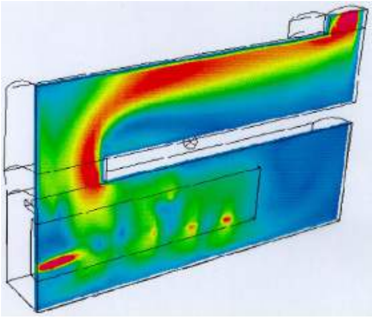

IEA Bioenergy Task 33 Workshop Horw, 26. October 2016

Gasification and Combustion: Comparison of the Potential

Thomas Nussbaumer

Verenum, Zurich, and Lucerne University of Applied Sciences, Horw

IEA-Delegate Bioenergy Task 32 for the Swiss Federal Office of Energy

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Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
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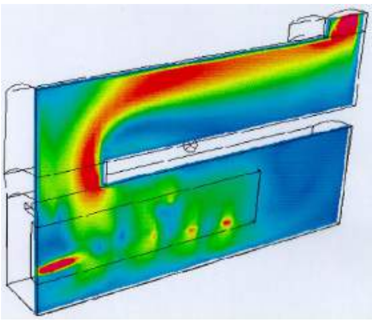
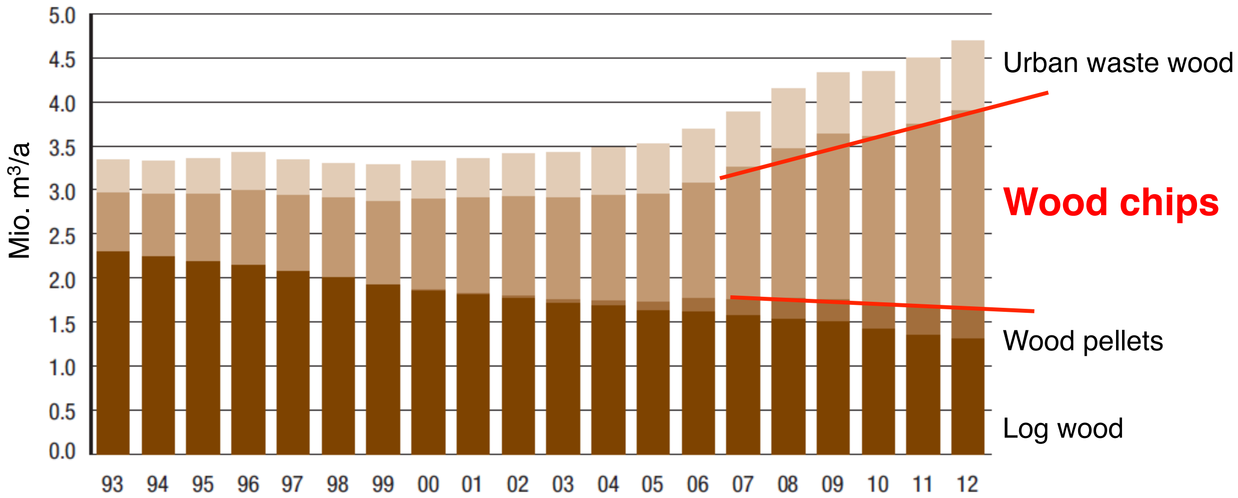
Bundesamt für Energie



1. Potential and priorities to use biomass

Energy wood in Switzerland - Trends

1. Log wood is decreasing
2. Wood pellets are increasing but on a low level
3. Focus is on wood chips combustion > 500 kW



[1] Jahrbuch Wald und Holz 2013, BAFU

Energy wood in Switzerland - Potential

today: 4.3% of end energy, mainly for buildings and CH

potential: > 7% (plus 65% of today = target)

Opportunities for renewable energies

	Exergy content	fluctuating (–) storable / on-demand (+)
Wind power	100%	–
Solar power	100%	–
Solar heat	15%	–
Ambient heat	0%	+
Biomass heat & power	100%	+

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Needs for CO_2-neutral energy

1. Buildings low exergy (< 10%) ➔ heat pumps + solar heat
➔ need for heat-on-demand: biomass!

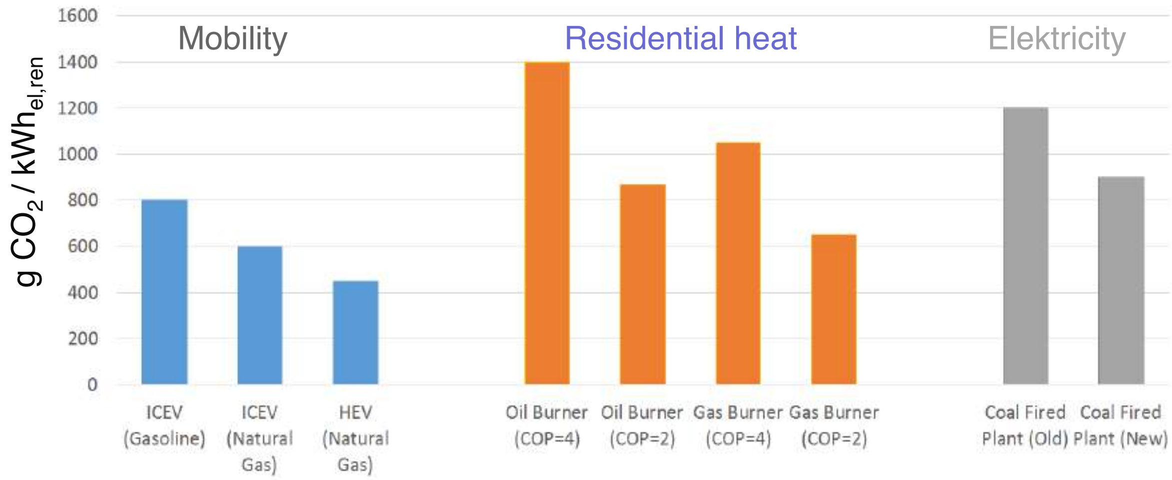
2. Electricity PV (1000 h/a) and wind (2000 h/a & import)
➔ need for power-on-demand: biomass!

3. Process heat 12.4 % of end energy (wood = 7% total = 55%)
➔ temperatures > 200°C by biomass or electr.

4. Mobility need for "power-on-demand" and high energy density:
➔ electricity (all renewables) and/or biofuels

Mobility:

CO_2-Mitigation per 1 kWh Renewable Electricity for Substitution of Fossile Energy in Different Sectors



[K. Boulouchos, 14. Holzenergie-Symposium, ETH Zurich, 16.9.16, www.holzenergie-symposium.ch]

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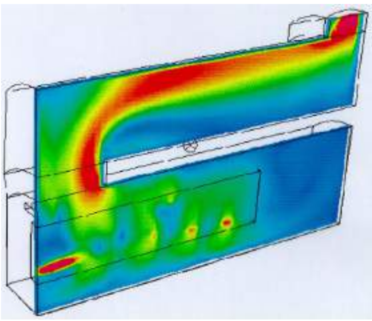

1. Potential and priorities to use biomass
2. Biomass combustion today

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Log wood for residential heating

Stove

Tiba/Wodtke (MOMO)

