and Lignite coal in Circulating Fluidized Bed

Project Duration: 3 Years (September 2008- September 2011)

Clients: EİE, OGM

Partners: METU,TUBITAK,GAMA

Supporting bodies: TUBITAK Taral 1007

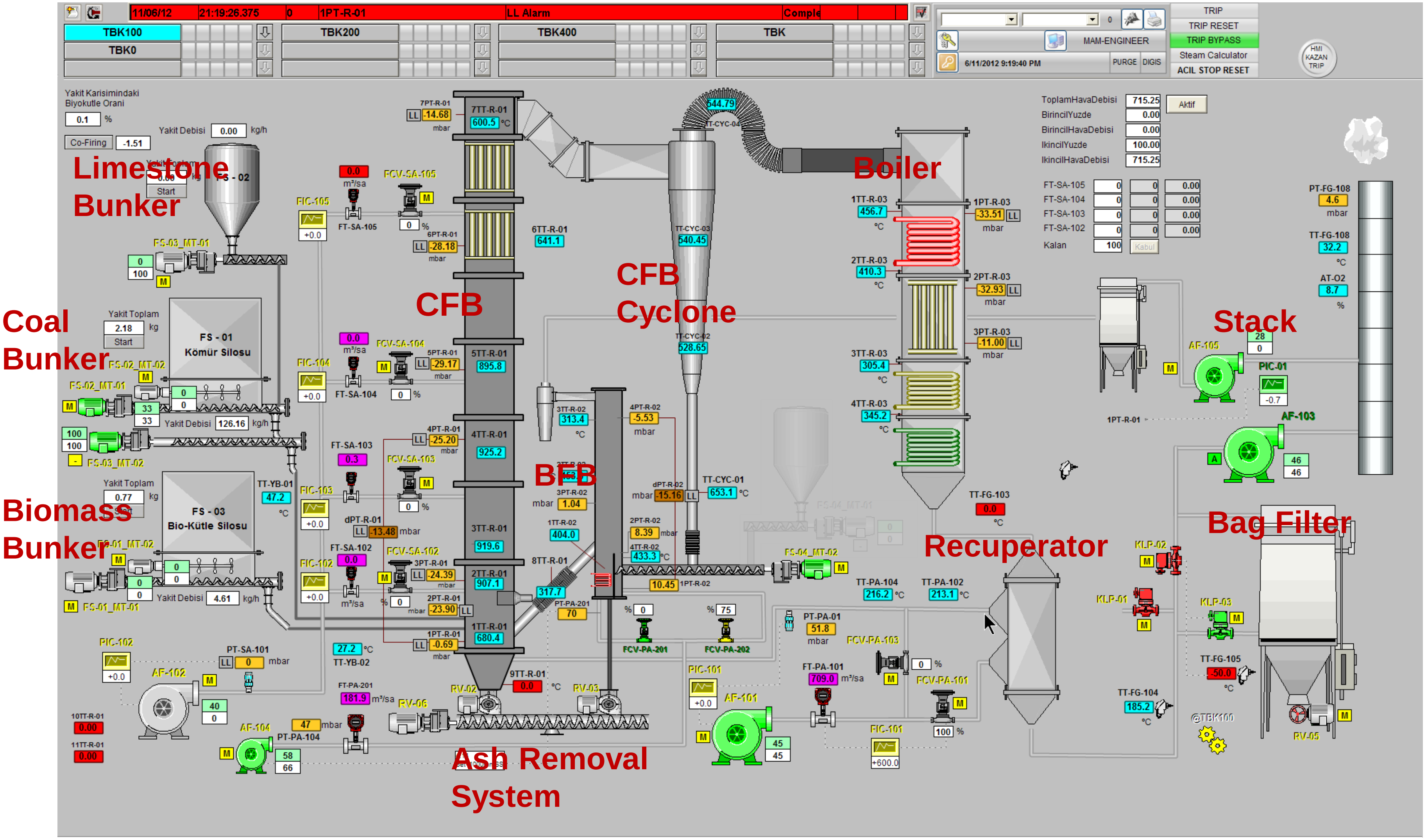
Innovative Aspects: Multi fuel (biomass/coal) design circulating fluidized bed combustion and gas cleaning systems for CHP applications

