Workshop

Waste Gasification

08. May 2018, Petten, the Netherlands

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and

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Introduction

Gasification is a technology that allows conversion of solid fuels to synthesis gas (syngas) rich in hydrogen and carbon monoxide. The syngas can be used in combined heat and power (CHP) production and/or for production of biofuels and/or chemicals. Compared to other waste-to-energy methods like burning or incineration, the gasification process allows the syngas to be cleaned of contaminants prior to its use. Because of the range of materials found in waste and its comparatively unclean nature, it can be more challenging to process than other types of biomass.

In May 2018, IEA Bioenergy Task 33 (Gasification of Biomass and Waste) hosted a workshop on waste gasification together with ECN (Netherlands), who hosted the workshop. Nine presentations from seven different countries were given, which showed the breadth of technologies and applications. During a technical tour the day after the workshop, participants were able to visit two companies employing gasification technology, ESKA and Torrgas.

Creating syngas through gasification permits closing the loop on waste's lifecycle, thereby minimizing disposal of otherwise valuable components. Examples of closing the circle include the ESKA gasifier for recycle of reject paper products as well as Proerg's technology for gasification of poultry manure, which can produce power and heat for poultry producing companies.

As seen in this workshop, great progress is being made and today waste gasification is an actual technology. In this way several challenges such as e.g. waste disposal, CO_2 reduction and feedstock price can be addressed. This report provides a summary of the workshop presentations, highlighting critical advances and technology demonstrations.

Waste gasification

Workshop presentations

Waste gasification overview: two-stage incineration and "true" gasification

L. Waldheim, WaC, Sweden

Lars Waldheim has prepared a study on Waste gasification on behalf of the Task 33 and this study was presented here. The final version will be published at the Task 33 website at the end of 2018.

The content of the study will be as following:

1 Wastes as a gasifier fuel (not special or hazardous waste)

– Waste fuel characteristics and waste fuel standards
– Contaminants and emission precursors

2 Waste quantities and disposal
3 Regulatory considerations
4 Waste gasification and gas cleaning technologies

– General description
– Specific technologies in projects

5 Considerations for the use of the product gas

– Fuel gas
– Power and CHP
– Fuel and chemical products

6 Target market, technical requirements and barriers
7 Waste gasification developers, plants and projects

During the presentation, the definition of gasification, general purposes and waste-specific purposes were introduced as well as direct, indirect and multi-stage indirect gasifiers.

Industrial Emissions Directive 2010/75/EC was presented and definitions of waste incineration plant, waste co-incineration plant and end-of-waste conditions for waste gasification product gas was explained. In the following table fuel gas cleaning methods can be seen.

Table 1: Overview on 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			

Also sulfur removal is very important in gas cleaning; sulfur removal technologies are listed in the following table.

Table 2: 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*

As an example of waste gasification, Japanese waste gasification of Nippon Steel & Sumikin engineering Co. Ltd. Shaft furnace was presented as well as the Japanese MSW incinerator/gasifier market.

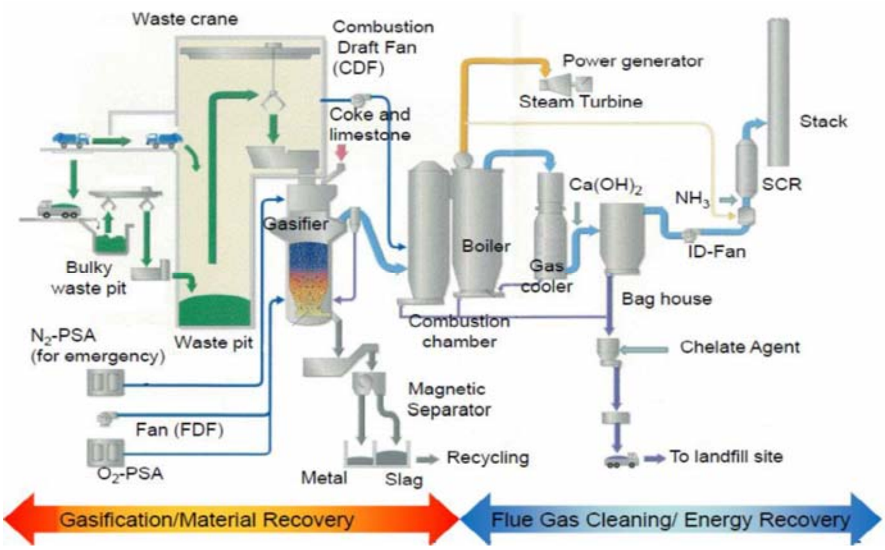


Figure 1: Nippon Steel & Sumikin engineering Co. Ltd. Shaft furnace

Further technologies presented: CEMEX Zementwerk Rüdersdorf, anhui conch Kawasaki Engineering Co. Ltd., ESKA graphic paper, Kymijärvi II in Lahti, CHO Power, CHOPEX in France, LLT Villers-sous-Montrond, SynTech Bioenergy Centre Ltd. etc.

In the following table a waste gasification strategic aspects are summarized with pros and contras.

Table 3: Waste gasification strategic aspects

Disadvantages	Gasification related factors / Advantages
Waste available for thermal treatment	
Waste reduction schemes	Landfill bans
Recycling targets	Special wastes, recycling
Conv. treatment overcapacity	
Economics of thermal treatment	
General decline in power prices	Landfill bans and disposal cost
Expansion of RE power	R3 recovery as chemicals
Lower heat demand, heat pumps etc. Carbon pricing for fossil part	Biofuels incentives?
Investment costs to meet BAT	
Risk, new technology introduction barriers	
Other aspects of thermal treatment	
Acceptance of waste-derived fuels	Landfill bans
New technology introduction barriers	Change to R1 efficiency value?