Boiler

Liebi LNC

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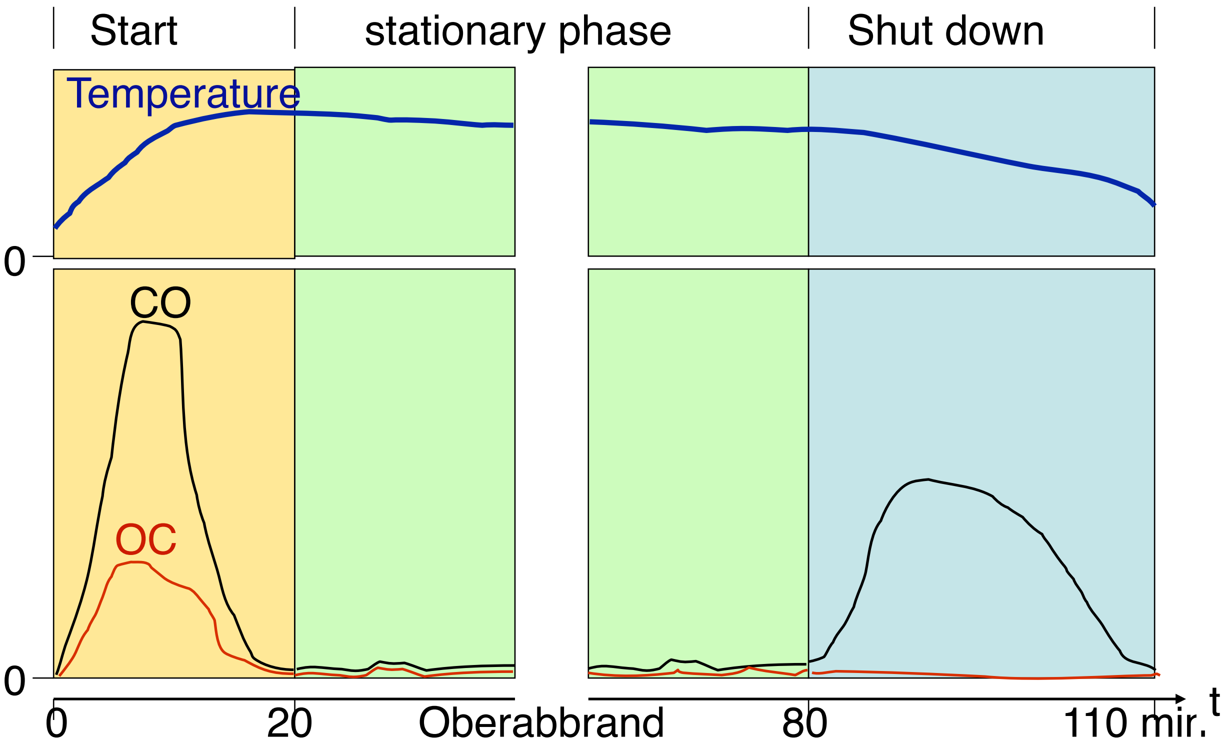
Challenge of log wood: Batch process: VOC, COC, Soot



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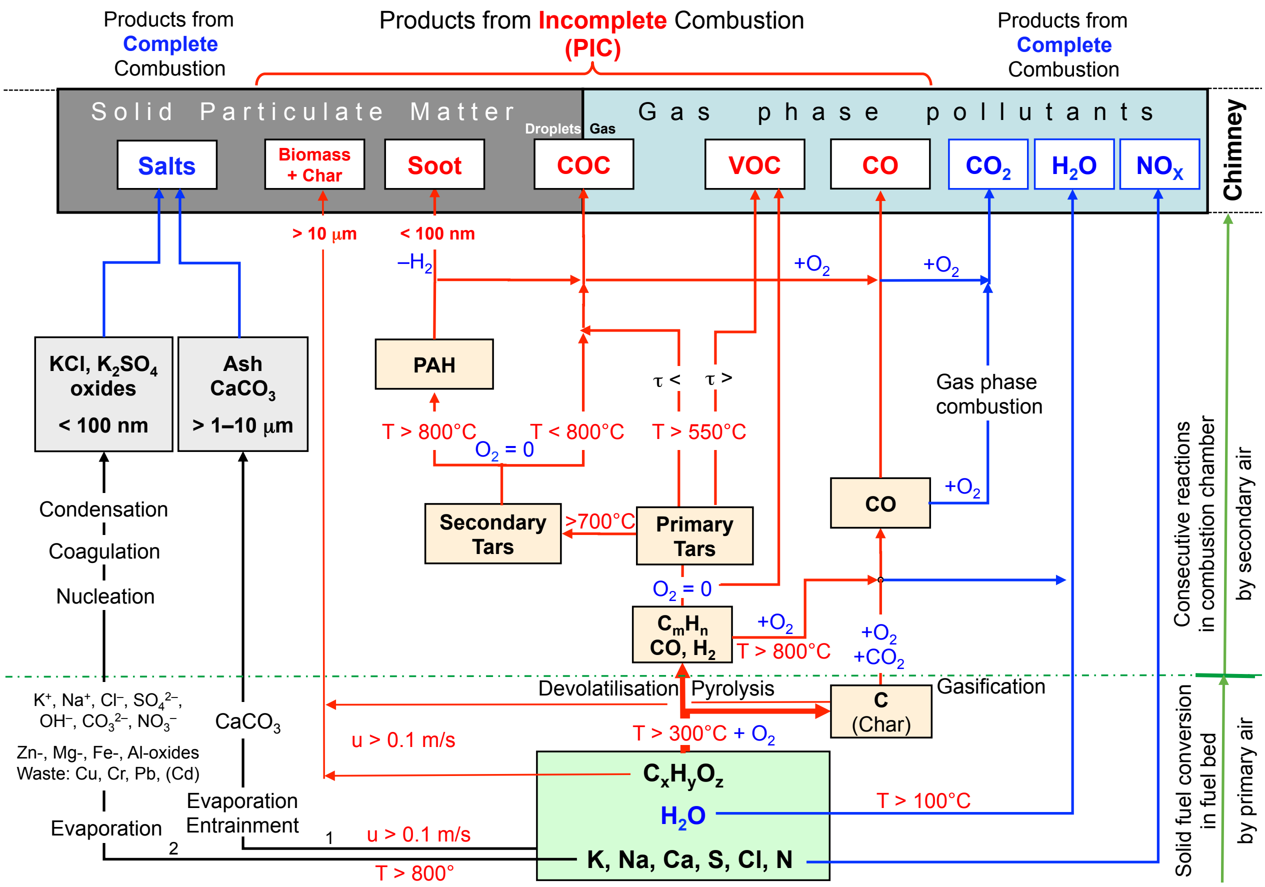


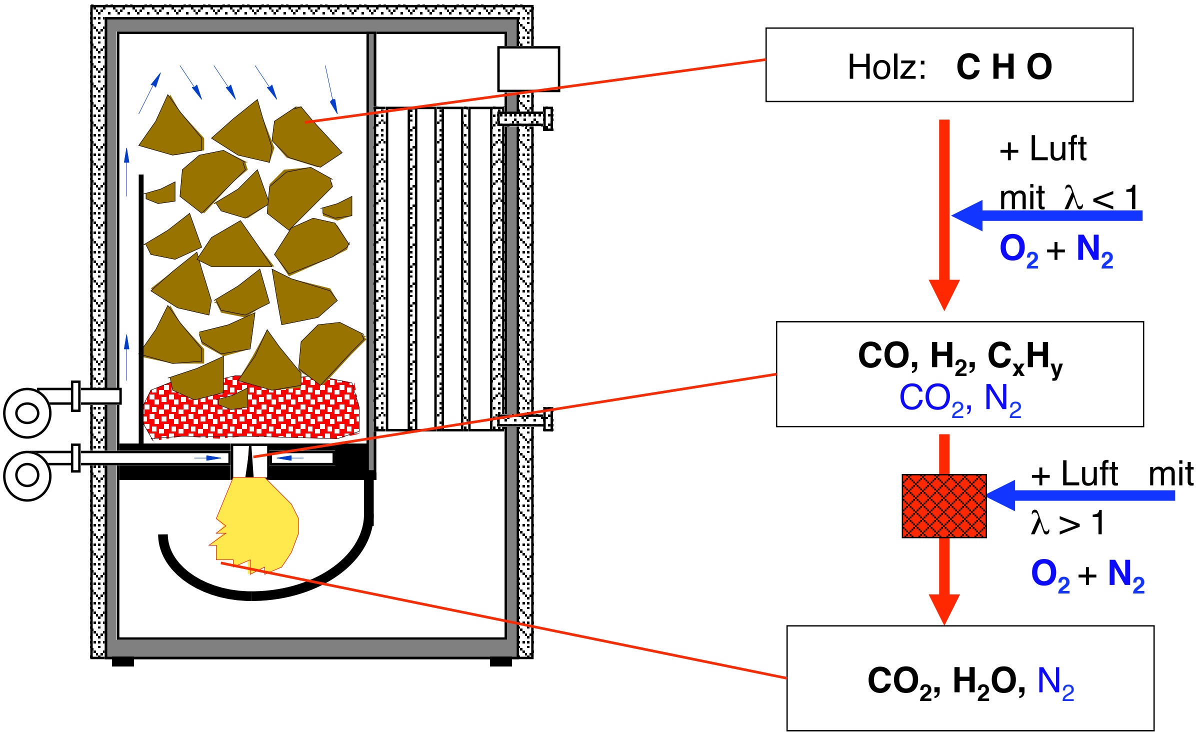
T: [Evans and Milne, 1987], H_2: [Jess, 1996]
u Gas velocity, τ Residence time, </> short/long
1 Solid-particle-path, 2 Solid-vapour-particle-path