Existing/Planned Systems: 750 kWth CFB combustion

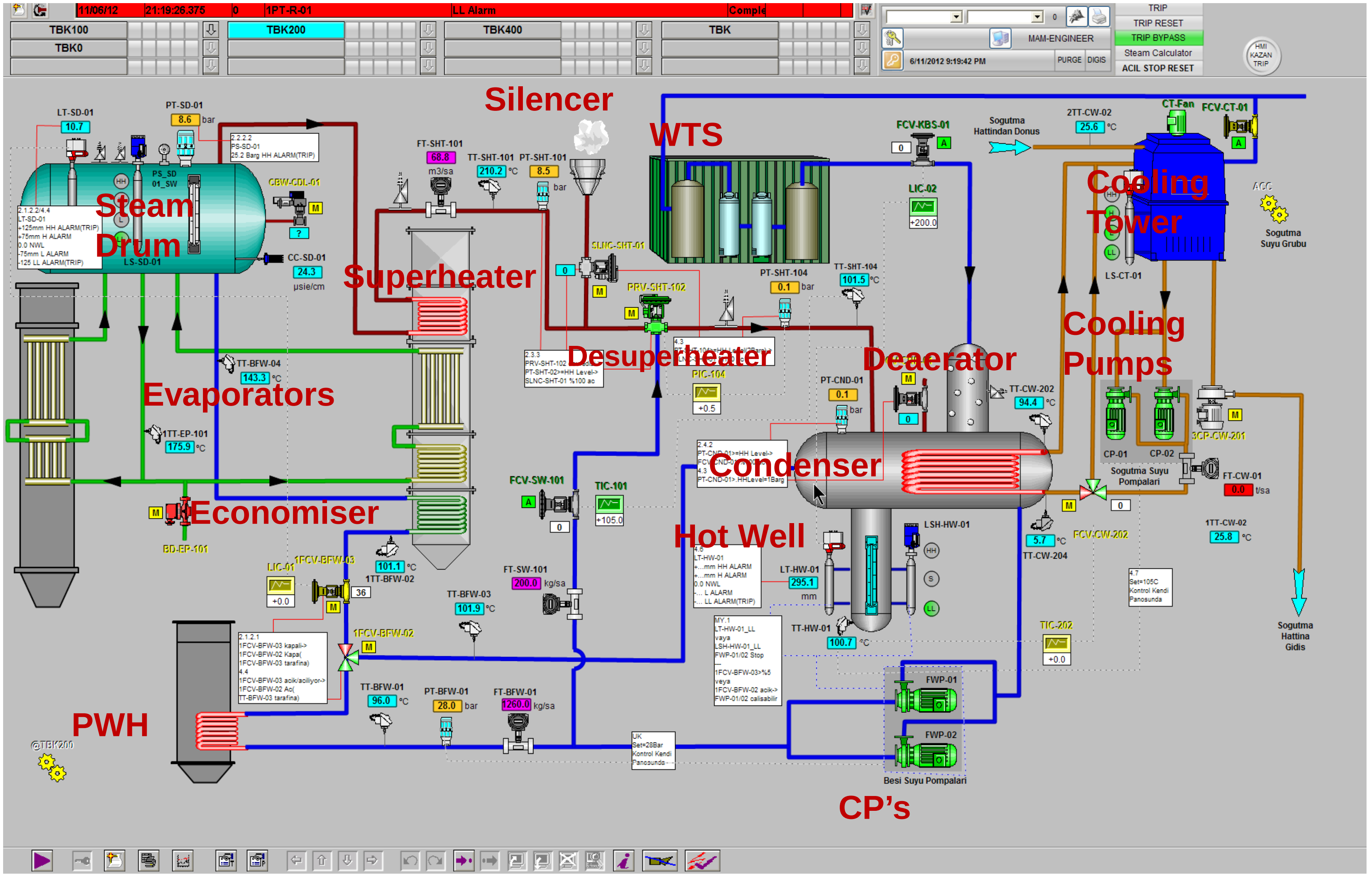
Industrial Application Options: Up to 15MWe

