IEA Bioenergy Task 33 Workshop
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Waste gasification overview; two-stage incineration and "true" gasification

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1996 Report

IEA Biomass Agreement

TASK X. BIOMASS UTILIZATION
BIOMASS THERMAL GASIFICATION AND GAS TURBINES ACTIVITY

Sub-task 6 - Gasification of Waste

Summary and Conclusions of Twenty-five Years of Development

Erik Rensfelt, TPS Termiska Processer AB
Anders Östman, Kemiinformation AB

Study Content

- **Wastes* as a gasifier fuel**
  - Waste fuel characteristics and waste fuel standards
  - Contaminants and emission precursors
- **Waste quantities and disposal**
- **Regulatory considerations**
- **Waste gasification and gas cleaning technologies**
  - General description
  - Specific technologies in projects
- **Considerations for the use of the product gas**
  - Fuel gas
  - Power and CHP
  - Fuel and chemical products
- **Target market, technical requirements and barriers**
- **Waste gasification developers, plants and projects**

*MSW, IW etc. but not special or hazardous wastes

Gasification

Definition

The transformation of a combustible solid or a liquid to a gaseous form

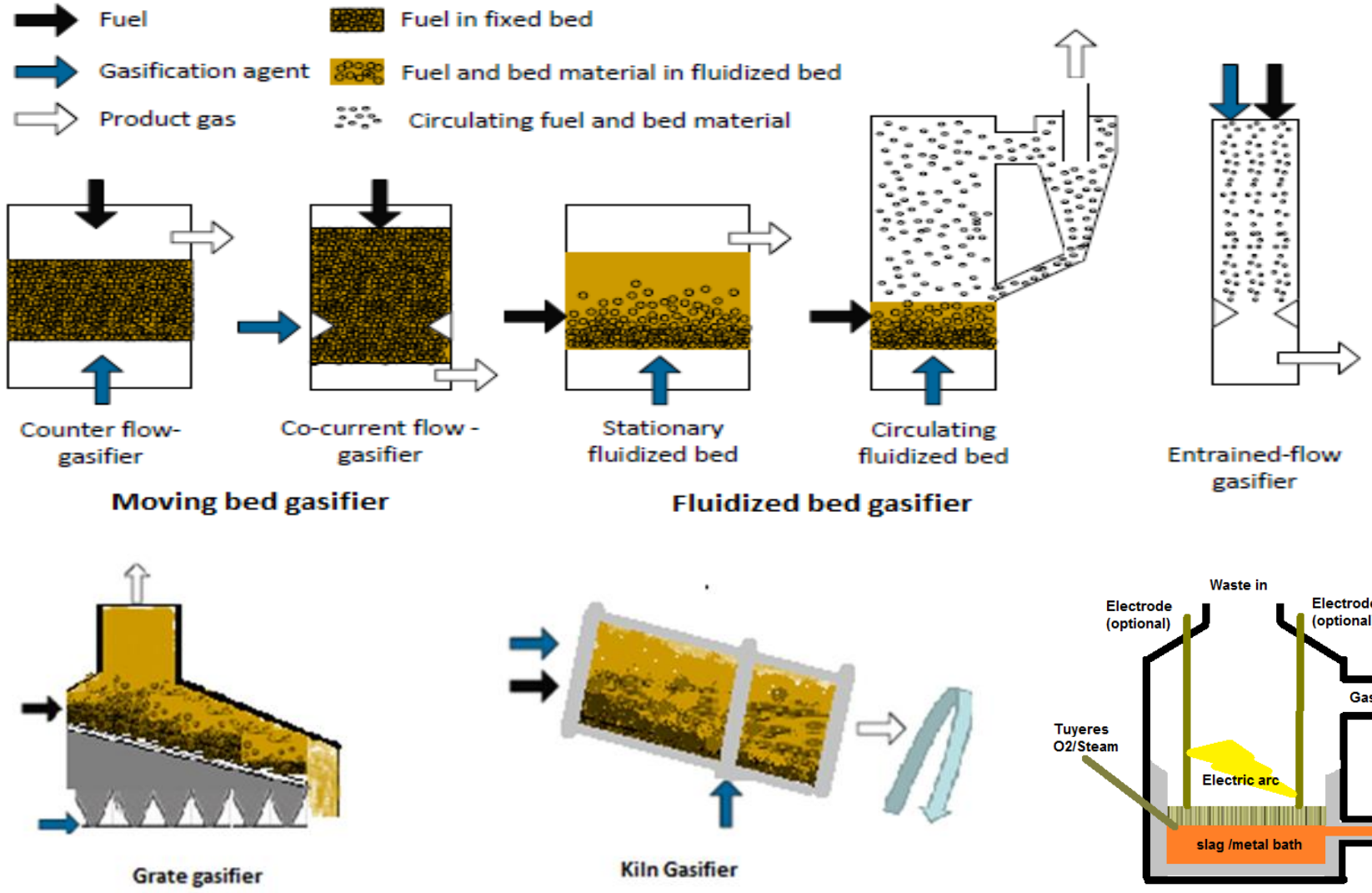
General purposes

- To provide a more flexible use of the original fuel
- To allow separation of combustible components from inorganics/ash
- To allow cleaning from certain contaminants
- To access certain chemical building blocks e.g. hydrogen

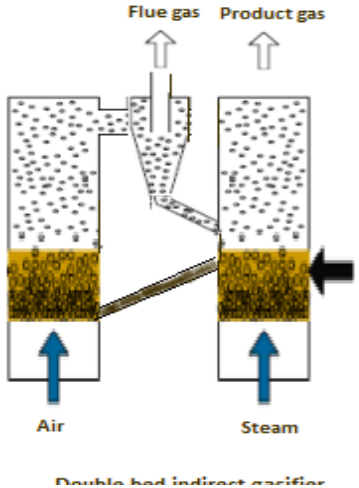
Waste-specific purposes

- To accomplish ash vitrification without external energy input
- To accomplish pre-combustion cleaning of smaller gas volume
- To thereby fulfill end-of-waste criteria for downstream uses of gas

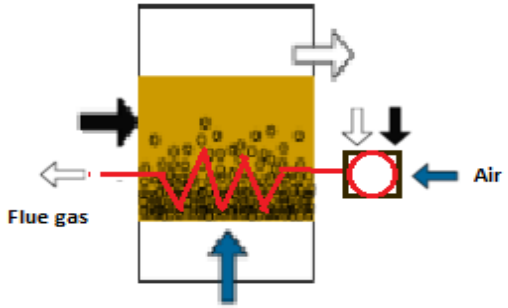
Direct Gasifiers



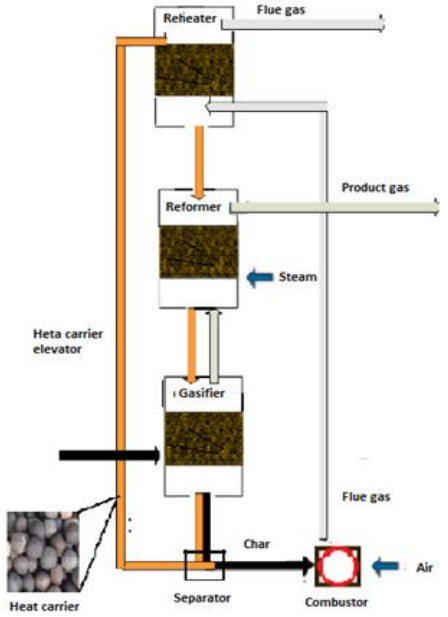
Indirect, Multi-stage Indirect Gasifiers



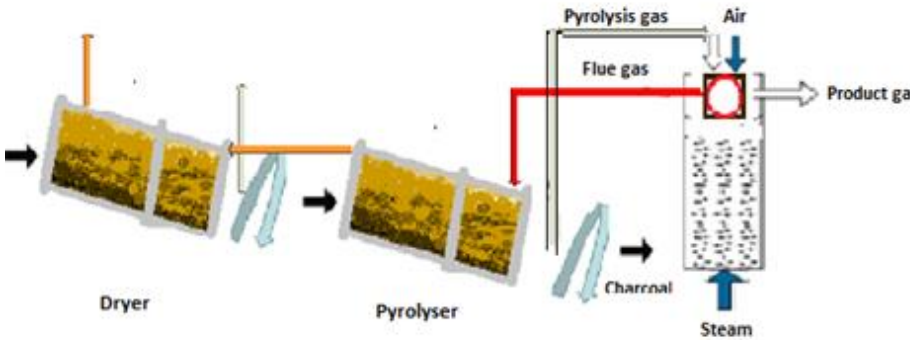
Double bed indirect gasifier



Indirectly heat fludized bed

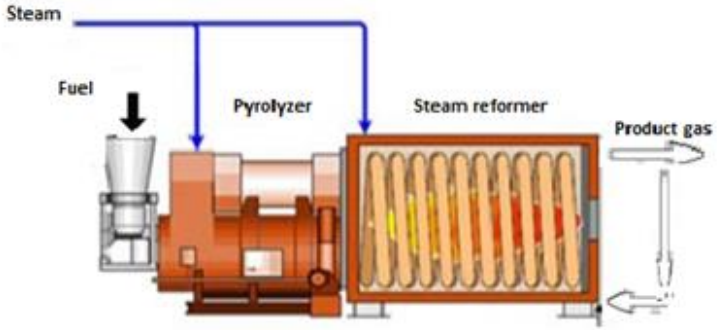


Heat carrier fixed bed gasifier



Charcoal gasifier

Heat Integrated gasifier



Refoming gasifier

Database, Developers

APP Advanced Plasma Processes (UK)	FB (Outotec)	CHP, syngas	Pilot unit Swindon Tyseley Urban Resource Centre 1 000 tpa SNG demo in constr.
Biomass Energy Systems, Inc. (BESI)	Kiln		S. Korea 4 tph
Biomass Power Ltd.	Step grate		Hoddesdon 10 MWe start-up Aberdare 11 MWe in construction Belfast 15 MWe in construction Hamilton, in planning Washwood, in planning
Brightstar Environmental	Separation by autoclaving Ext. heated pyrolysis Steam gasification of char Solid Waste and Energy Recycling Facility (SWERF)	CHP	Kembla Grange, Wollongong, Australia 50 000 tpa 2001-2004
Chinook Science (USA)	Pyrolysis		West Midlands. 160 000tpa ASR converted to 40 MWe Eastern US 160 000 tpa ASR Also claims to have 16 plants in operation worldwide. Three projects, Westbury, Dagenham and Skelton Grange in planning in the UK.
CHOPEX	Fixed bed plasma PRME gasifier Kobelco gasifier	CHP	Morcenx, France 40 MW Three project in planning in France, Thouars, Locminé and Montauban de Bretagne