COC: Condensable Organic Compounds
VOC: Volatile Organic Compounds

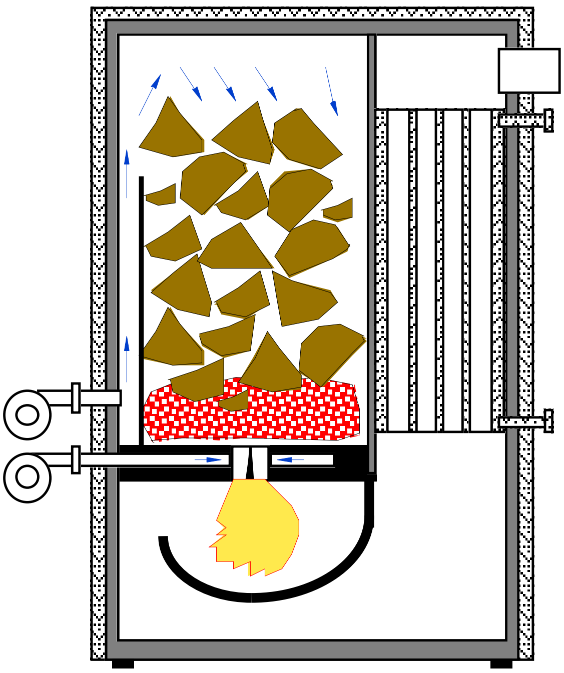
[Nussbaumer, ETH Nanopart. Conf. 2016]

Start-up of wood stoves: Ignition from the top

Two stage combustion (gasifier ?) in boilers - established



Two stage combustion (gasifier ?) in boilers - established



Potential Improvements
by gasification:

1. reduce pollutant emissions:

a) start-up

b) avoid inappropriate conditions

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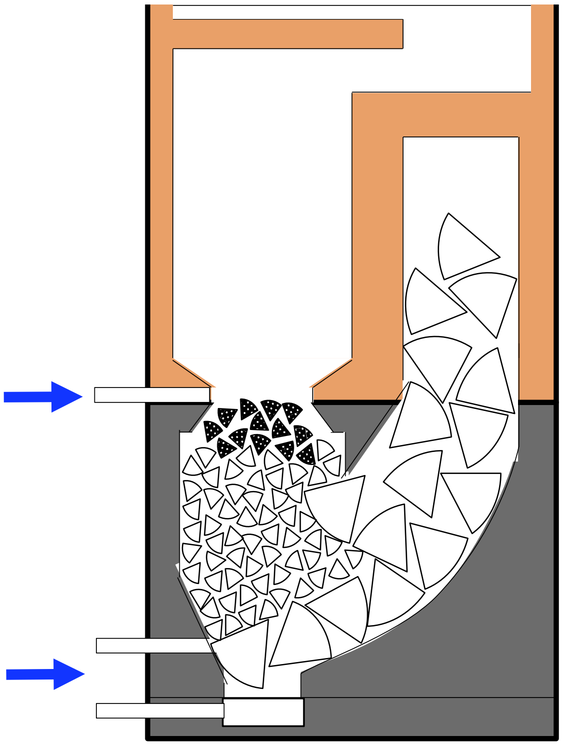
Two stage combustion for log wood stoves (gasifier ?): R&D



Verenum [P. Odermatt & T. Nussbaumer, 12. Holzenergie-Symposium, 2012]

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How about gasification?

simple, batch-wise updraft gasification

1980's
T.B. Reed, Biomass Foundation

2016

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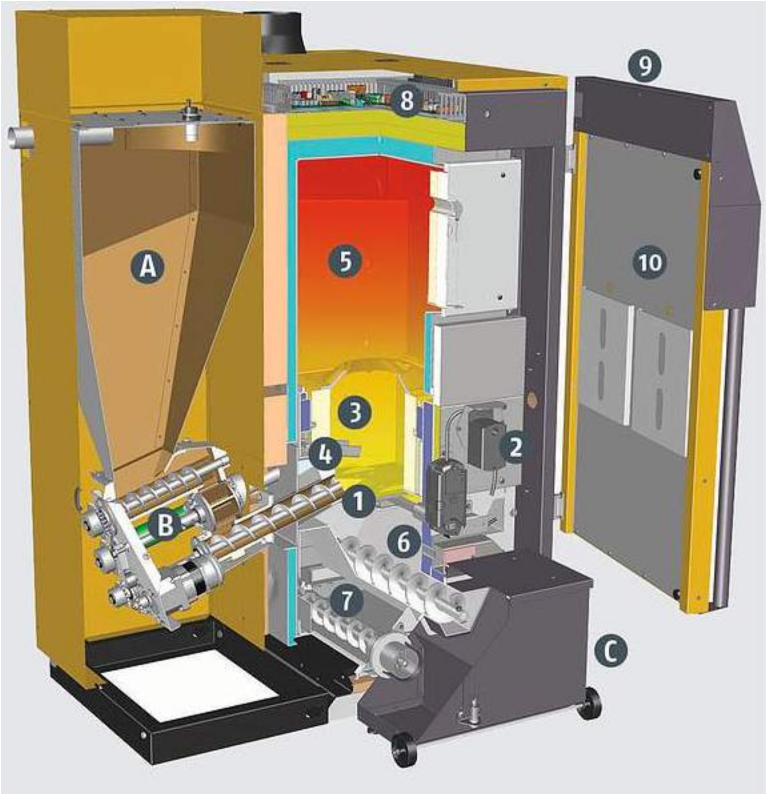
Two stage combustion pellet boiler - established



Potential Improvements by gasification:

- reduce complexity & cost
- reliability
- lifetime

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Eta PE-K 35–90 kW
www.eta-heiztechnik.at

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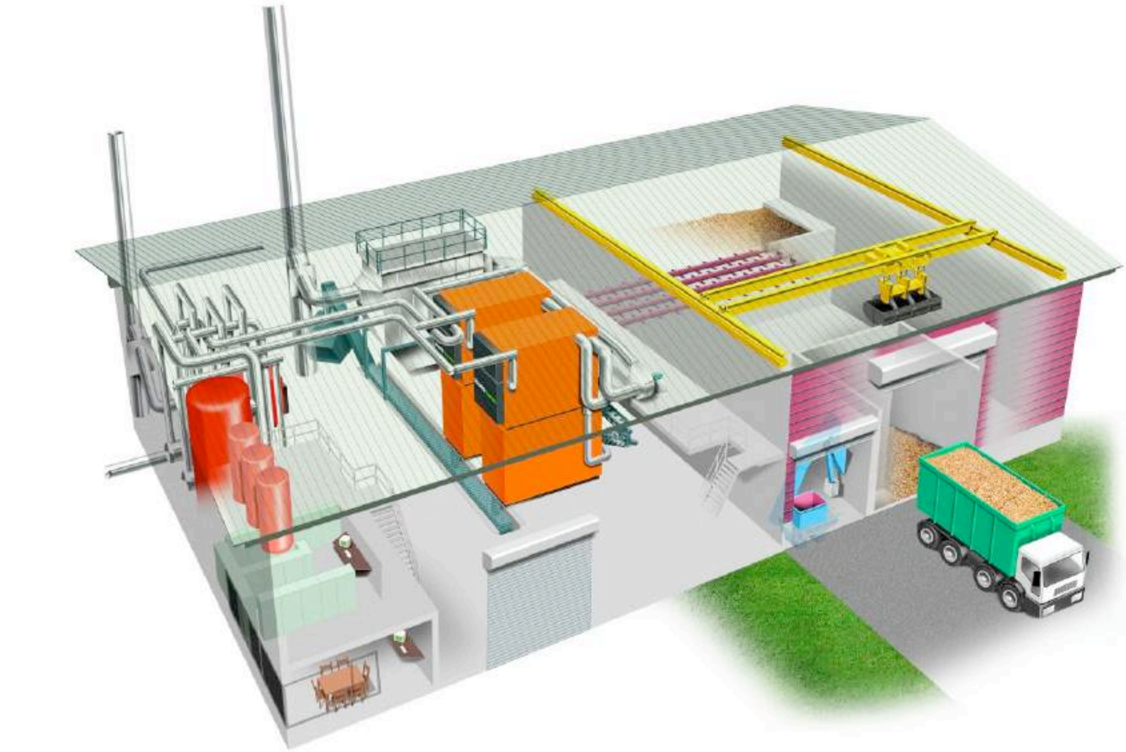
Automatic biomass plants e.g. for district heating (DH)