Valmet CFB gasifier

J. Isaksson, Valmet, Finland

Construction principle of the Valmet gasifier:

- rugged steam frame
- self-standing structure
- prefabricated refractory
- fuel feed with air lock
- 100% redundant systems for fuel and ash handling

Valmet CFB gasifier applications:

- product gas for industrial kilns
- product gas for power boilers
- product gas from waste for power production

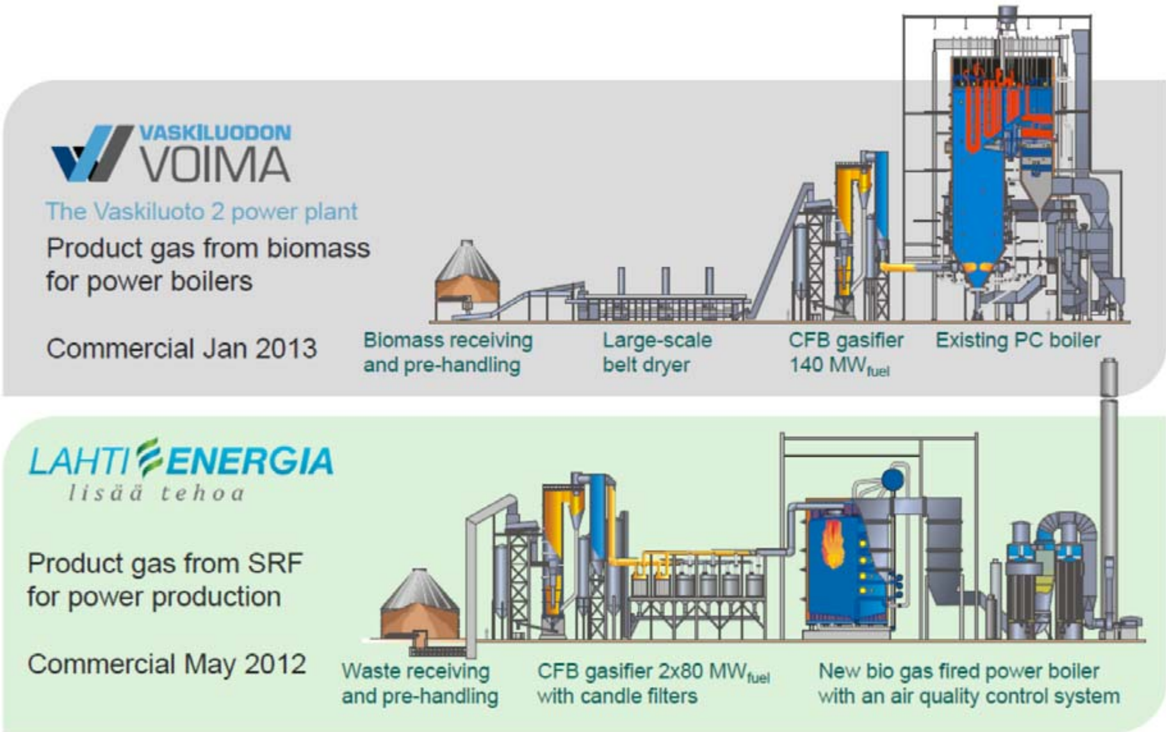


Figure 2: Plants in commercial operation

Vaskiluodon Voima Oy gasification project

- Existing 560 MW coal-fired power plant
- Adjoined a 140 MW biomass gasifier and dryer
- Up to 40 percent replacement of coal by local fuel sources
- biomass feed 140 MW, chipped or crushed biomass (forest and industrials residues, bark, stump, round wood, etc.)
- biomass replaces 25-100% of coal depending on the boiler load

Schedule:

- contract signed in June 2011, plant in operation 12/2012
- total project costs < 40 M€, below 700 €/kWe

Vaasa biomass gasifier

- a major, cost effective power plant fuel conversion from coal to wood biomass with a short implementation time
- existing, pulverized fuel fired boiler was utilized with minimal changes
- up to 40% fuel to power efficiency for woo biomass in a condensing mode

Kymijärvi II – waste gasification plant

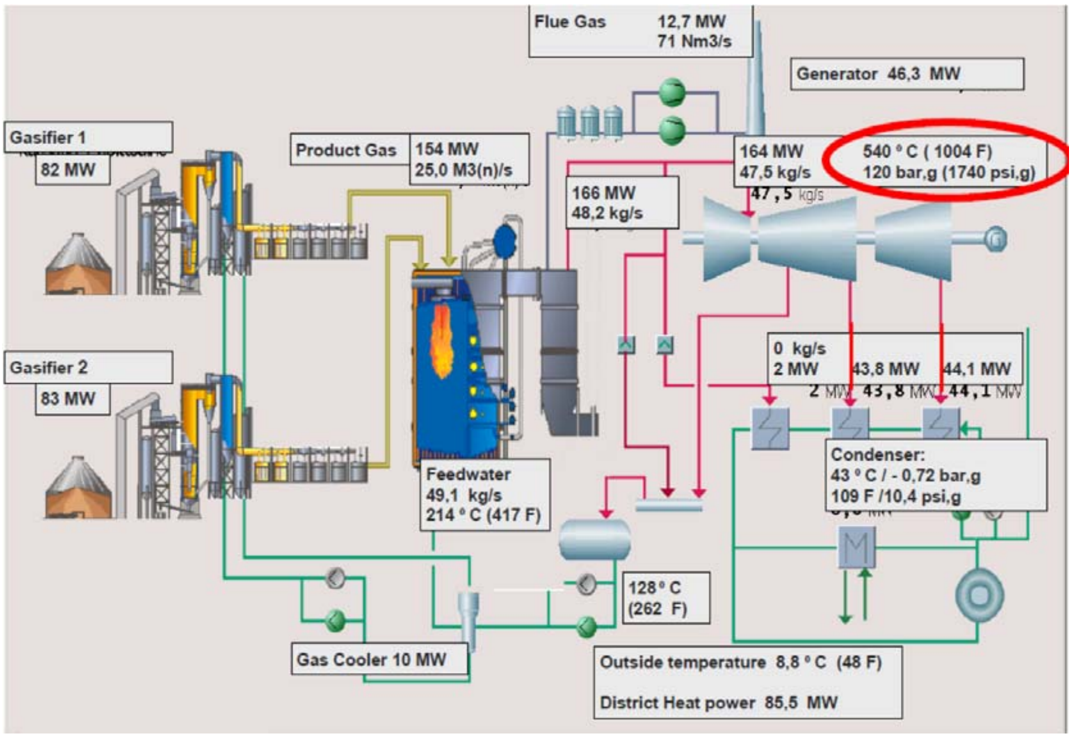


Figure 3: Scheme of Kymijärvi II

- world´s largest waste gasification plant in operation since 2012
- over 1 million tons of gasified waste
- main improvements:
    - filter regeneration unit
    - recirculation of bottom ash and chemical in APC
    - rotary feeders and fuel feeding
    - control and operational praxis
    - safety and maintenance praxis