Over 70 entries

Database, Plants and Projects

Kurobe	Nikko Mikkaichi Recycling Co. Ltd.	Kurobe, Toyama (JP)	Ebara	1*63 tpd	ASR , waste plastic		2002
Kushiro		Kushiro City (JP)	Mitsubishi	4.6 Mwe	Waste		In Planning
Kymijärvi I	Lahden Lampovoima Oy	Lahti (FI)	Metso	2*80 MW	SRF (wastes)	CHP	In op. 2012
Kymijärvi II	Lahden Lampovoima Oy	Lahti (FI)	Foster-Wheeler	70 MW	Wood residues	Indirect co-firing	In op. 1997
Kyouku		Kyouku (JP)	Mitsui	2*2 tph			2003
Lebanon WTE Gasification Project	PHG Energy	Lebanon, TN, USA	PHG Energy	64 stpd,	SRF, tyres, sludge	0.4 MWe	In construction
Levenseat	Levenseat Renewable Energy	Forth, Lanark, (UK)	Outotec Energy	105 000 tpa	RDF	11 MWe/ 16 MWh th	2017
Lida	Minami-Shinshu Union	Lida, Nagano (JP)	Ebara	2*47 tpd	MSW	0.4 MWe	2003
Lisburn		Lisburn (UK)	Energos	80 000 tpa	Wastes	Power	In planning
Locminé	CHO Power	Locminé (FR)	CHO Power	45 000 tpa	Sorted MSW	11 MWe	In planning
Mahad		Mahad (IN)	Concord Blue			H2	Op

Over 250 entries

Thermal Treatment, My Taxonomy

Industrial Emissions Directive 2010/75/EC.

“’waste incineration plant’ means any stationary or mobile technical unit and equipment dedicated to the thermal treatment of waste, with or without recovery of the combustion heat generated, through the incineration by oxidation of waste as well as other thermal treatment processes, such as pyrolysis, gasification or plasma process, if the substances resulting from the treatment are subsequently incinerated;”

‘waste co-incineration plant’ …..main purpose is the generation of energy or production of material products and which uses waste as a regular or additional fuel or in which waste is thermally treated for the purpose of disposal…….

End-of-waste condition for waste gasification
product gas: gases “are purified to such an extent that…… they can cause emissions no higher than those resulting from the burning of natural gas”

Fuel Gas Cleaning

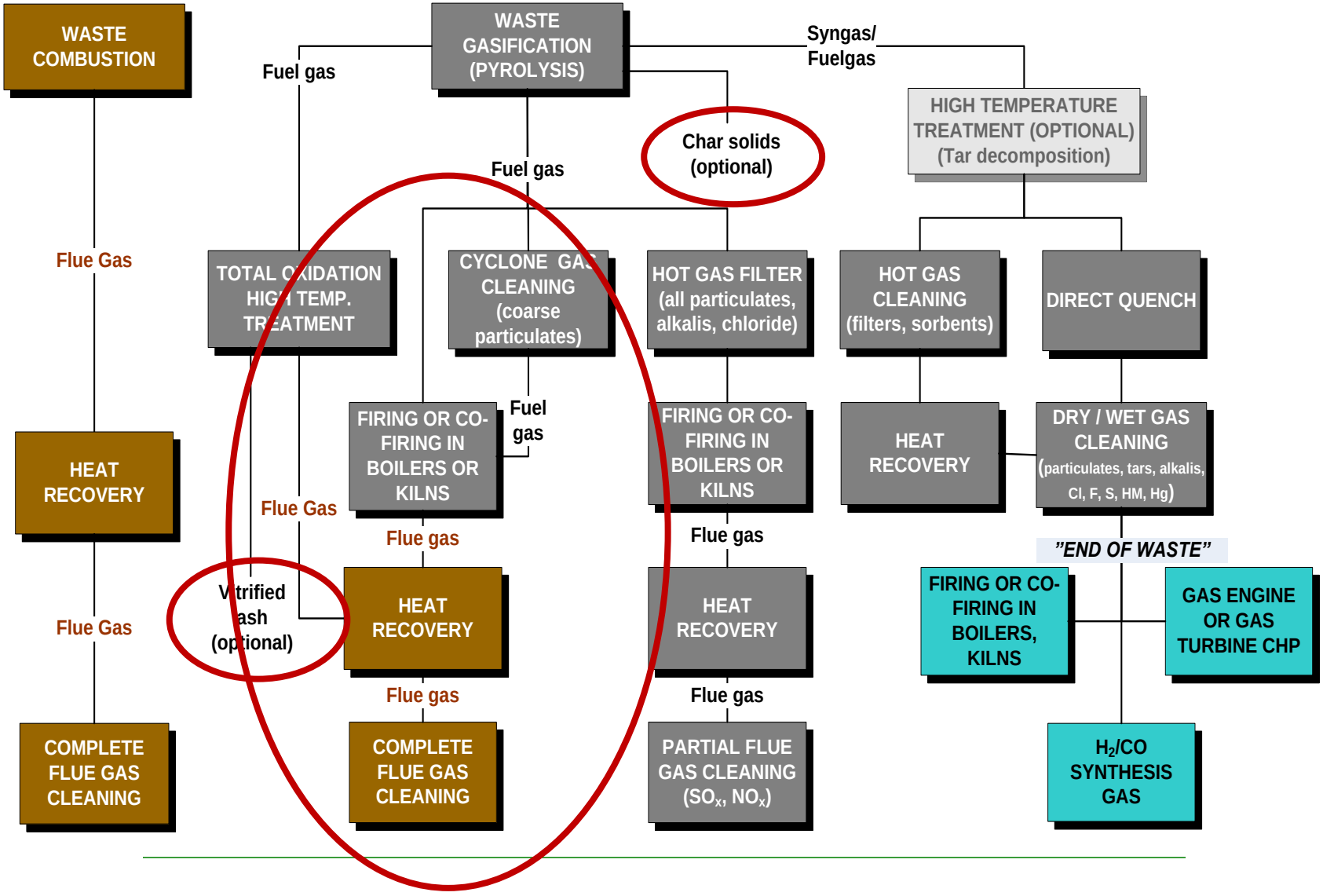
Contaminant/ Reg. emissions	**Cleaning methods**			
Tars	In Reactor thermal, plasma (molten bath)	Sec. reactor thermal, plasma (catalyst)	Scrubbers Water, FAME Tar liquid OLGA	WESP (after scrubbers)
Particulates incl. most HM at lower temp.	Cyclones	Filters 300- 400 °C 150- 200 °C	WESP (after scrubbers)	Scrubbers
HCl, HF	Condensation as NaCl(s), KCl(s)	Lime, sodium (bi)carbonate	Scrubber (alkaline)	Sorbents for traces
Ammonia, HCN	(Catalysts, sorbents, *development*)	Scrubbing (acidic, alkaline)	Cat. hydrolysis (HCN)	
Hg	Activated Carbon			

Sulfur Removal Technologies

Project	Gas use	Upstream	Sulfur removal
Air Products, Teesside, UK	*GT-CC*	COS Hydrolysis	Liquid ox. (LO-Cat)
Plasco, Trails Road, CA	*ICE*		Thiopaq
Thermoselect, Fondotoce IT	*ICE*		Lo-Cat
Thermoselect, Karlsruhe, DE	*ICE*		Sulferox
JFE Thermoselect Chiba, Izumi, Nagasaki, Fukuyama, Osaka. Kurashiki, Isahaya, Tokushima, Yorii, JP	*ICE*		LO-Cat? LO-Cat
Thermoselect, Mallagrotta, IT	*ICE*		LO-Cat?
Mitsubishi (Thermoselect). Mutsu	*?*		Tokyo Gas (Taxahax)
UBE, JP	*Synthesis*		LO-Cat
Enerkem, Alberta Biofuels, CA	*Synthesis*		(n.a. proprietary)
SynTech Bioenergy, Wednesbury	*ICE*	$NaHCO_3$	Alk. scrubbing, PAC
APP, Tyseley, UK	*Synthesis*	$NaHCO_3$	Alkaline scrubbing*

**hypochlorite oxidation in process water*

Thermal Treatment, My Taxonomy



ELV Directive (End-life of Vehicles) 2000/53/EC

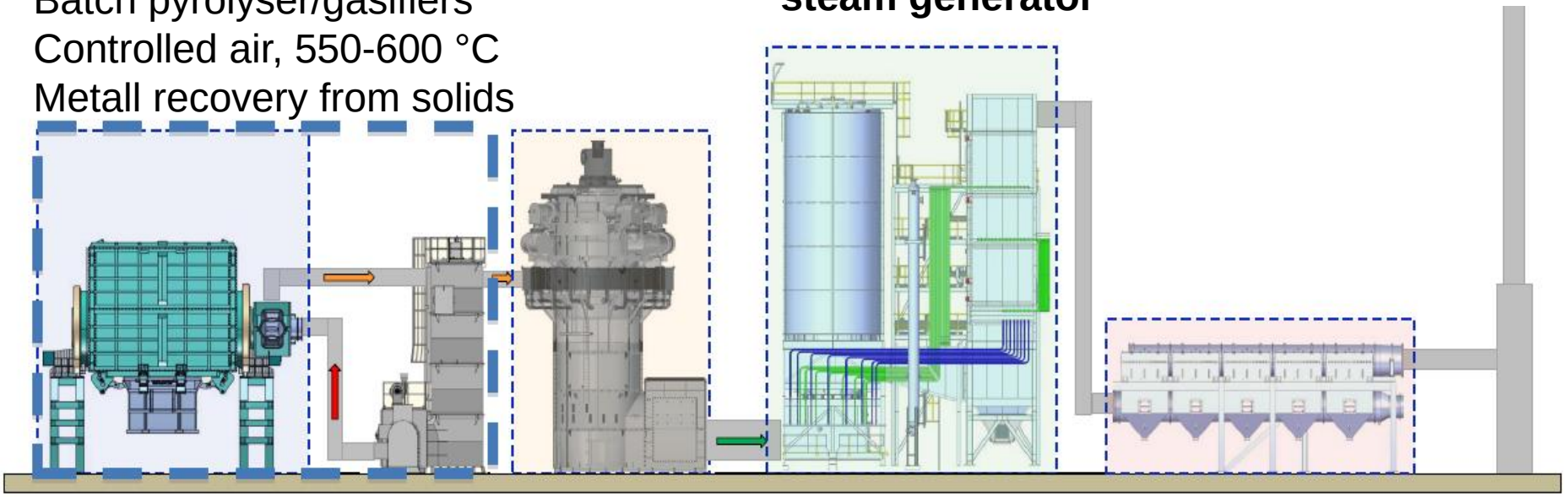
ELV Directive : min. 85 % material recovery from vehicles
2015-, < 5 % to disposal, remainder to energy recovery.