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6.4 MW, AVARI Wilderswil (BE), Schmid AG

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Automatic biomass plants e.g. for district heating (DH)

+ established

+ high fuel moisture and high ash possible

– need of particle removal (ESP)

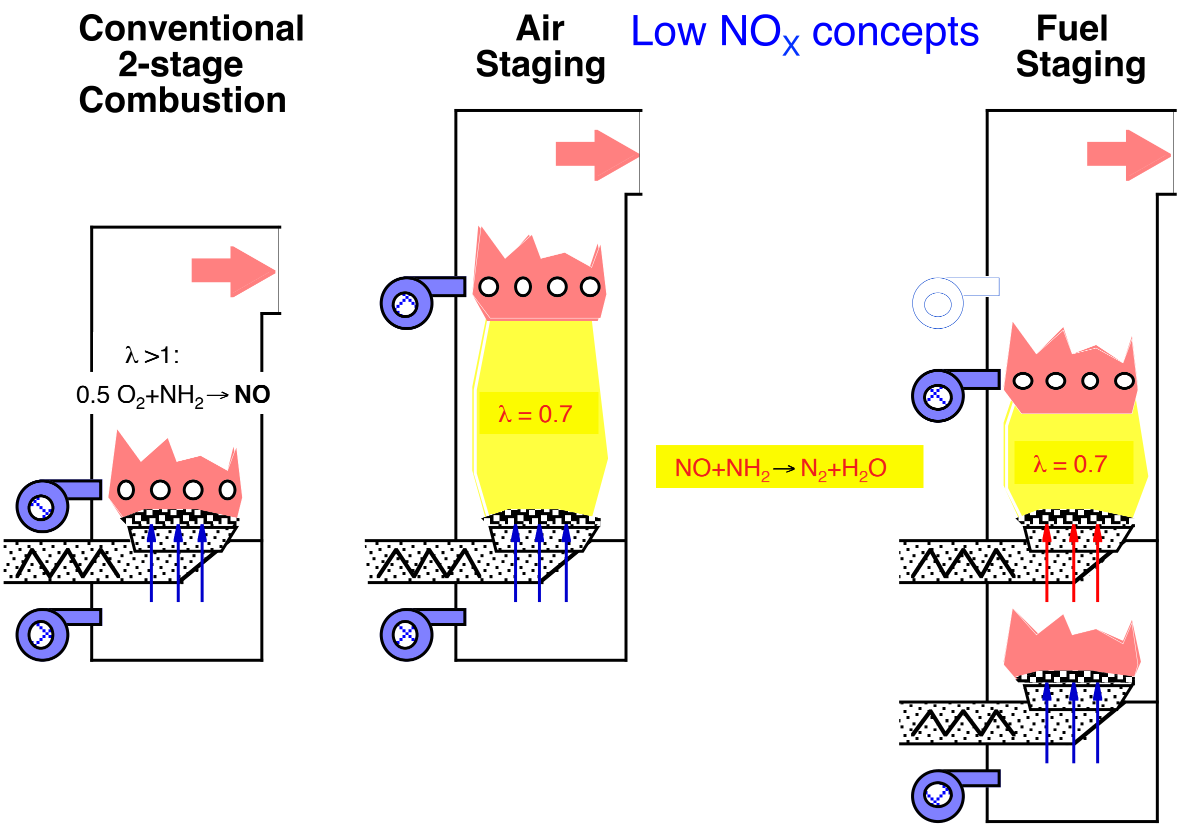
– need of heat storage due to limited load range

– fuel NO_X emissions

– high investment cost

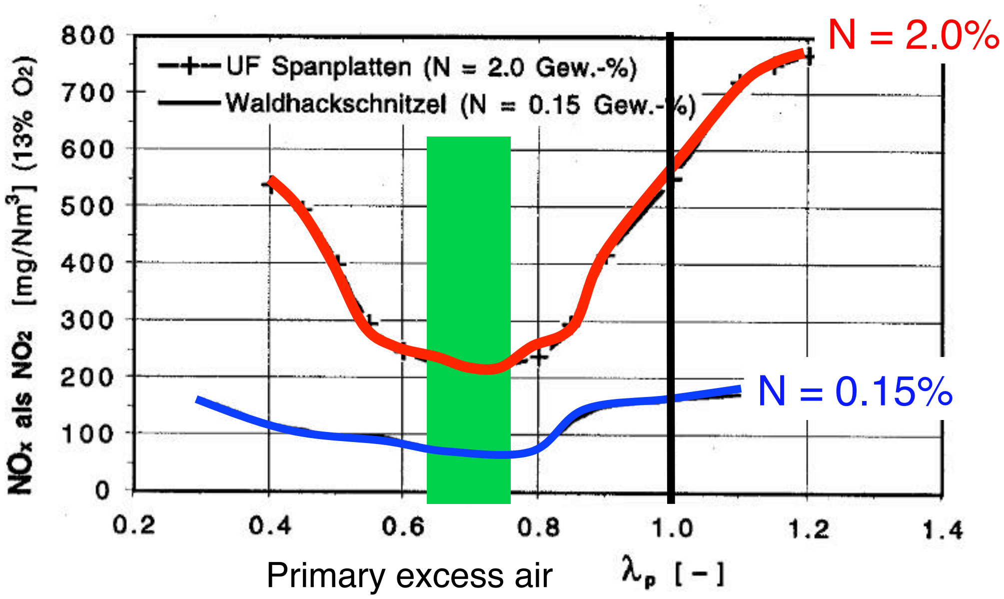
Potential Improvements by gasification

Low NO_X concepts



[T. Nussbaumer, Energy & Fuels, Vol. 17, No 6, 2003, 1510–1521]

Air staging



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[Keller & Nussbaumer, 1994]

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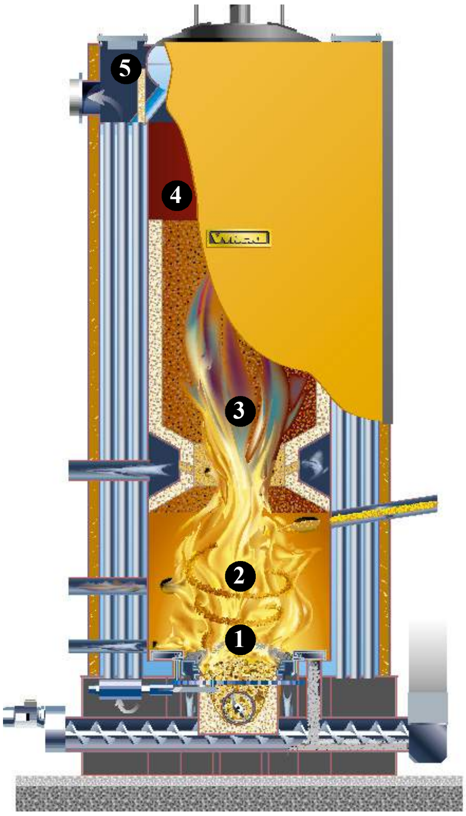
1.5 MW Pilotanlage Vyncke



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[Fastenaekels & Nussbaumer, 2002]

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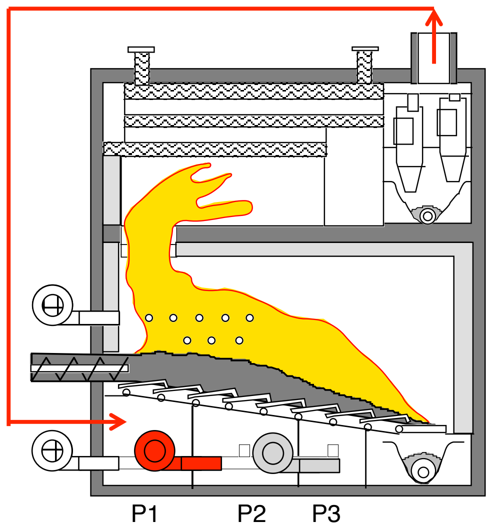
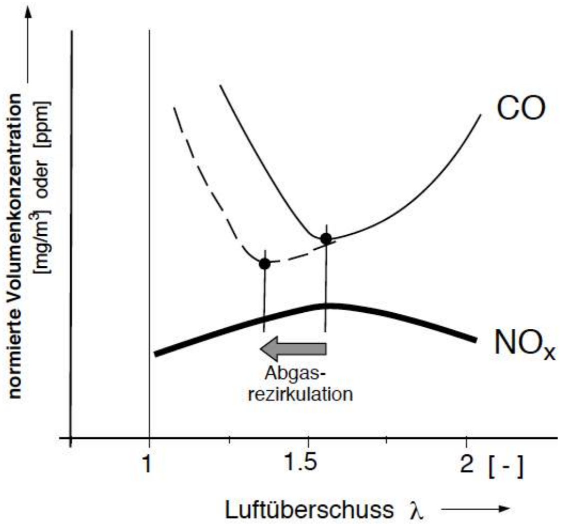
Current project to improve load range and reduce fuel NO_X: Multi-sector grate and flue gas recirculation