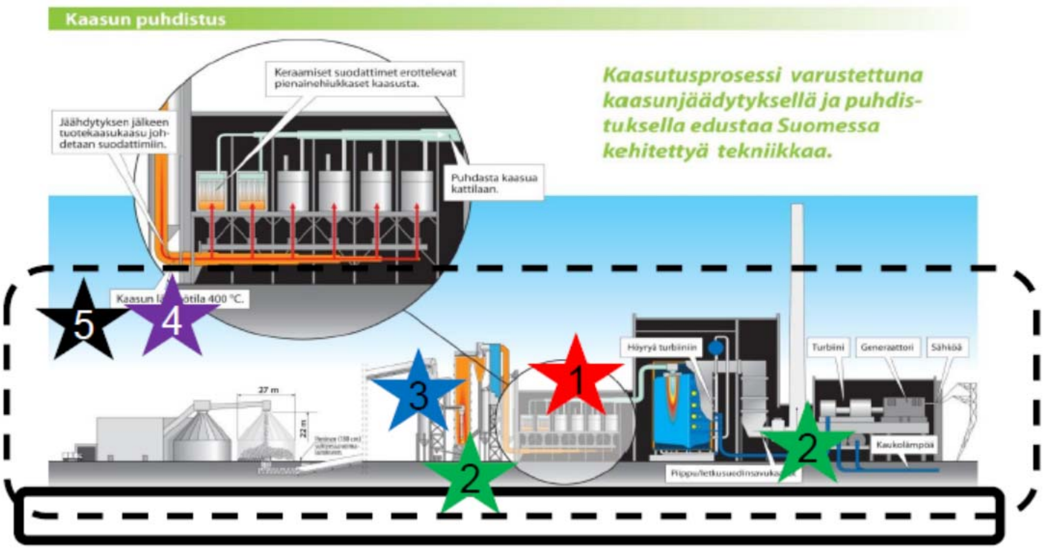


Figure 4: Main improvements of the Kymijärvi II plant

Lime kiln gasifiers:

- Chenming Huanggang, China, 2018 – under construction
    - gasifier 50 MW
    - dryer evaporation 12 t/h
- Metsä Fibre Äänekoski, Finland, 2017 – operational
    - gasifier 87 MW
    - dryer evaporation 23 t/h
- APP OKI, Indonesia, 2017 – operational
    - gasifier 2x110 MW
    - dryer evaporation 2x 19 t/h

A new concept for co-firing RDF/SRF

- Combines positive experiences from Lahti and Vaskiluoto => Co-firing of cleaned gas from waste gasification in an existing boiler
- Minimum impact on boiler operation, corrosion, ash quality and emissions
- Highest electrical efficiency from waste to electricity
- Utilization of the existing power plant infrastructure
- Efficient way to use biomass or waste fuels and reduce GHG emissions
- Investment is reduced compared to a new EfW facility by 40-60%

Valmet waste gasification – next steps:

1. corrosion is not limiting the steam cycle selection
2. improved reliability with double hot gas filter concept

Commercially proven solutions:

- high efficiency WtE technology for el. production
- partial or complete fuel change in existing power plants
- firing of industrial processes with gasified biofuel or waste

SYNOVA: Waste-to-energy

B. van der Drift, Synova, the Netherlands

SYNOVA acquired Dahlman Renewable Technology (DRT) in 2017 and a Joint Venture was created between SYNOVA/DRT and ECN/TNO in 2017: MILENA gasification and OLGA tar removal.

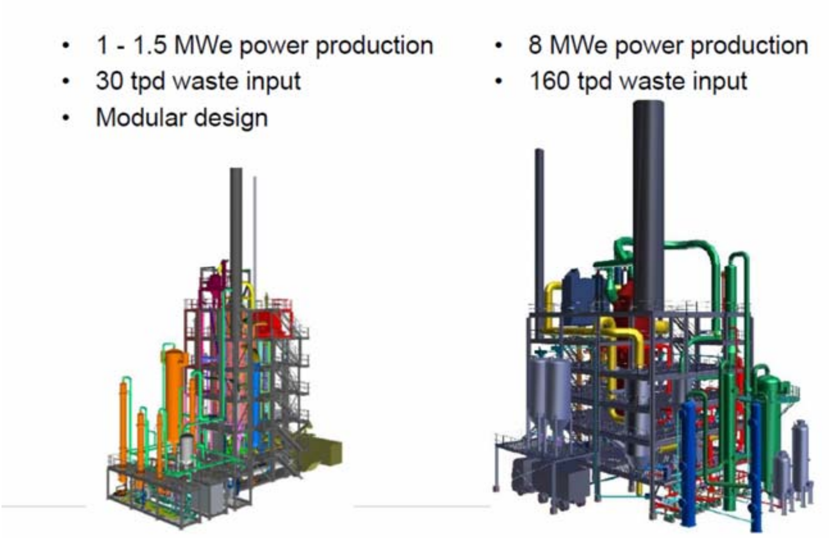


Figure 5: Synova plants

Project M30:

- Thailand
- materials recycling facility for 350 t/d MSW to RDF
- 8 MWe net output

EQTEC: From RDF to SNG – Previous experiences to overcome gasification challenges

C. Berrueco Moreno, EQTEC, Spain

EQTEC focuses on RDF, which is an “opportunity” resource and will produce SNG, a competitive fuel.