Chinook Science /ERM

350 000 ton treated, < 200 000 tons SRF (shredder residues fines),
40 MW_e, West Midlands, UK, in operation. Also considered for RDF

RODECS® 2*2*6 ton/h
Batch pyrolyser/gasifiers
Controlled air, 550-600 °C
Metall recovery from solids

Heat recovery steam generator

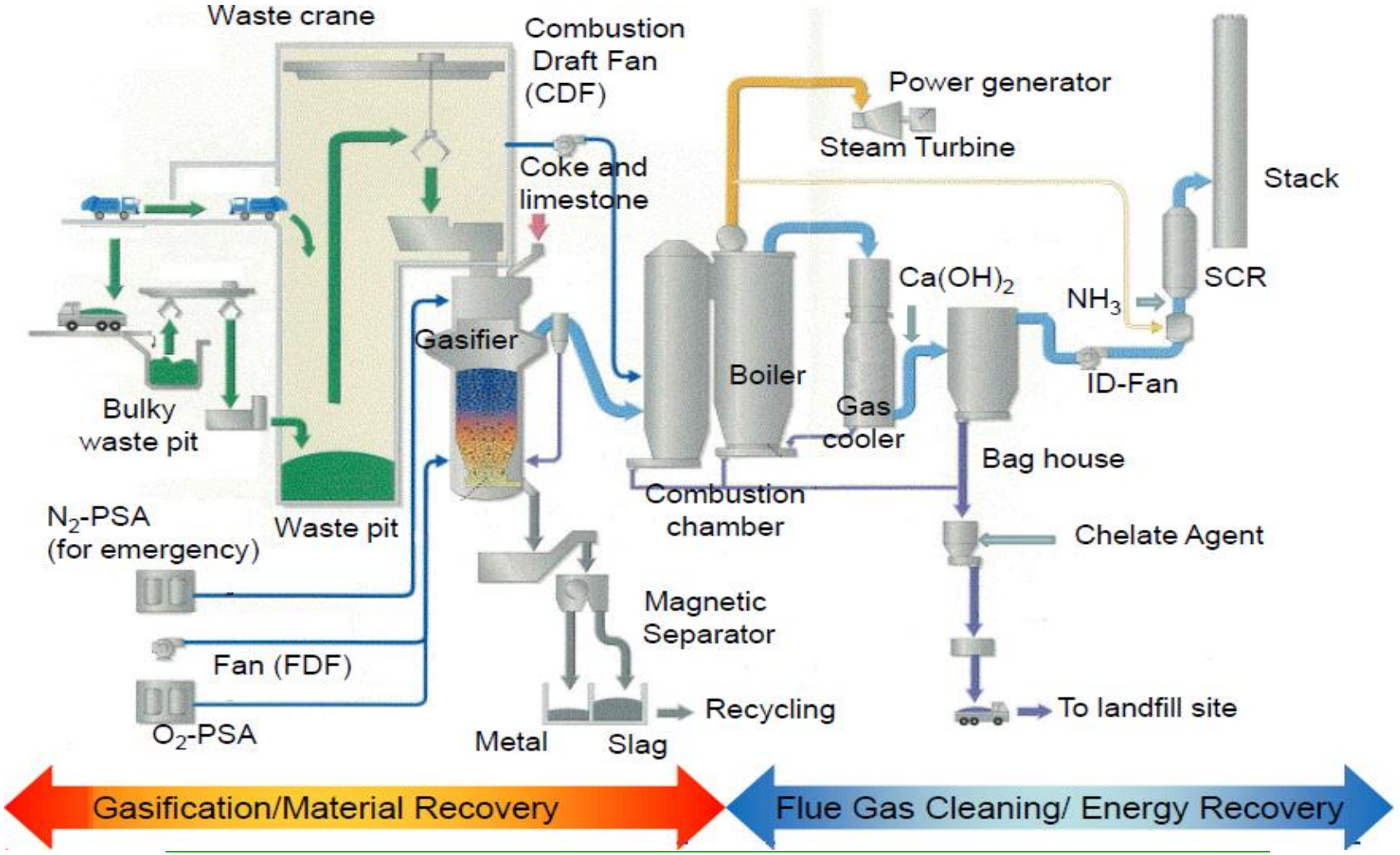


Combustion chamber
850-1 400 °C, (Nat. gas support)

Air pollution control

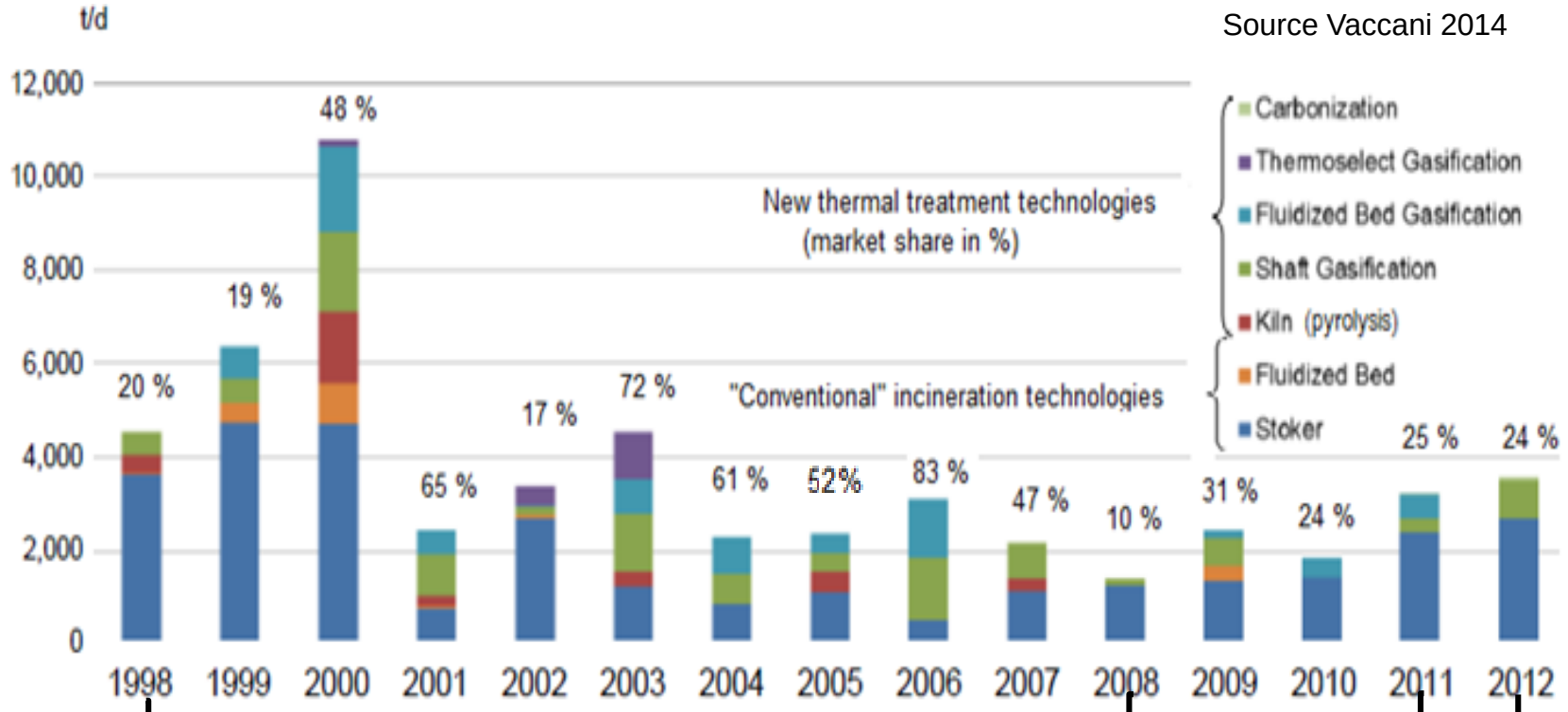
Example; Japanese Waste Gasification

Nippon Steel & Sumikin Engineering Co. Ltd Shaft Furnace



Japan MSW Incinerator/gasifier Market

Source Vaccani 2014



1998

ash melting required for all new incinerators Investment subsidy of 30-50 %.

2008

ash melting no longer required, but has 50 % inv. subsidy, (30 % w/o melting)

2011

Post- Fukushima. Promotion of energy generation. Inv. subsidy 33-50 % based on energy performance.