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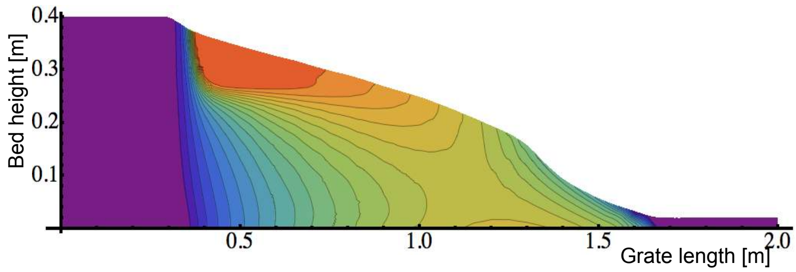
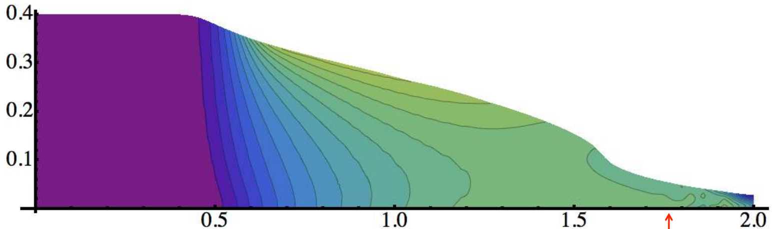
Fuel bed model (FBM)

1 Reference Case
with ideal conditions



2 Increased moisture
(40% instead of 30%)

+ 10% Moisture



Solid fuel conversion is deccelarated and results in unburnt carbon in the grate ash

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[J. Martinez, G. Barroso]

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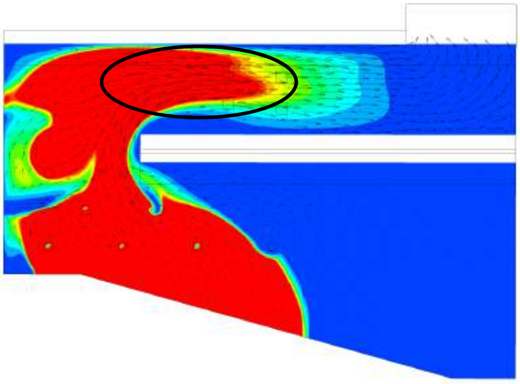
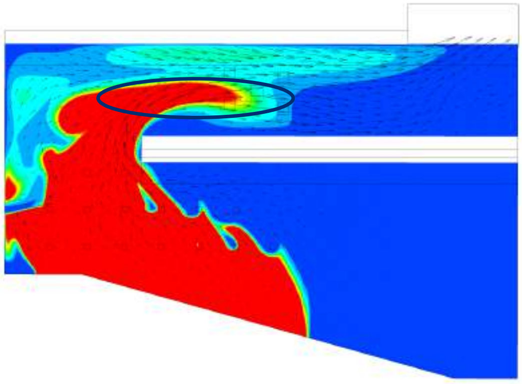
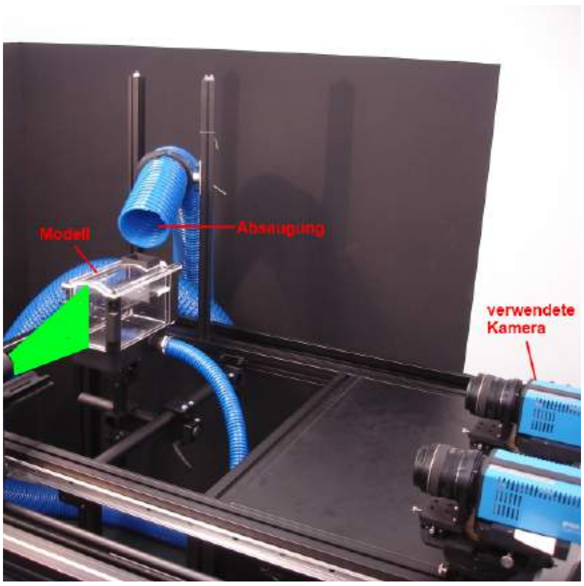
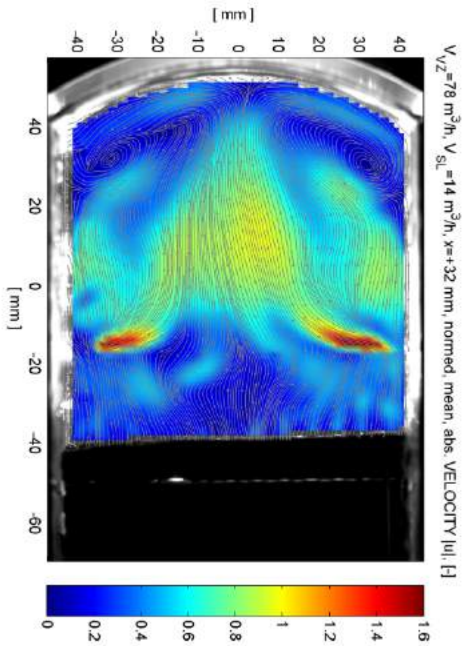
Boiler optimisation by CFD and PIV





Particle Image Velocimetry (PIV)

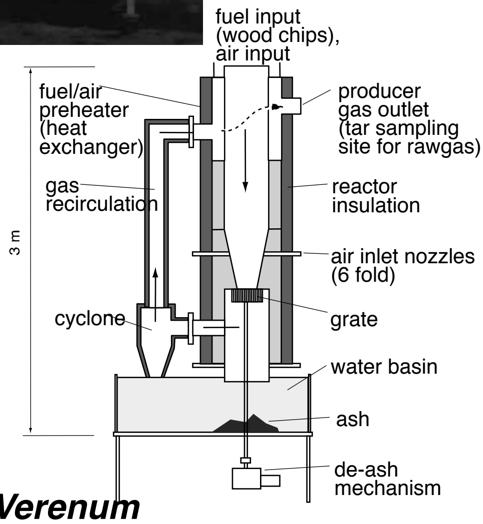




How about gasification?

Co-current downdraft gasifier 1990-2000

$[mg/m_n^3]$ 11% O_2	Engine exhaust	Biomass boiler
NO_X	53	220
PM	2	121



1. PM: Process internal particle reduction
2. NO_X: NH_3 scrubbing and lean combustion

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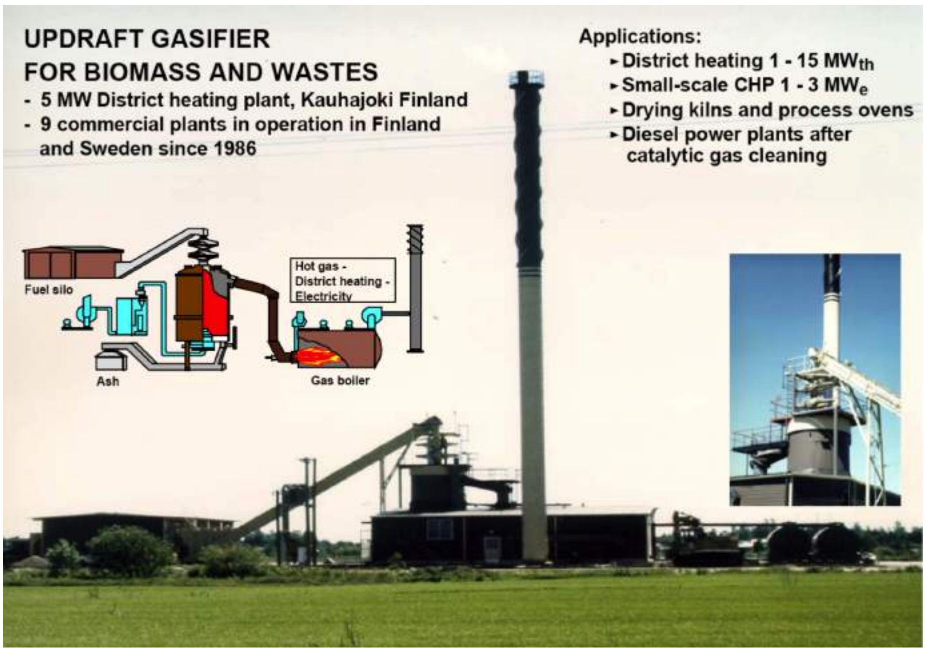
How about gasification?