A price overview is given below:

- ✓ Gasoline: 574 $/T: 55 €/MWh
- ✓ Diesel: 858 $/T: 69 €/MWh
- ✓ Bioethanol: 713 $/T: 85 €/MWh
- ✓ Biodiesel: 945 $/T: 83 €/MWh

- ✓ Bio SNG:
  - ~ 40-65 €/MWh ⟶ Plant capacity > 50 MWt
  - ~ 60-120 €/MWh ⟶ Plant capacity < 5 MWt
- ✓ SNG from RDF: ~ 25-40 €/MWh
- ✓ Reduction of emissions
- ✓ CO_{2eq} much lower
- ✓ Waste valorization & other social benefits

In the following figure, the process technology can be seen.

The pretreatment of the feedstock is crucial for the process, feedstock is highly heterogeneous and contains contaminants such as sulphur, chlorine and heavy metals. The moisture content must be held about 15wt%, which is why the dryer is needed.

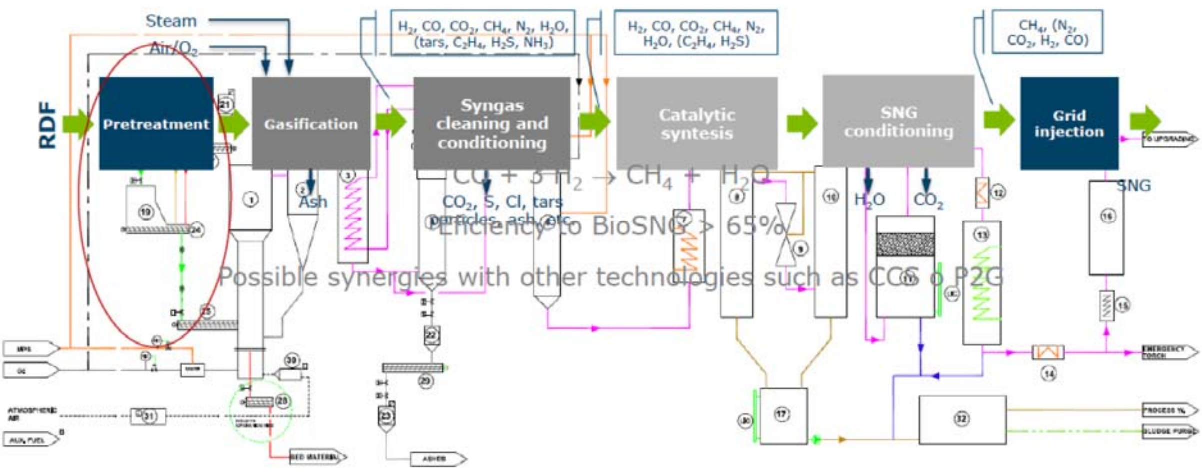


Figure 6: EQTEC process technology

EQTEC gasification is based on a bubbling fluidized bed technology with O_2/steam mixture as oxidizing agent, and two stages gasification: steam gasification and air combustion.

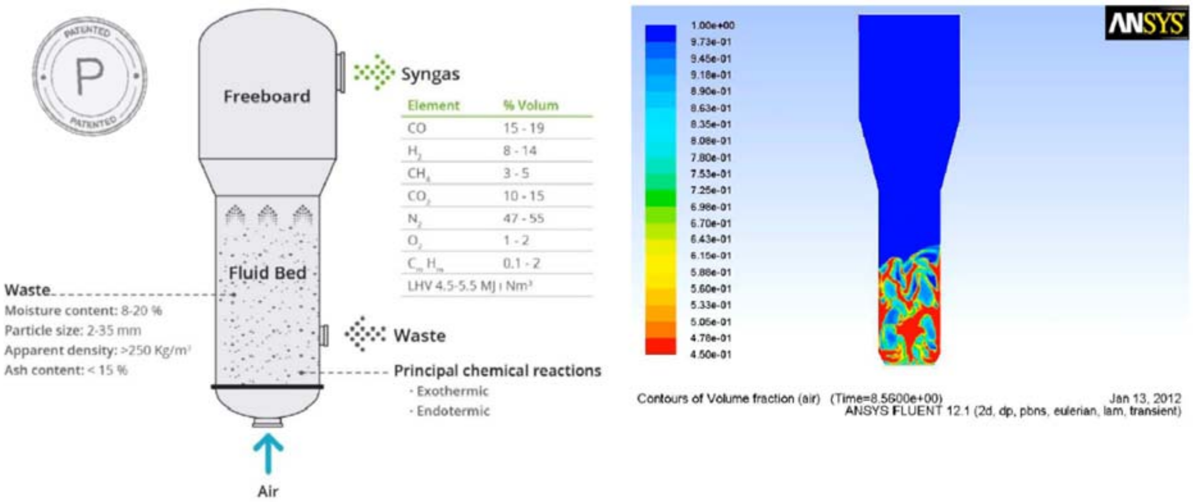


Figure 7: EQTEC gasification

The syngas cleaning is a key point of the technology; the contaminants in syngas can be seen in the following table. Carbon can cause catalyst deactivation (tar, BTX, etc.) and particles as well as N, S, Cl compounds catalyst poisoning.