2012

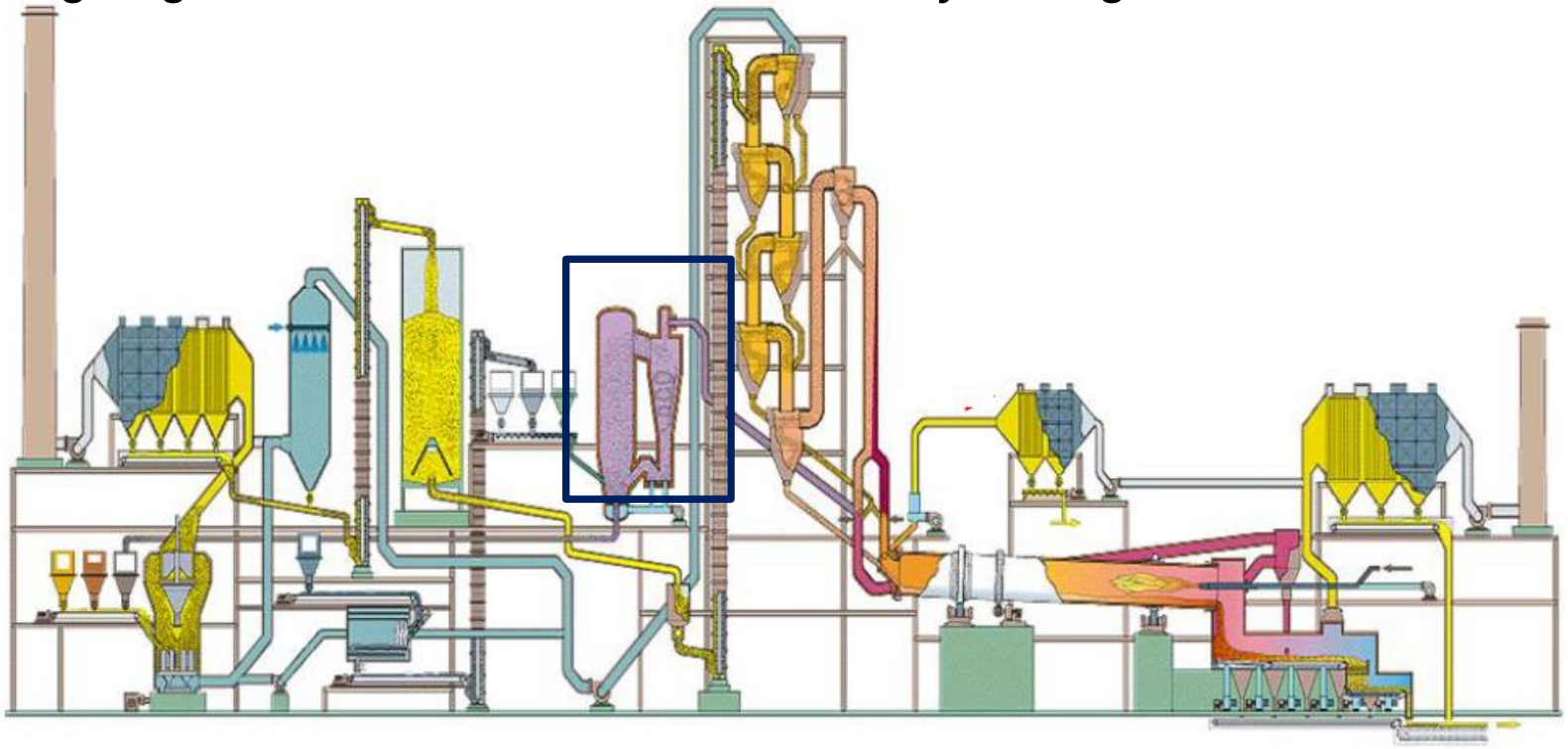
FiT. 0.15 €/kWh 20 years (2014)

Technologies, applications

CEMEX Zementwerk Rüdersdorf

~ 100 MW_{th} Lurgi CFB gasifier1996 (20-25 tph coal ash, coal, waste in comb.)
Today ~70 % of energy from secondary (waste) fuels, 33% biogenic

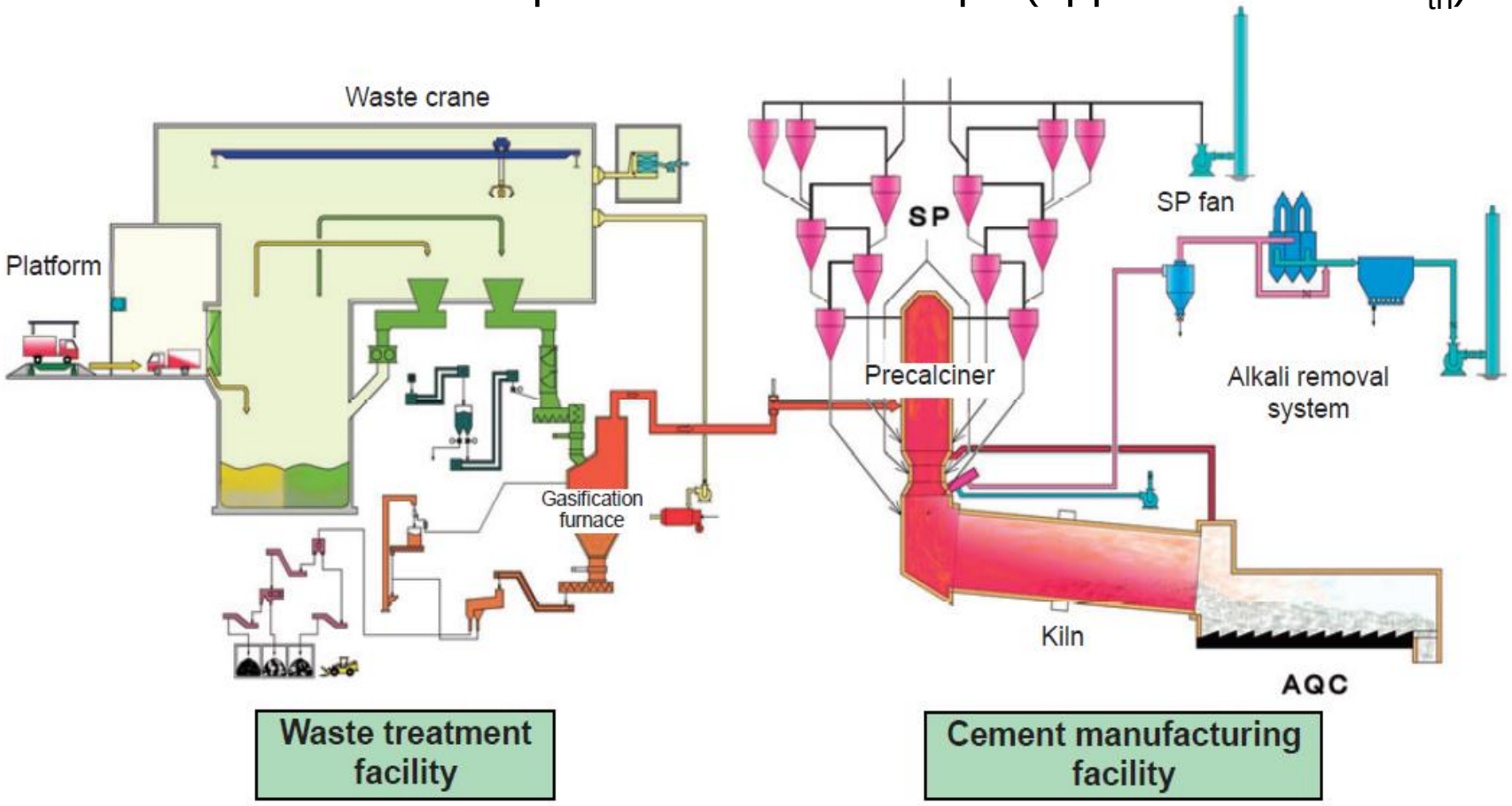
~ CFB plant revamped in 2011 (Outotec) to increase waste fraction
On-going work to enhance metall recovery from gasifier ash



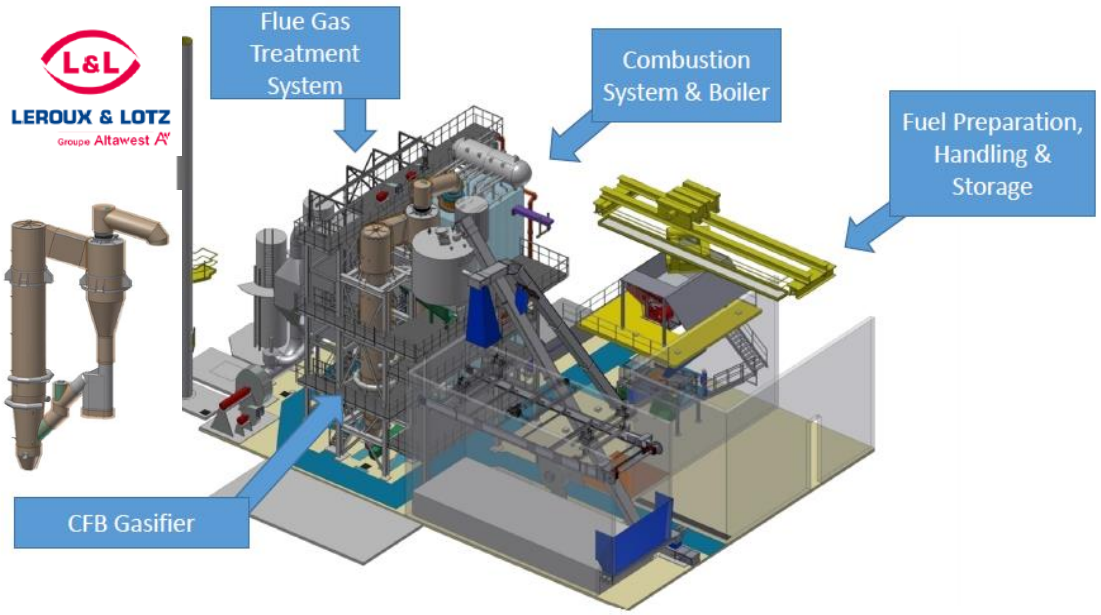
Technologies, applications

Anhui Conch Kawasaki Engineering Co., Ltd.

> 20 FB gasification plants using waste installed in cement plants in China since 2012 at capacities of 200-400 tpd (approx. 30-80 MW_{th})



Technologies, applications



ESKA graphic paper, Hoogezand, NL

- Fuel: fiber rejects from ESKA plant, 25 000 ton/y, (approx. 12 MWth)
- Air blown CFB gasifier coupled to a steam boiler @ 16 bar sat
- Thermal efficiency ~ 85%
- Commissioning 2016, performance test 2017

Fuel Preparation (crane, shredder, magnetic + non-magnetic separator) **Storage & Dosing** (c/w reclaim system, conveyors and surge bin), **CFB Gasifier, LCV Combustion System, Heat Recovery Steam Generator, Fluegas System**

Waste Framework Directive 2008/98/EC

R1: Energy recovery

$$\text{Energy efficiency} = \frac{(GWh_e * 2.6 + GWh_{th} * 1.1 - GWh_{f+i})}{0{,}97 * (GWh_w + GWh_f)} > 0.65$$

R1 Waste Incinerator (WI) power, heat and CHP technologies	Power prod. (% energy)	Heat prod. (% energy)	"Energy Efficiency"
Limiting WI, power only	26	0	0.65
Limiting WI, heat only	0	57	0.65
Typical WI with some CHP	15-20	22-10	0,65
Typical WI CHP, w/o flue gas cond.	25	60	1.35
Typical WI CHP, with flue gas cond.	25	65	1.41
Lahti-type waste gasification CHP	31	56	1.47

R3: Recycling/reclamation of org. substances which are not used as solvents (incl. composting & other biological transformation processes).

Includes gasification & pyrolisis using the components as chemicals.