Updraft co-current gasifer



Bioneer-Vergaser, Kauhajoki, Finnland [VTT 2002]

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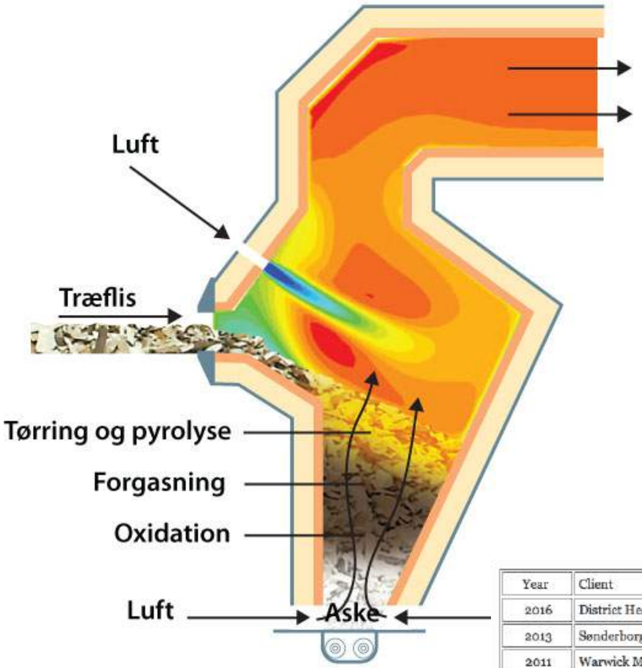
How about gasification?

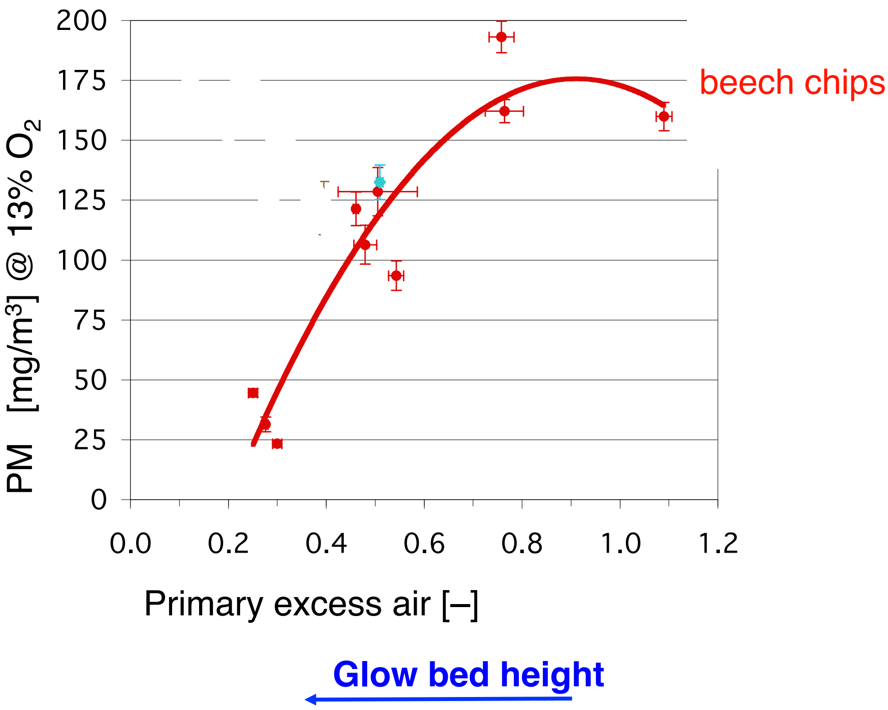
Dall Energy gasifier-boiler 2 – 12 MW



Emission	Dall Energy
Dust (mg/Nm3)	20 out of furnace !!!!
NOx (mg/Nm3)	175
CO (mg/Nm3)	
100 % Load	15
40% Load	15
20% Load	15

Year	Client	Task	Status
2016	District Heating Company	Engineer and prepare CHP plant	Plant to be commissioned in 2017
2013	Sønderborg District Heating	9 MW Dall Energy biomass plant	Plant in operation
2011	Warwick Mills, USA	2 MW Dall Energy biomass plant	Plant in operation
2010	Bogense District Heating	8 MW Dall Energy Furnace	Plant in operation
2009	EUDP	Proof of concept Dall Energy Furnace	Proof of concept verified in 2010

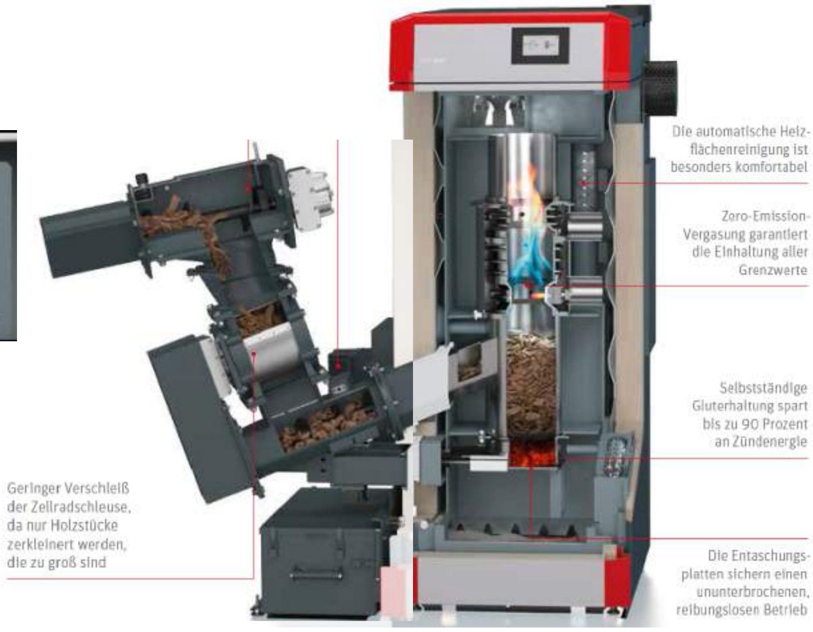
'Low Particle Combustion' = Updraft Gasification ≠ Low NO_X



How about gasification?

Counter-current updraft gasifier 2016

Feeding crucial
(and fuel size?)

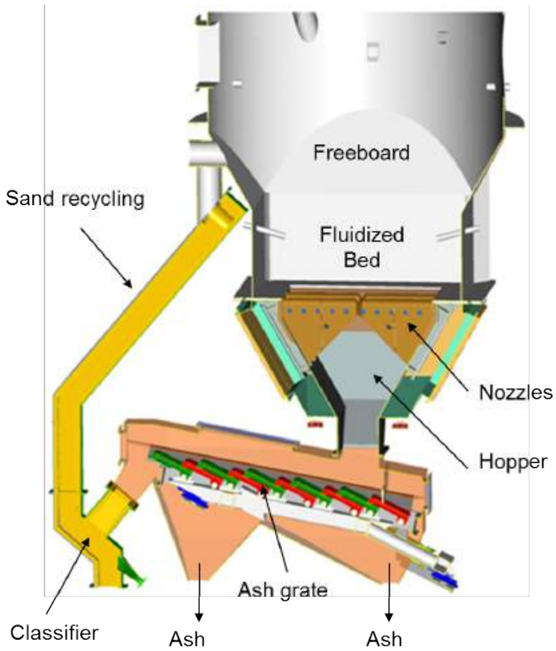


1 mg/m^3 PM on wooch chips

Verenum Windhager PuroWin 30 kW – 2016 for wood chips HOCHSCHULE LUZERN

FBC 42 MW

42 MW Wirbelschicht
11 MWe Dampfturbine
15 t Holz pro Stunde
Fernwärme und Strom
(Wärme-Kraft-Kopplung)



[P. Kolbitsch, Bertsch, 13. Holzenergie-Symposium, 2014]