Table 4: Contaminants in syngas

Contaminant	Typical concentrations in syngas	Engine	Catalytic synthesis
Tar	10000-15000 mg/Nm³	< 55 mg/Nm³	5 mg/Nm³
Particles	10000 mg/Nm³	< 50 mg/Nm³	10 mg/Nm³
Alkalis (Na+K)	1600 mg/Nm³	-	1 mg/Nm³
NH_3 (+HCN)	3000 ppmv	< 55 mg/Nm³ (N total)	100 ppmv (Total N)
Sulphur (H_2S, COS, CS_2)	100 ppmv	< 1150 mg/Nm³ (S total)	0.2 ppmv (Total S)
Halogens (HCl, HF, HBr)	25000 ppbv	< 100 mg/Nm³ (Total halogens)	<25 ppbv (Total halogens)
Heavy metals	< 300 mg/Nm³	-	<1 mg/Nm³

Integrated RDF & biomass gasification plant in Gallina, Italy:

- feedstock 900 kg/h of straw pellets
- reduced gasification temperature
- development of high temperature filter
    - Optimization of filtering temperature to retain heavy metals and avoid tar deposition on the filter candles

EQTEC participates in the POLYGEN project.

Reject gasifier ESKA

A. J. Grootjes, ECN, the Netherlands

The ESKA gasifier processes 25 kt/a paper rejects to produce steam for direct use in the cardboard production line in Hoogezand. In this way natural gas driven CHP is replaced/reduced and residues are disposed. The ESKA´s cycle is closed.

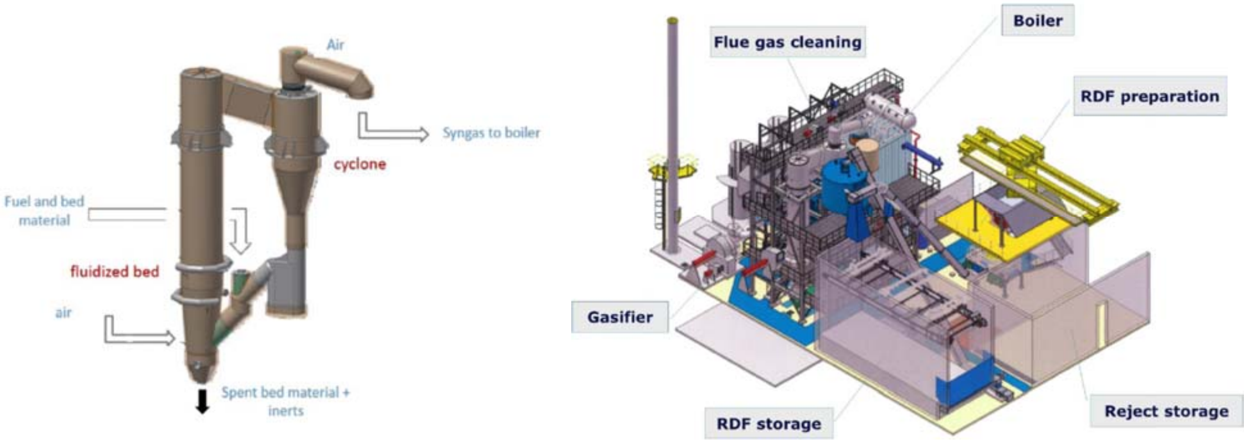


Figure 8: Reject gasifier ESKA

Gasifier features:

- 10-13 MWth input
- boiler produces 5-16 ton/h steam (196°C, 13,6 bar)
- system engineered and built by Leroux & Lotz in 2016, in operation in 2017
- fully automatic operation
- current challenges:
    - not always full capacity
    - large variation in LHV and composition
    - blockages of gasifier, boiler and ash-handling
    - broken thermal expansion joints
    - not yet fully automatic operation

TKI-toeslag project ESKAGAS

- Applied research project of ECN and ESKA, funded by TKI-BBE and ESKA
- The project focuses on options for valorization of the product gas of the paper rejects gasifier by co-production of high value products
- Quantification and value analysis of the co-products, their impact on the ESKA case and co-production routes are subjects in the ESKAGAS project
- The research results of this project can be used for other gasification technologies and projects, like the projects in Alkmaar (SCW, Ambigo) or Amsterdam (Blue Planet)
- Co-production is possibly the next step for these projects to prove that sustainability and value can be further increased

Table 5: Gas composition

Main gas components, dry basis (vol%)	March 20	March 21
CO	5.4	6.3
H_2	5.2	2.8
CO_2	15.5	14.7
CH_4	3.4	2.6
N_2	66.1	n.m.
C_2H_2	0.1	n.m.
C_2H_4	2.4	n.m.
C_2H_6	0.1	n.m.
Benzene	0.8	n.m.
Toluene	0.1	n.m.
Ar	0.8	n.m.
Total	99.9	n.m.
H_2O (wt%)	38	26

Trace components, dry basis (ppmv)	March 20	March 21
Sum C_3	228	196
Sum C_4	251	302
Sum C_5	67	84
Sum C_6	0	0
H_2S	52	n.m.
COS	37	20
Thiophene	5	6
Methylmercaptane	0.26	0.13
Other S-organics	3	3
Tar (g/Nm3)	17	12

Even without subsidy is this plant economically feasible and considering the challenging feedstock, the system operates very well.

Co-production of BTX seems technically feasible.

Waste gasification in fluidized bed for cogeneration application – Terracotta collaborative project

M. Insa, EDF, France

Focus of EDF is combustion, but EDF is in gasification active as well.

A pilot plant in Epinal can be seen in the following figure.