But no quantitative criteria on the expected recovery efficiency

Two-Stage Incinerator Examples

Waste "gasifiers"/"two-stage" incinerators vs. modern incinerators

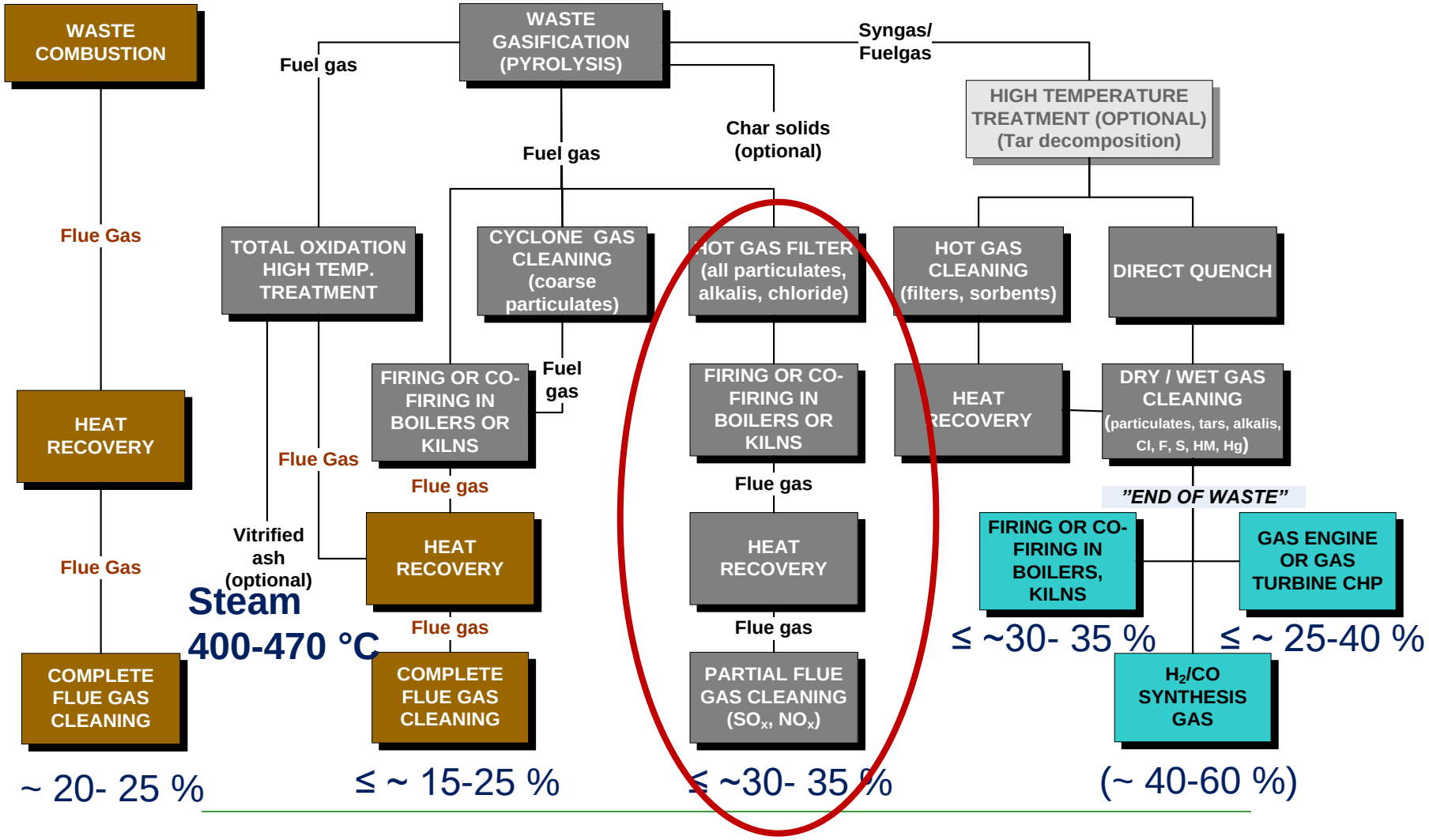
- **lower efficiency**
  - **partially due to smaller scale**
  - **partially for process reasons**
- **similar air pollution control (APC) technology, i.e. similar environmental performance**

Drivers

- **claimed cost benefit at small scale**
- **potential for ash vitrification w/o external energy (Japan)**
- **UK Renewable Obligation system promoted gasification technology in the past**
  - **2 MJ/Nm^3, 1 ROC/MWh, 4 MJ/Nm^3, 2 ROC/MWh**
  - **Waste incinerators w/o CHP 0 ROCs**
- **New UK CfD system spark price for R1 "Advanced Conversion Technology" 114 £/MWh 2014, 74 £/MWh 2017**

Technologies, applications

Efficiency to electric energy (biofuels)



Kymijärvi II, Lahti, Finland

Fuel 2*80 MW SRF etc.

250 000 ton waste / year

120 bar/ 540C

50 MW_e / 90 MW_{th}.

31 % / 88 % efficiency

(Reheat cycle estimate 35 % el.)

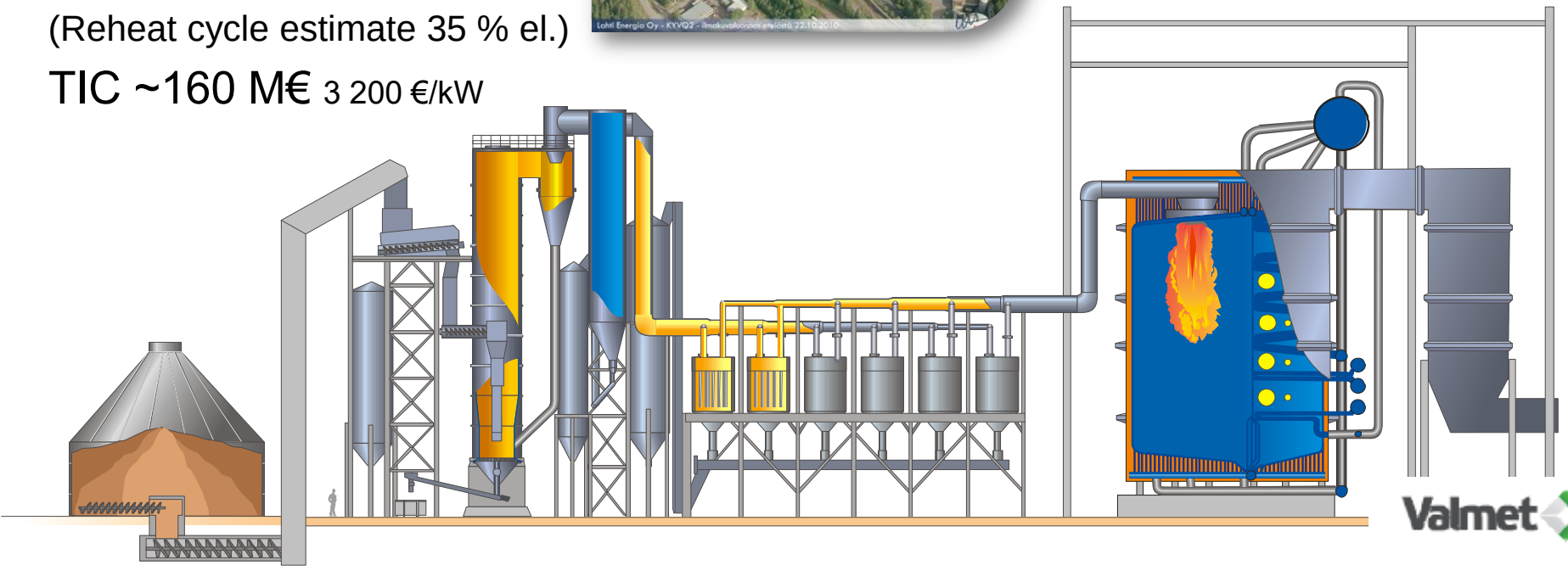
TIC ~160 M€ 3 200 €/kW

30 000 op. hrs 2012 to 2016

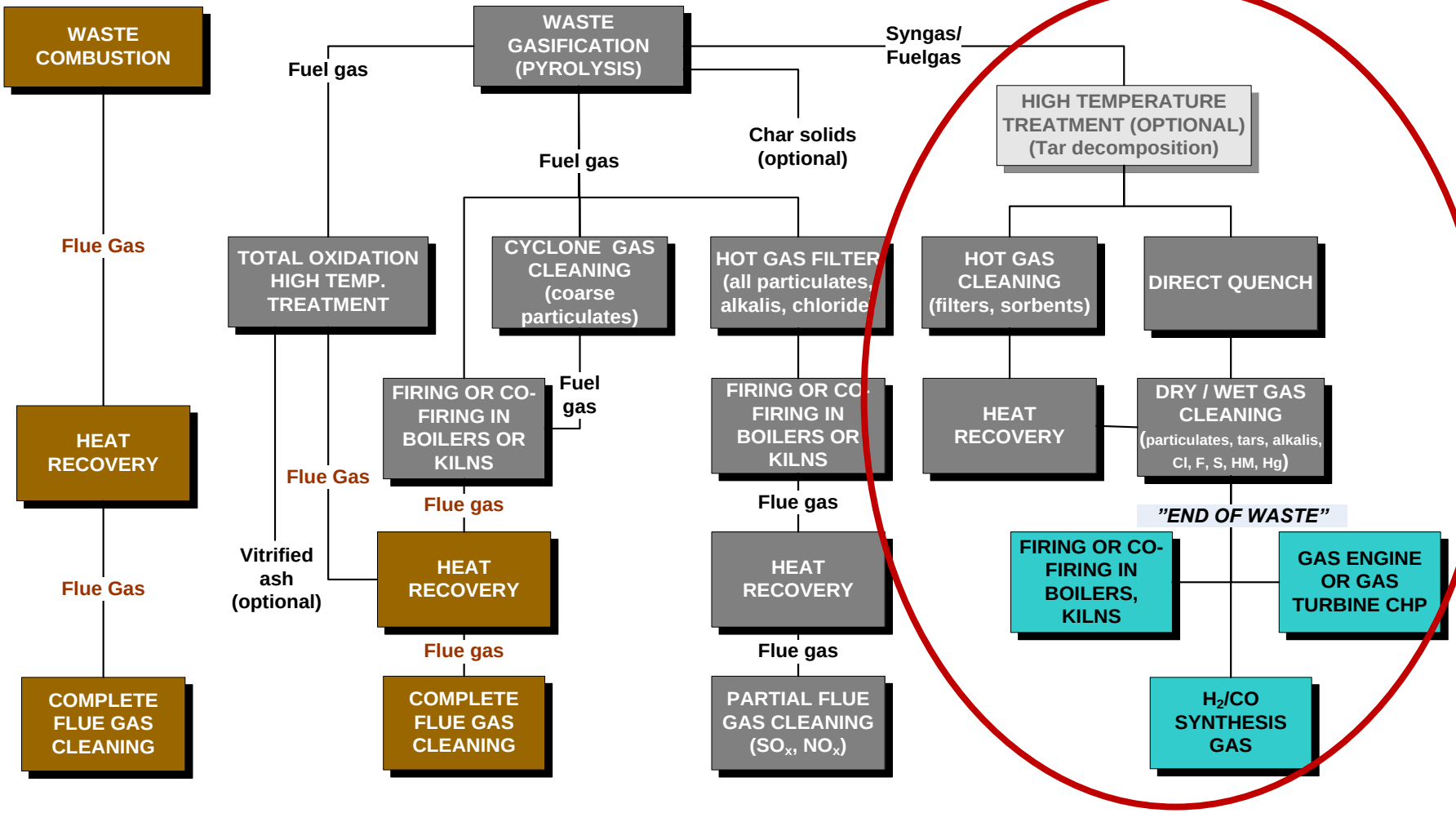
Fuel quality an issue.