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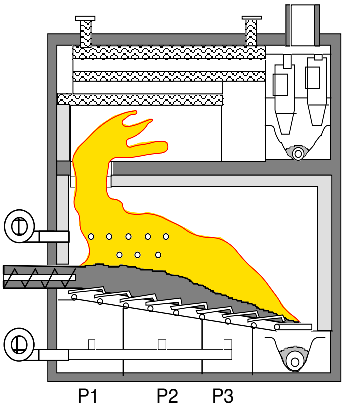
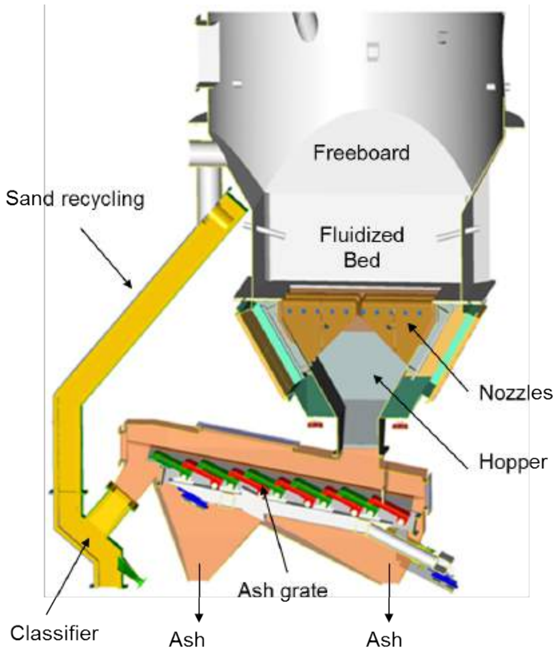
Moving grate

+ Flue gas recirculation
+ Grate cooling
+ ...



FBC



[P. Kolbitsch, Bertsch, 13. Holzenergie-Symposium, 2014]

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Process heat for bakery by thermal oil (290°C)

0.89 kg Wheat

0.67 kg Mehl

1 kg Bred/ Bakery goods

0.22 kg milling residues MR

0.22 kg MR Pellets = 1 kWh

0.33 kWh

0.67 kWh

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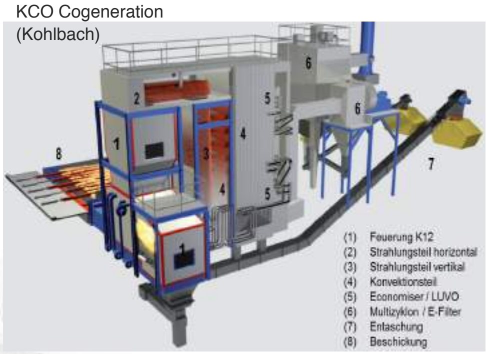
[G. Weinhofer, P. Hennemann, T. Nussbaumer, in T. Nussbaumer (Ed.), 14. Holzenergie-Symposium, Zurich, 16.9.16, www.holzenergie-symposium.ch]

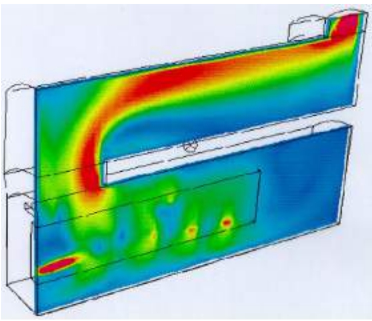
Process heat for bakery by thermal oil (290°C)

Schafisheim:
Total 600 Mio. CHF
10 Mio. CHF for energy plant

KCO Cogeneration
(Kohlbach)



[G. Weinhofer, P. Hennemann, T. Nussbaumer, in T. Nussbaumer (Ed.), 14. Holzenergie-Symposium, Zurich, 16.9.16, www.holzenergie-symposium.ch]



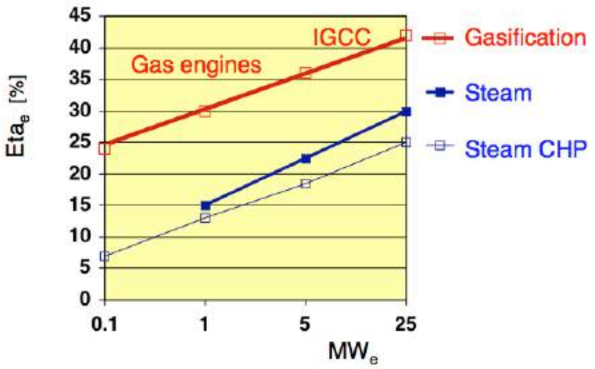
1. Potential and priorities to use biomass
2. Biomass combustion today
3. Potential of biomass gasification

1. Heat production, in future in particular process heat

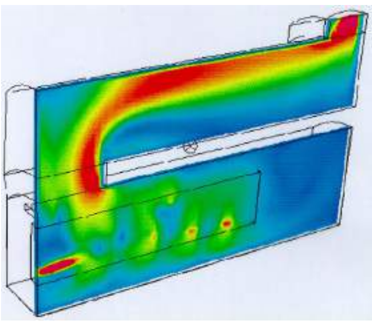
- on-demand: faster load changes and broader range
- with low PM and low NO_x
- at reduced cost (?)

2. Power and CHP

- higher electrical efficiency
- on-demand: faster
- with low PM and low fuel NO_X
- at reduced cost (?)



3. Syngas for biofuels: Priority 3



1. Potential and priorities to use biomass
2. Biomass combustion today
3. Potential of biomass gasification
4. Scenarios for biomass utilisation

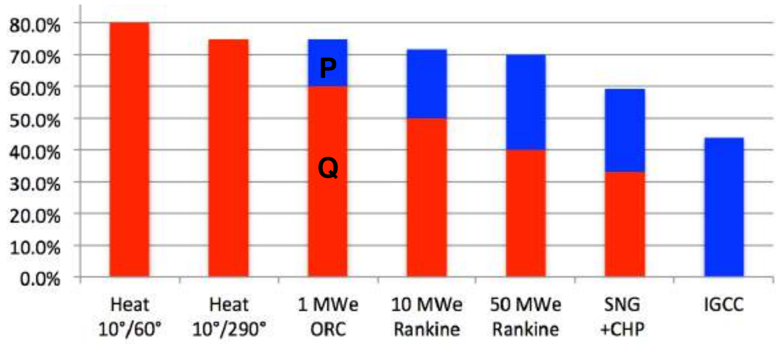
Scenarios for Heat and Power from Biomass

Process efficiency	**Heat 10°/60°**	**Heat 10°/290°**	**1 MWe ORC**	**10 MWe Rankine**	**50 MWe Rankine**	**SNG +CHP**	**IGCC**
η_1 for biomass conversion	100%	100%	100%	100%	100%	66%	80%
η_q	80%	75%	60%	50%	40%	50%	w.c.: 0%
η_e	0%	0%	15%	22%	30%	40%	55%

Chain efficiency (Quantity)		**Heat 10°/60°**	**Heat 10°/290°**	**1 MWe ORC**	**10 MWe Rankine**	**50 MWe Rankine**	**SNG +CHP**	**IGCC**
$\eta_1 \cdot \eta_q$	Q_{net}	80.0%	75%	60%	50%	40%	33%	0%
$\eta_1 \cdot \eta_e$	P_{net}	0%	0%	15%	22%	30%	26%	44%
$\eta_1 \cdot \eta_{tot}$	$Q_{net}+P_{net}$	**80%**	**75%**	**75%**	**72%**	**70%**	**59%**	**44%**

Process chain efficiency

$\eta_{tot} = \eta_1 (\eta_q + \eta_e)$



Verenum [T. Nussbaumer, *Holz-Zentralblatt* 39 (2016) 947–948] HOCHSCHULE LUZERN

Scenarios for Heat and Power from Biomass

Process efficiency	**Heat 10°/60°**	**Heat 10°/290°**	**1 MWe ORC**	**10 MWe Rankine**	**50 MWe Rankine**	**SNG +CHP**	**IGCC**
η_1 for biomass conversion	100%	100%	100%	100%	100%	66%	80%
η_q	80%	75%	60%	50%	40%	50%	w.c.: 0%
η_e	0%	0%	15%	22%	30%	40%	55%

Chain efficiency (Quantity)		**Heat 10°/60°**	**Heat 10°/290°**	**1 MWe ORC**	**10 MWe Rankine**	**50 MWe Rankine**	**SNG +CHP**	**IGCC**
$\eta_1 \cdot \eta_q$	Q_{net}	80.0%	75%	60%	50%	40%	33%	0%
$\eta_1 \cdot \eta_e$	P_{net}	0%	0%	15%	22%	30%	26%	44%
$\eta_1 \cdot \eta_{tot}$	$Q_{net}+P_{net}$	**80%**	**75%**	**75%**	**72%**	**70%**	**59%**	**44%**