Biomass Combustion in TUBITAK MRC

Biomass Combustion in TUBITAK MRC

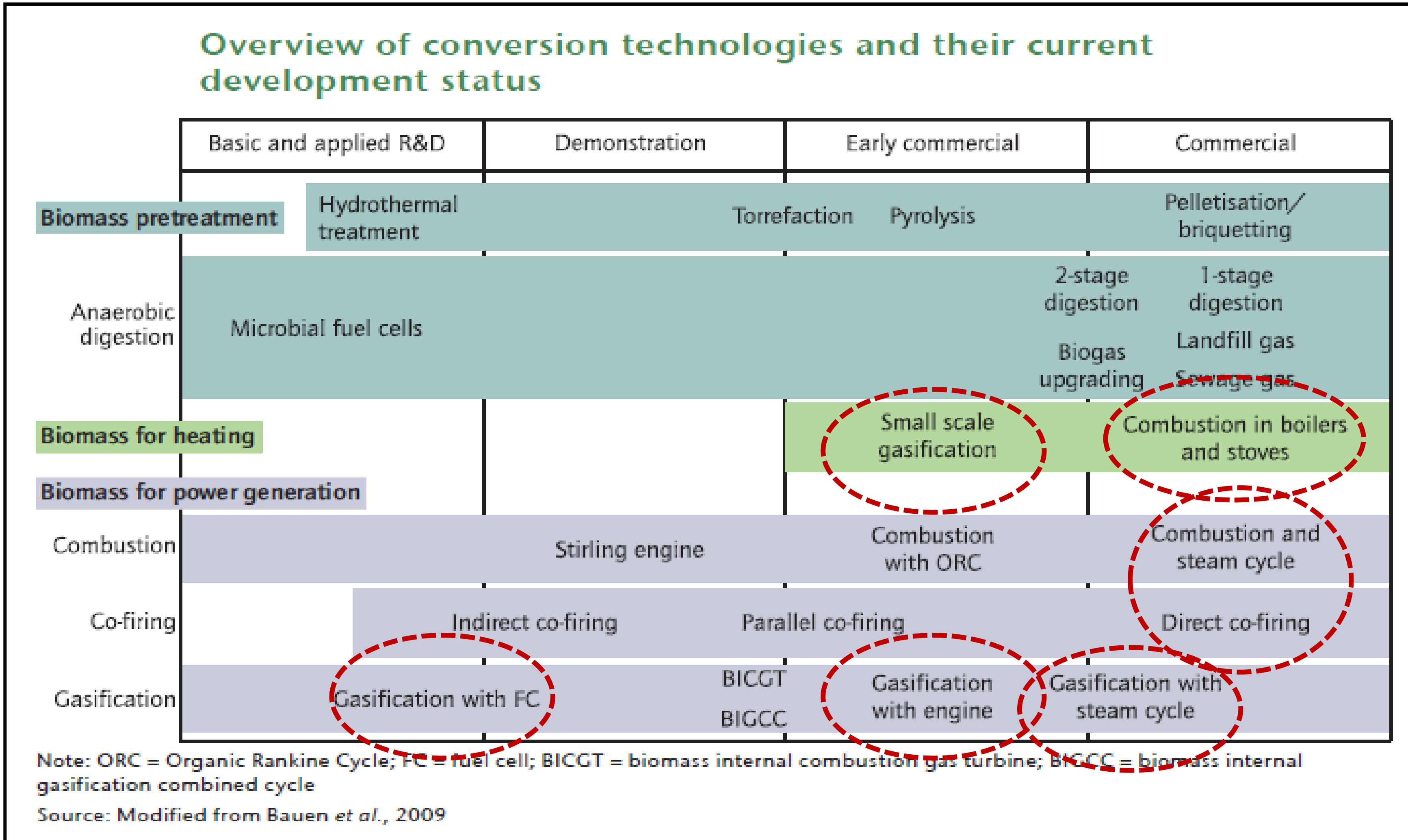


Biomass Combustion in TUBITAK MRC



Biomass Combustion in TUBITAK MRC

Development of Gasification Technology



This roadmap was prepared in 2012. It was drafted by the IEA Renewable Energy Division..

THANK YOU FOR YOUR PATIENCE!

QUESTIONS?????

COMMENTS????

hayatiolgun1958@gmail.com