Gas filter new feature, maintenance, learning.

Gas firing, emissions OK, no corrosion in boiler or gas cooler



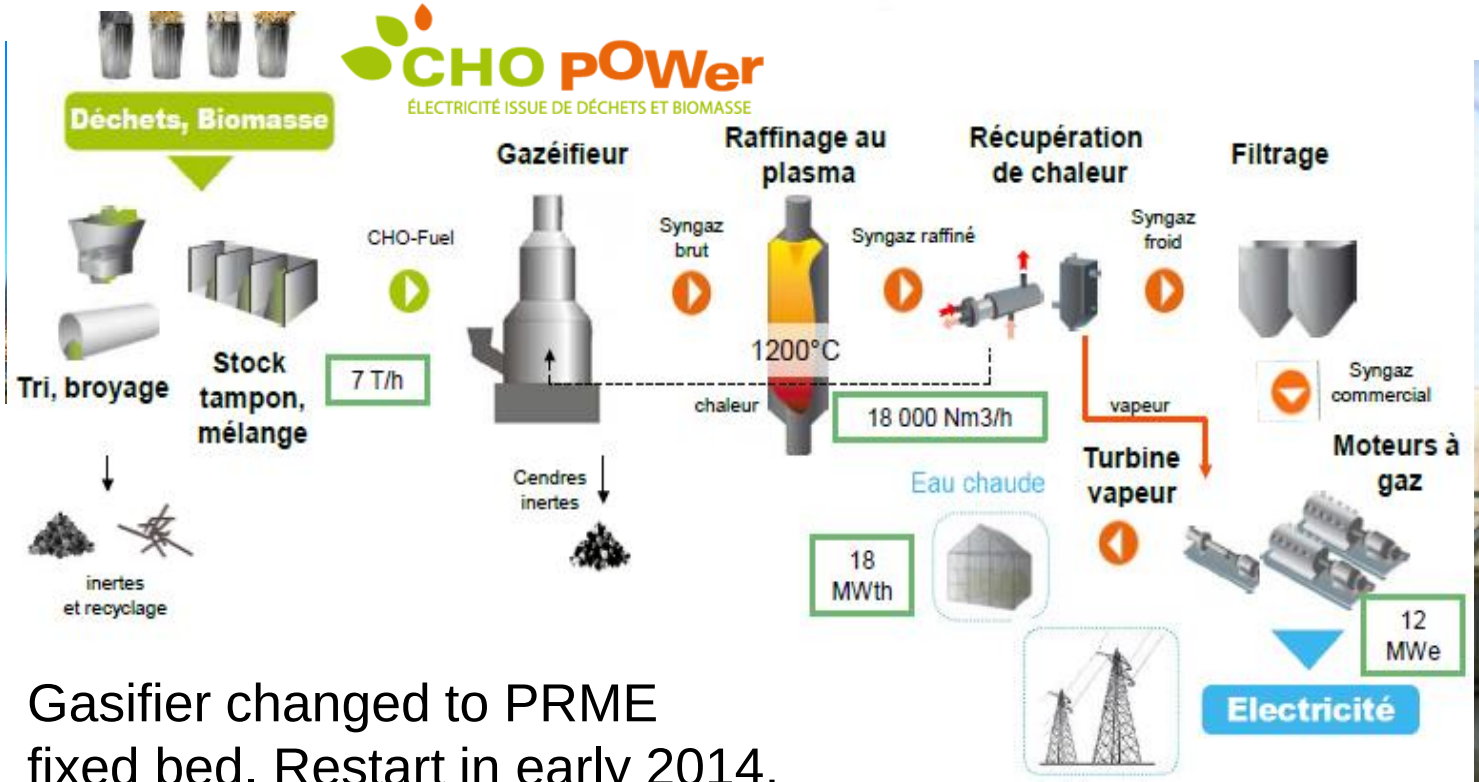
Technologies, applications



(Europlasma) CHO Power, CHOPEX, France

Morcenx

12 MW_e+18 MW_{th} plasma gas cleaning system, start 2012
Insolvency + refinancing + re-enginering in 2013



Gasifier changed to PRME fixed bed. Restart in early 2014,
Acceptance tests mid-2017.
3 projects in development in France

Construction worker.

Other developments, France and UK

LLT, Villers-sous-Montrond

CFB gasifier + thermal tar reactor + gas cleaning system + motors, 7 MW_e + 10 $MW_{th.}$

In construction to start in 2018

SynTech Bioenergy Centre Ltd, Wednesbury

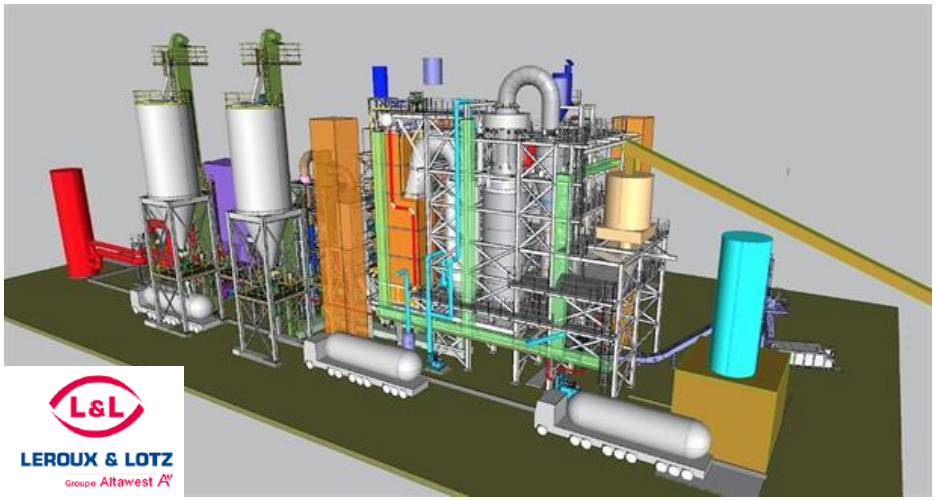
Parent of **Frontline Bioenergy** LLC.

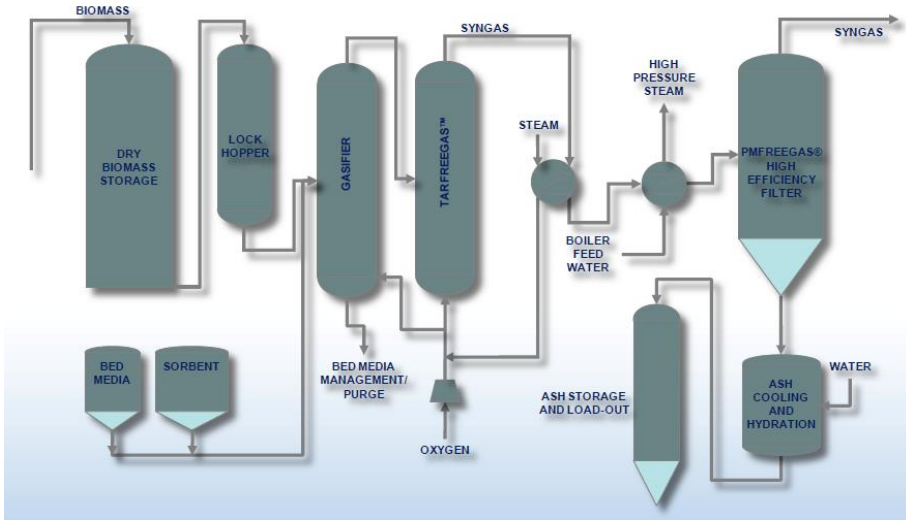
40 ton/day RDF, 1.5 MWe, some CHP

Press. O2-blown FB, thermal reformer, gas cleaning to “end-of-waste”, high-efficiency engine

10 million £ cost, 50 % from ETI

Mechanical completion end of 2017





Air Products, Ineos

Teesside, UK

2 *350 000 ton/year waste
Each 49 MW_e gross, 37 MW_e net.
AlterNRG atm. Plasma gasifiction,
2*Solar Titan GT-CC per unit
Ext. pre-combustion gas cleaning
Investment 500 million $ per unit
Commissioning in 2014.
Both projects stopped in 2016

Vero Beach, FL

Biomass waste, MSW
Syngas fermentation
30 000 m^3 of ethanol, 6 MW_e gross
Oxygen-blown two-stage gasifier
130 million $.
Commissioning late 2012,
reengineering in 2014 and restart.
Ineos stopped activities in 2016.