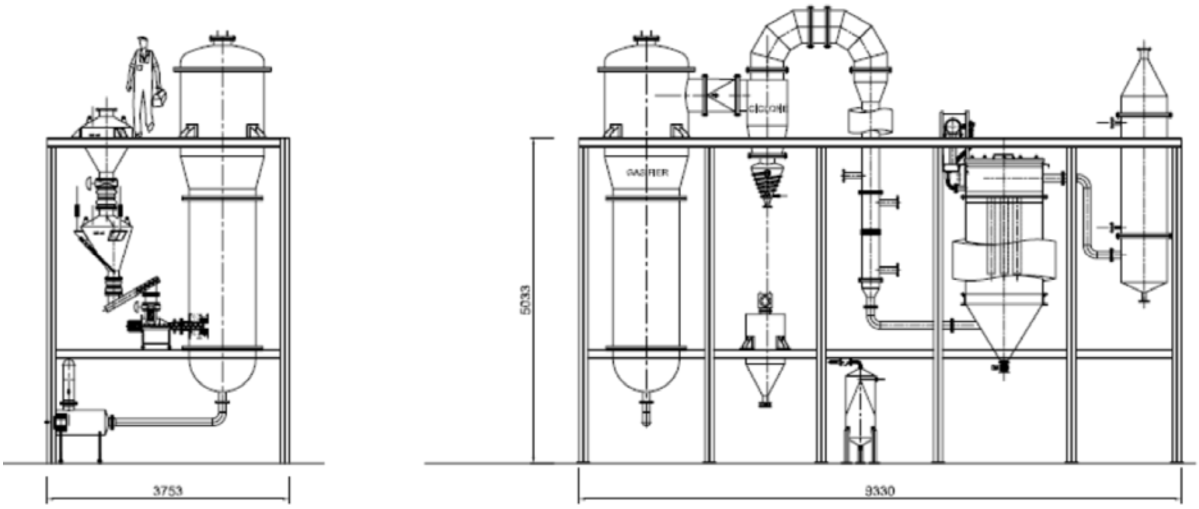


Figure 9: EDF gasification – pilot plant in Epinal

EDF is also involved in the TERRACOTTA project as coordinator and end-user.

TERRACOTTA keydata:

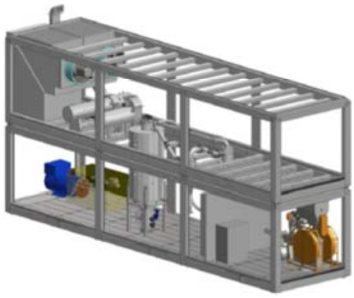
- 6 partners: LRGP, LERMAB, EQTEC, EDF, DPIT, TIRU
- duration 32 months (since 2016)
- 4 technical work packages:
    - preparation and characterization of SRF
    - tests in lab plant
    - tests in pilot plant in representative environment
    - preliminary study of process industrialization
- budget / ADEME financial contributions: 651 k€/299 k€

Poultry manure gasification with a small CHP plant

R. Andreatta, Proerg, Italy

Gasification unit features:

- downdraft gasifier
- Otto-cycle engine
- feedstock:
  - waste wood
  - poultry manure
  - sewage sludge
  - dried fruit shells
  - grape waste
  - coffee waste
  - olives cakes



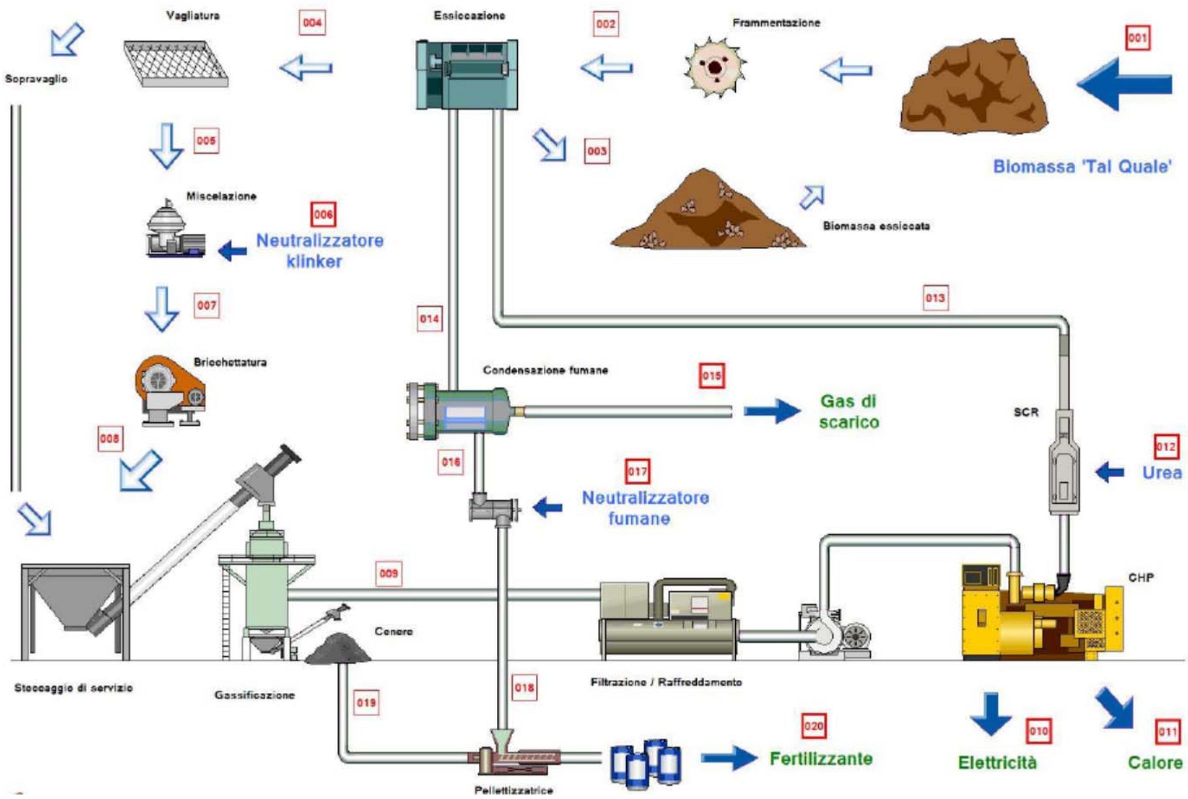


Figure 10: Gasification unit and process diagram

Poultry manure has a high ammonia and high ash content as well as low ash fusibility temperature, which makes this feedstock challenging. One way how to solve those problematic issues is to input additives to increase the ash melting temperature.

Lignin gasification – the AMBITION project

E.T. Liakakou, B.J. Vreugdenhil

The aim of the Ambition project is advanced biofuel production with energy system integration.