Evaluation by EnV	f [–]
Q (Heat)	100%
P (Power, Electricity)	175%

Exergy	°C	
$T_{ambient}$	10	η_C
$T_{q\text{ - warm water}}$	60	15%
$T_{q\text{ - bakery}}$	290	50%
Electricity / Power		100%

Evaluation by EnV		**Heat 10°/60°**	**Heat 10°/290°**	**1 MWe ORC**	**10 MWe Rankine**	**50 MWe Rankine**	**SNG +CHP**	**IGCC**
$f_{q,EnV}$	Q_{net}	80%	75%	60%	50%	40%	33%	0%
$f_{e,EnV}$	P_{net}	0%	0%	26%	39%	53%	46%	77%
$f_{e,EnV}$ ≥ 70%	$Q_{net}+P_{net}$	**80%**	**75%**	**86%**	**89%**	**93%**	**79%**	**77%**

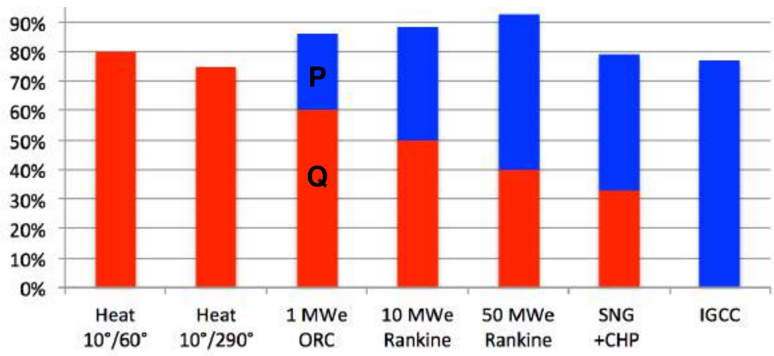
Exergetic efficiency (Quality)		**Heat 10°/60°**	**Heat 10°/290°**	**1 MWe ORC**	**10 MWe Rankine**	**50 MWe Rankine**	**SNG +CHP**	**IGCC**
$\eta_{q,ex}$	Q_{Carnot}	12%	37%	9%	8%	6%	5%	0%
$\eta_{e,ex}$	P	0%	0%	15%	22%	30%	26%	44%
η_{ex}	Q_{Carnot}+P	**12%**	**37%**	**24%**	**30%**	**36%**	**31%**	**44%**

Verenum [T. Nussbaumer, Biomass for Swiss Energy Future Conference 2016, Brugg, 7 September 2016] HOCHSCHULE LUZERN

Ranking today

Rating by EnV

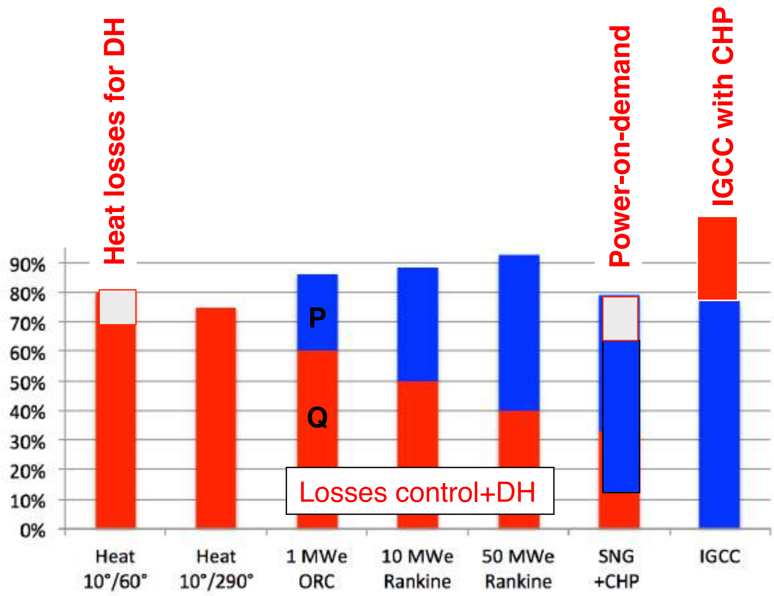
$f_{EnV} = \eta_1 (\eta_q + 1.75\ \eta_e)$



Ranking today

Rating by EnV

$f_{EnV} = \eta_1 (\eta_q + 1.75\ \eta_e)$



Operation

h/a	2000	5000	2000	5-8000
mode	HoD	Base load CHP	PoD	Base P

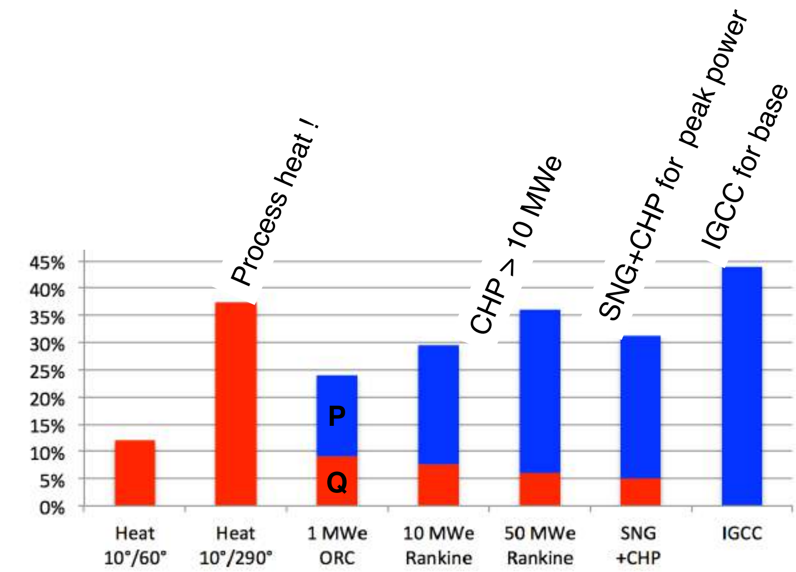
Ranking future

Exergetic efficiency

$\eta_{ex} = \eta_1 (\eta_q \eta_C + \eta_e)$

Heat 10°/60°: η_C = 15%

(Heat 10°/290°: η_C = 50%)



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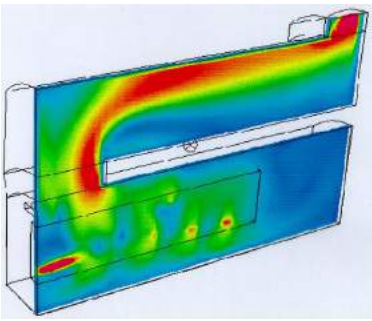

1. Potential and priorities to use biomass
2. Biomass combustion today
3. Potential of biomass gasification
4. Scenarios for biomass utilisation
5. Conclusions

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1 Biomass combustion is established

– for heat at reasonable cost but with PM and NO_X

– for CHP with low electrical efficiency and at high cost

2 Biomass gasification exhibits a potential

– for heat with faster operation and low PM and NO_X

– for CHP with higher electrical efficiency and at lower cost

3 Gasification exhibits a gap between the claim and the reality

– Advantages (PM, NO_X, el. efficiency) have been demonstrated

– Costs and complexity are claimed to be low (TRUE or FALSE ?)

– Reliability is claimed to be high (TRUE or FALSE ?)

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www.hslu.ch
www.verenum.ch
www.holzenergie-symposium.ch

Nussbaumer, T.: Combustion and Co-combustion of Biomass: Fundamentals, Technologies, and Primary Measures for Emission Reduction, Energy & Fuels, Vol. 17, No 6, 2003, 1510–1521

Nussbaumer, T.: Verfahren und Potenzial der Biomasse-Vergasung, 7. Holzenergie-Symposium, 18. Oktober 2002, Zürich, ISBN 3-908705-01-0, 103–146

Nussbaumer, T.: Economic assessment of power production from wood in IGCC plants and in natural gas fired combined cycle plants, 15th European Biomass Conference, Berlin 7–11 May 2007, OD8.1, pp. 2307–2310, ISBN 978-88-89407-59-X

Nussbaumer, T.: System analysis of overall efficiencies of different routes for bioenergy, Workshop of IEA Bioenergy Task 32, 15th European Biomass Conference, Berlin 7–11 May 2007

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