GoGreenGas

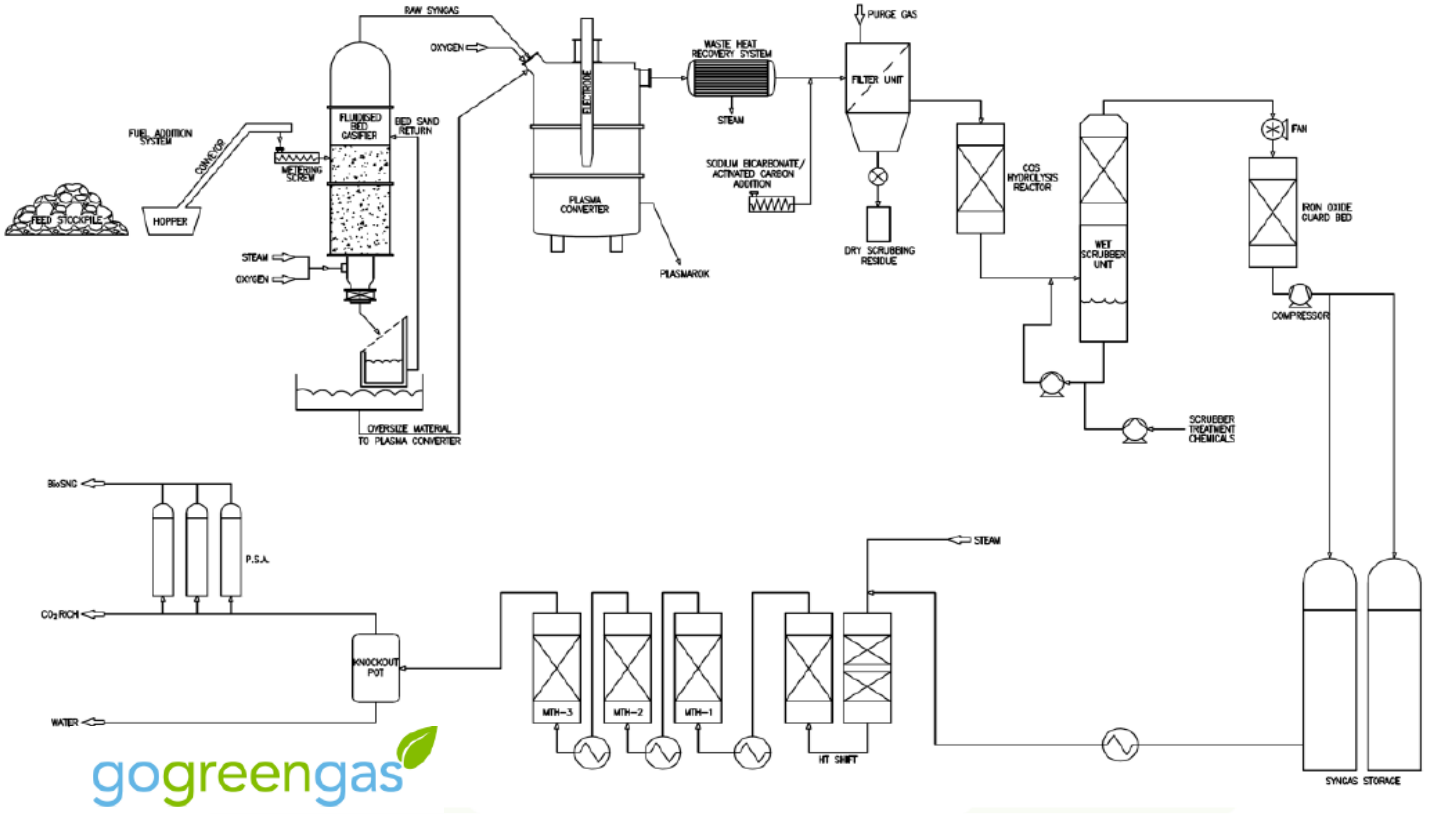
27 M£, 4.4 MW SNG Demo in construction in Swindon to start 2018.

Support 11M£ Dep. Of Transport, 5 M£ Ofgem

Partners Cadent (8.7 M£), APP, Carbotech, Progressive Energy

APP gasification (Outotec oxygen-blown FB gasifier, plasma reformer)

AMEC Foster Wheeler gas conditioning, synthesis



gogreengas

Enerkem, Edmonton, Kanada

100 000 ton per year RDF plant. Product 38 000 m^3 of methanol/ethanol
Commissioning initiated 2013, installed ethanol step 2016.
Ramping up production in 2018.

Plans for 220 000 m^3 methanol in Rotterdam for plastic wastes

EP ENVI RED II Amendments

Annex IX Part A. Feedstocks for the production of advanced biofuels ~~and fuels, the contribution of which towards the target referred to in the first subparagraph of Article 3(4) shall be considered to be twice their energy content~~:

(a) Algae if cultivated on land in ponds or photobioreactors.

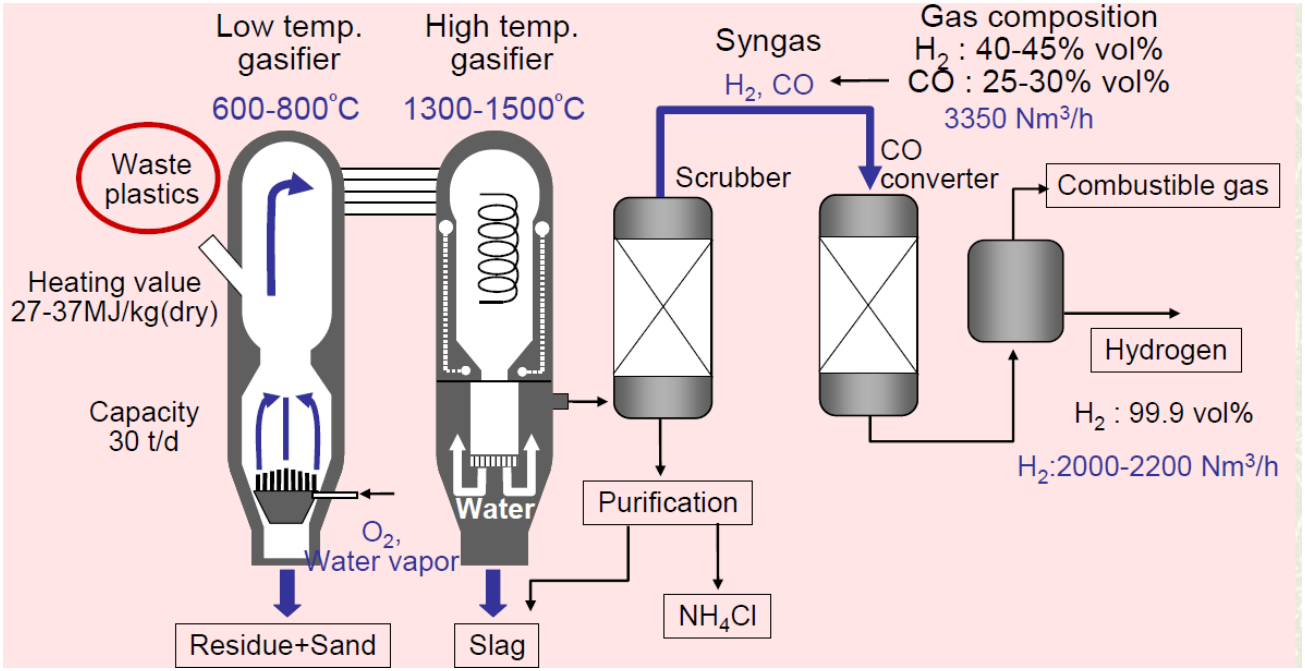
(b) ~~Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.~~

(c) Bio-waste as defined in Article 3(4) of Directive 2008/98/EC ~~from private households~~ subject to separate collection as defined in Article 3(11) of that Directive.

(d) Biomass residues resulting from ~~other renewable fraction of~~ industrial production ~~waste~~ not fit for use in the food chain, or feed chain or for reprocessing into not food material. This includes ~~including~~ material resulting from retail and wholesale and the bio-based chemical productions, agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B of this Annex.

etc.

Ebara-Ube



Showa Denko K.K

EUP technology

64 kton/y plastic waste. Start-up 2003.

Syngas for hydrogen and ammonia

Expansion of the plant in 2015 to make 65 % of the hydrogen required for ammonia production

Thermochem Recovery Inc (TRI)

Directly-, indirectly-heated, fluidized bed steam reforming

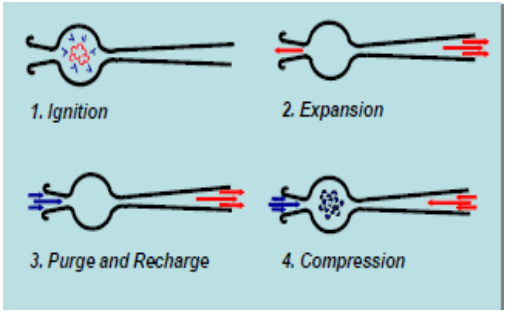
Black liquor gasifier in operation since 2006 (Norampac, Trenton, Ont.)

Pilot plant 4 ton per day w. integrated FT synthesis at Durham NC

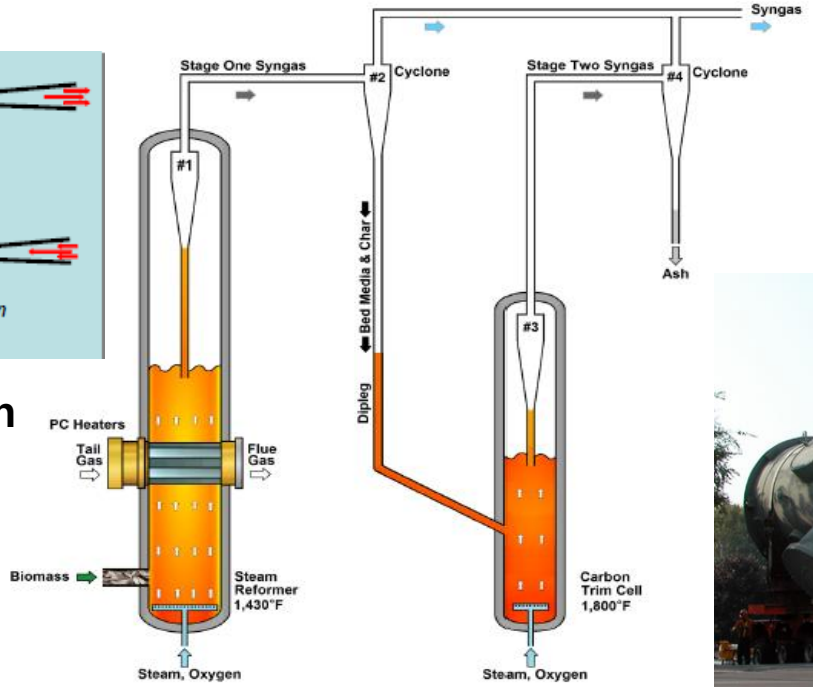
- Gasifier supplier to Fulcrum Sierra biofuels

  160 kton RDF, 40 000 m^3 FT fuels. Reached financial closure in 2017

- TRI is partnering with Velocys, BA for waste plants in the UK.