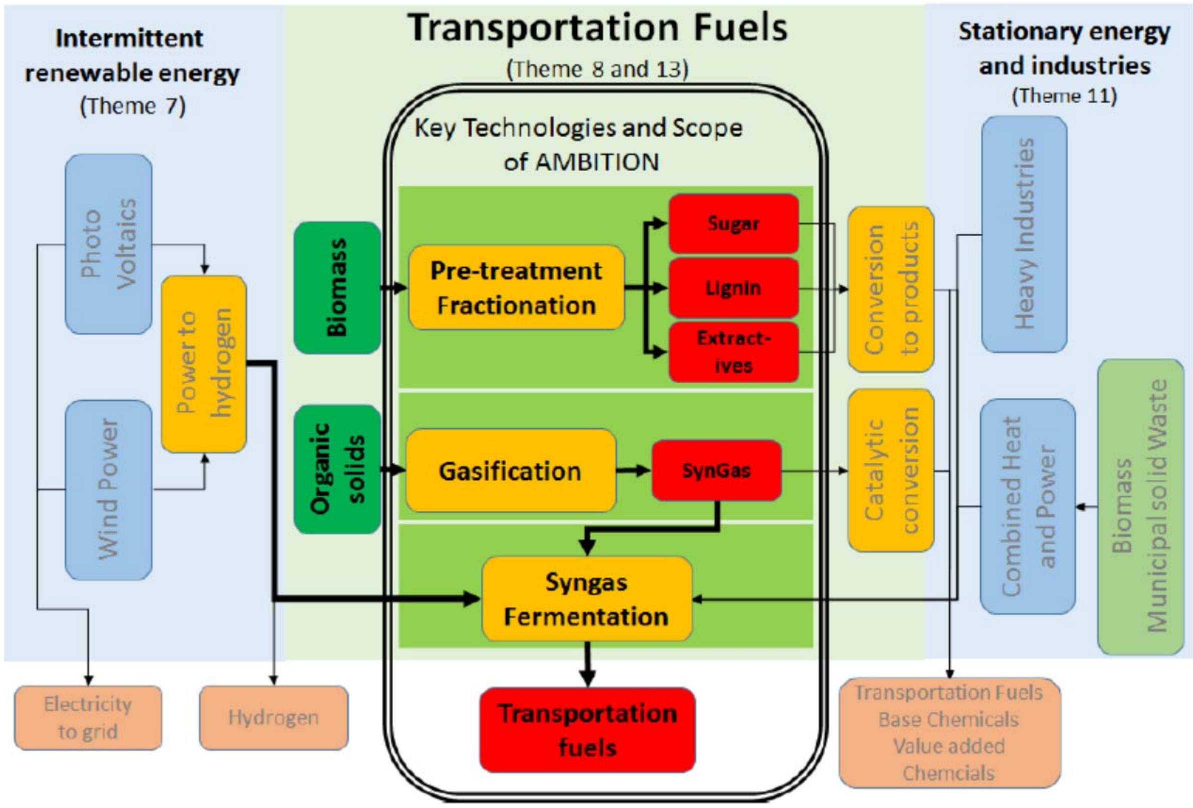
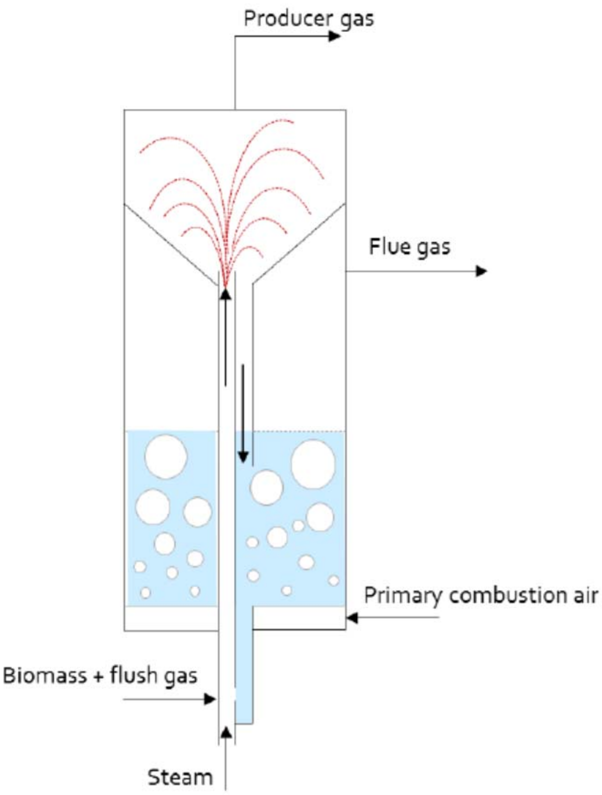


Figure 11: Scope of the AMBITION project

The specific objective is gasification and gas cleaning:

- Valorization of biorefinery residues by adapting existing gasification technologies
- Increase process efficiency by utilizing the lignin-rich residue, in combination with the development of energy-efficient, economically viable pathways for syngas cleaning and syngas fermentation
- Comparison between different gasification technologies focusing on gas quality
    - Fixed bed gasification (typically at smaller scale → good match with the fermentation technology)
    - Fluid bed direct gasification (flexible in feedstock, mature technology)
    - Indirect gasification (produces a high value gas → co-production schemes to maximize the value from the feedstock)



Milena indirect gasification:

- high efficiency, low steam use, no ASU
- 12-15 MJ/Nm^3, low N_2
- heat transfer through bed material circulation
- 30 kW lab scale and 800 kW pilot scale
- Complete biomass conversion: ~80% to product gas & the remaining char is converted in the combustor in order to keep a good energy balance

Figure 12: Scheme of Milena gasification

Table 6: Lignin characteristics and product gas composition

On dry basis	C (wt%)	O (wt%)	H (wt%)	N (wt%)	S (wt%)	Cl (wt%)	Ash (wt%)	Volatiles (wt%)	LHV (MJ/kg)
Lignin A	47.2	33.0	5.6	**1.3**	**0.18**	**0.020**	**14.0**	65	18.4
Lignin B	**57.7**	33.8	6.2	**0.8**	**0.13**	**0.002**	0.1	72	22.9
Beech wood	47.5	48.8	6.4	0.2	0.02	0.010	1.3	81	17.8

Main gas components, dry basis (vol%)	Lignin A	Lignin B
CO	13.9	15.6
H_2	**8.6**	**14.1**
CO_2	17.9	18.0
CH_4	5.9	6.9
N_2	45.1	39.2
C_2H_2	0.1	0.3
C_2H_4	2.8	2.0
C_2H_6	0.3	0.1
Benzene	**0.5**	**0.7**
Toluene	**0.1**	**0.1**
Ar*	2.1	2.2
Trace components	2.3	1.1
H_2O (wt%)	42.6	42.1
H_2/CO	0.62	0.90
Product gas flow (L/h)	2960	2970
Product gas energy LHV (kW)	8.0	7.7

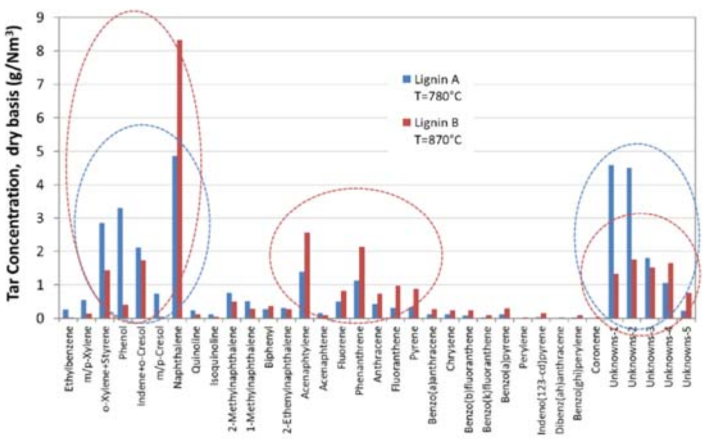


Table 7: Summary of results of lignin A and B

	Lignin A	Lignin B
Feedstock preparation:	Dried, milled, sieved to 6mm (2 wt% moisture)	Dried, pelletized, milled to <10mm (17 wt% moisture)
Difficulties in the gasification process due to:	Dense particles	Dense particles & fines
Average gasification temperature:	780°C	870°C
Total tar concentration in product gas (dry basis, vol%):	0.60	0.45
BTX concentration (dry basis, vol%):	0.6	0.8
Impurities concentrations (NH_3, HCN, H_2S):	High	Lower
Total NOx concentration in the flue gas:	570	370
Overall CGE (%, LHV):	< 60	< 70
Carbon conversion to product gas (wt%):	55-67	60-67

i-Milena (BFB) could be used for lignin gasification. Because of the longer fuel residence time the conversion to product gas will be increased. Optimum process conditions for primary tar reduction (excess of steam is available and better contact with catalytic bed material) can be achieved.

Electricity from wood for 2 €cents/kWh

M. Huber, Syncraft, Austria

Syncraft focuses on staged gasification of forest residues, but also waste wood is an option, which is challenging based on many factors:

- pretreatment – huge difference in pre-treatment step; a homogenous structure is the key to ensure proper operation
- contaminants – heavy metals, Cl, S, N

In 2019 a 400 kW demonstration plant will be finished in Austria.

Electricity costs with waste wood and production of activated carbon can be seen in the figure below. As can be seen in the figure, the electricity costs could be as low as 2 €cents/kWh if heat benefit as well as charcoal benefit were taken in account.

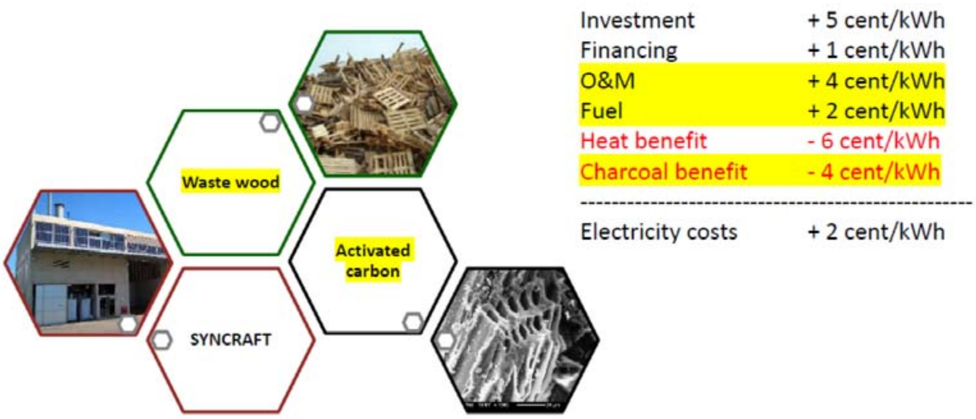


Figure 13: Electricity costs

Summary

In May 2018, IEA Bioenergy Task 33 hosted a workshop on waste gasification together with ECN. In the workshop nine interesting presentations were given, beginning with an overview on waste gasification, which is also a Task project for the 2016-2018 triennium.

The focus of the workshop was on industrial-scale implementation of waste gasification technology. Several companies, including ECN (Netherlands), EDF (France), EQTEQ (Spain), Proerg (Italy), Syncraft (Austria), Synova (Netherlands) and Valmet (Finland) presented their technology in the area of waste gasification. The gasifier of ESKA, which processes paper rejects, was introduced in a workshop presentation and was also one of the stops on the technical tour held the day after the workshop.

The workshop demonstrated that waste gasification technology is a reality and that there are industrial plants operating in many countries throughout Europe. The presentations also highlighted the range of designs and flexibility of gasification to be able to process various qualities of feedstock and to produce a range of products including heat, electricity, fuels and activated carbon.

All workshop presentations are online available at the Task 33 website.