Pulsed combustion heat transfer



Waste gasification strategic aspects

−	Gasification-related factor	+

Waste available for thermal treatment

Waste reduction schemes	Land fill bans
Recycling targets	Special wastes, recycling
Conv. treatment overcapacity	

Economics of thermal treatment

General decline in power prices	Land fill bans and disposal cost
Expansion of RE power	R3 recovery as chemicals
Lower heat demand, heat pumps etc.	Biofuels incentives?
Carbon pricing for fossil part	
Investment costs to meet BAT	
Risk, new technology introduction barriers	

Other aspects of thermal treatment

Acceptance of waste-derived fuels	Land fill bans
New technology introduction barriers	Changes to R1 efficiency value?

Thank you for your attention

Gasification news available at
IEA Bioenergy Task 33 Thermal Gasification web page

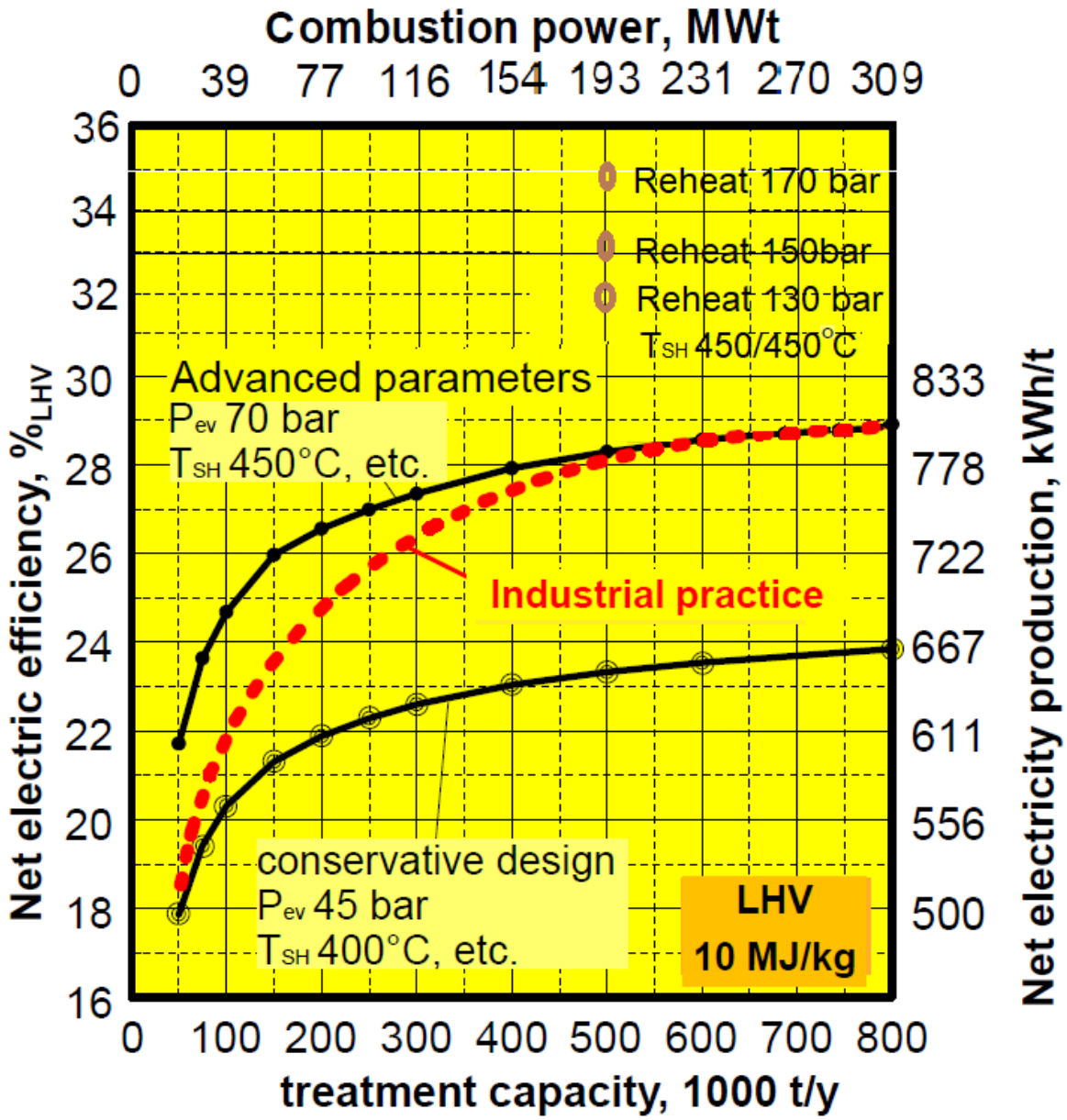
task33.ieabioenergy.com/

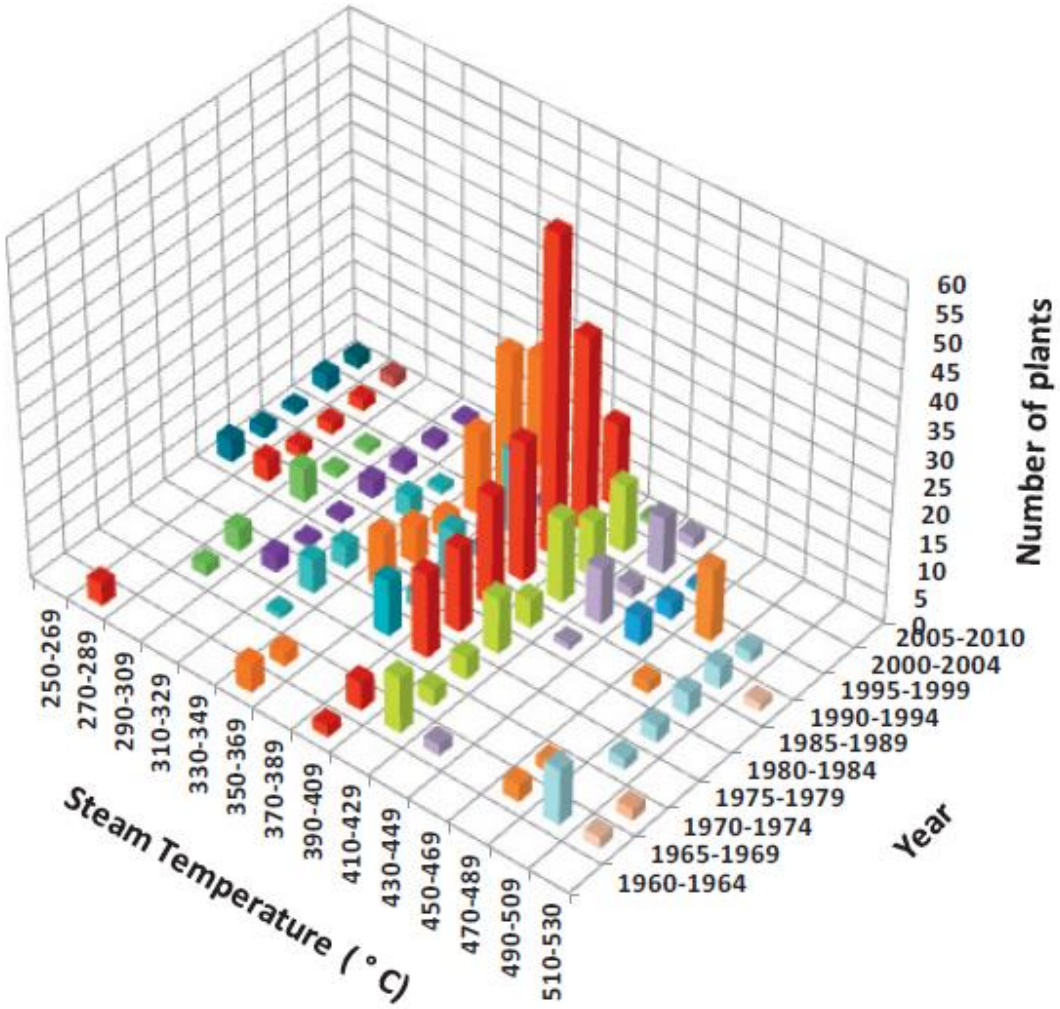
Limiting Emission Values

mg/Nm^3 dry gas @ 11 % O_2	EU Waste or Biomass firing (in brackets gas boilers, ICE,GT)			USA Waste Incineration 40 CFR Part 60			Japan	
Contaminant	IED	Biomass LCP >50 MW	Biomass MCP 1-50 MW	Large incinerators	Small incinerators	Biomass	Air Pollution Act**	Typical Client Criteria
Dust	10	13 (n.l)	13-33 (n.l.)	14	17	4	44-90	11
CO	50	66 (55, 166)	n.l.	15	45-180*	215	42	< 42
SO2	50	100-130 (20, n.l.)	130 (n.l.)	61 or 80 % red.	61 or 80 % red.	15	Site specific	160-175
NOx	200	100-130 (55, 83-125)	200-333 (316-333)	220	220	425	280-500	< 50
HCL	10			29 or 95 % red.	29 or 95 % red.	0.2	780	90-100

* Technology dependant. Mass brun lowest, stoker intermediate, fluid. bed highest

** The order establishing LEVs is undergoing revision and an amended order is expected shortly


Combustion power, MWt
0 39 77 116 154 193 231 270 309
36
34
32
30
28
26
24
22
20
18
16
Net electric efficiency, %LHV
833
778
722
667
611
556
500
Net electricity production, kWh/t
0 100 200 300 400 500 600 700 800
treatment capacity, 1000 t/y
Reheat 170 bar
Reheat 150bar
Reheat 130 bar
TSH 450/450°C
Advanced parameters
Pev 70 bar
TSH 450°C, etc.
Industrial practice
conservative design
Pev 45 bar
TSH 400°C, etc.
LHV
10 MJ/kg


Number of plants
60
55
50
45
40
35
30
25
20
15
10
5
0
Year
2005-2010
2000-2004
1995-1999
1990-1994
1985-1989
1980-1984
1975-1979
1970-1974
1965-1969
1960-1964
Steam Temperature (° C)
250-269
270-289
290-309
310-329
330-349
350-369
370-389
390-409
410-429
430-449
450-469
470-489
490-509
510-530