# Gasification of fermentation residues from second generation ethanol for production of hydrogen rich syngas in a pilot plant

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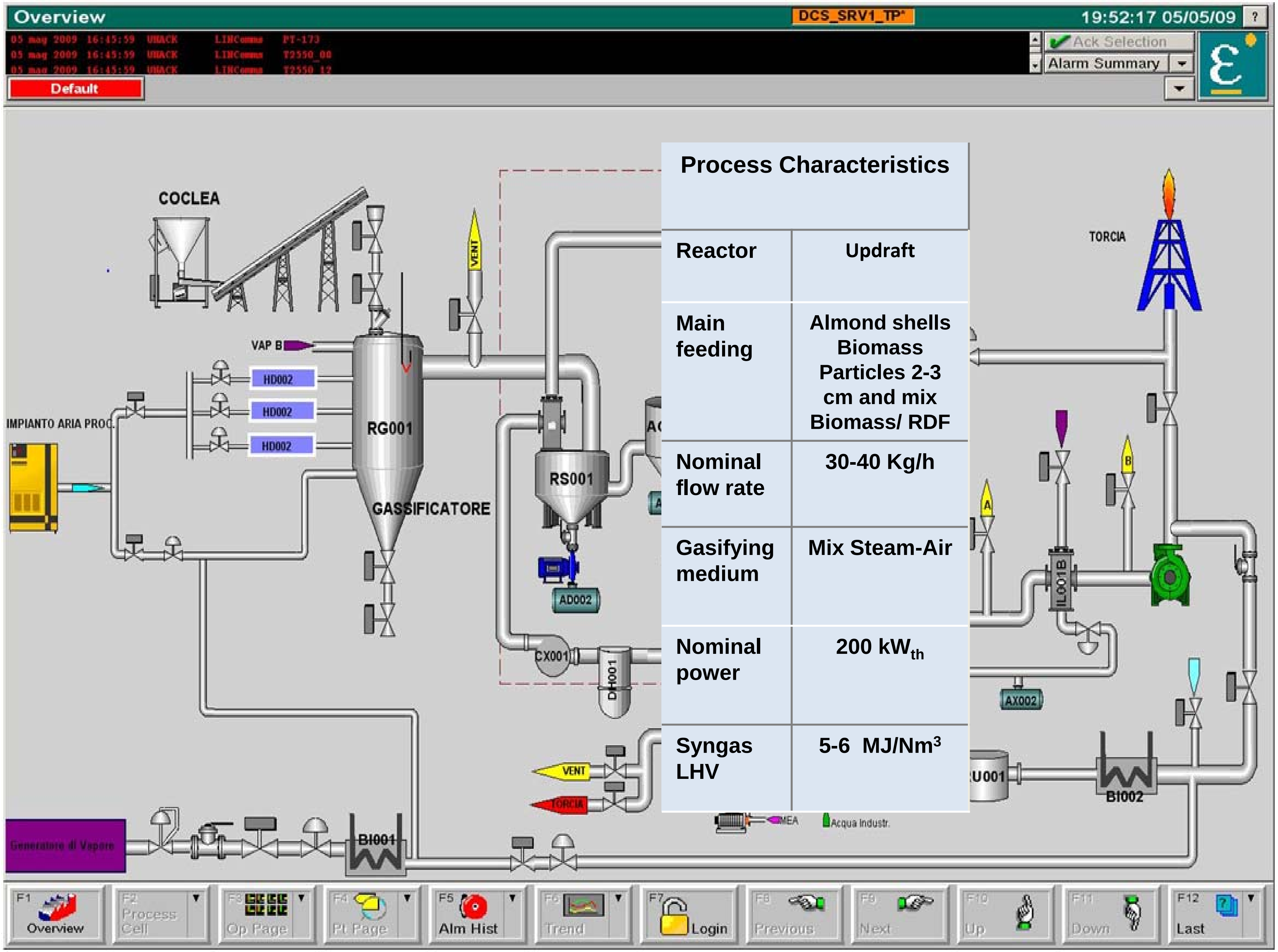
# Gasification of lignin in updraft reactor
# PRAGA PLANT: Process Scheme




| Process Characteristics | |
|---|---|
| Reactor | Updraft |
| Main feeding | Almond shells Biomass Particles 2-3 cm and mix Biomass/ RDF |
| Nominal flow rate | 30-40 Kg/h |
| Gasifying medium | Mix Steam-Air |
| Nominal power | 200 $kW_{th}$ |
| Syngas LHV | 5-6 $MJ/Nm^3$ |

# Gasification of lignin in updraft reactor
# PRAGA PLANT: Description


# Gasification of lignin: parameters

**Tests were carried out using lignin as feedstock and operating the gasification at the following conditions and atmospheric pressure:**

| | Lig1 | Lig2 | method |
|---|---|---|---|
| | | | |
| Bulk density, kg/m3 | 382 | 378 | ASTM E873 |
| Particle density, kg/m$^3$ | 710 | 707 | Vol. displacement (in house) |
| HHV MJ/kg | 18.5 | 19.5 | ISO 1928 |
| LHV MJ/kg | 17.9 | 18.5 | (a) |
| | | | |
| **Proximate Analysis** | | | |
| Fix Carbon, % | 21.6 | 24.6 | ASTM D 3172 |
| Volatile, % | 64.7 | 68.7 | ASTM D 3175 |
| Ash, % | 13.73 | 6.77 | ASTM D 1102 (600°C) |
| | | | |
| **Ultimate Analysis** | | | |
| C % | 48.0 | 50.5 | UNI EN 15104 |
| H % | 5.45 | 5.83 | UNI EN 15104 |
| N % | 2.7 | 0.69 | UNI EN 15104 |
| O% | 34.9 | 37.8 | (b) |
| Cl % | 0.075 | 0.041 | UNI EN 15289 |
| S % | 0.14 | 0.077 | UNI EN 15289 |

(a) Calculated from HHV on the basis of H content. (b) Calculated by difference: 100-%($SiO_2$+metals+C,H,N,S,Cl)

| | Lig1 | | Lig2 | |
|---|---|---|---|---|
| Gasification medium | Air | Air+ Steam | Air | Air + Steam |
| Feed, kgh$^{-1}$ | 22.5 | 22.5 | 21.0 | 21.0 |
| Moisture in feed, % | 6.8 | 6.8 | 7.0 | 7.0 |
| Air flow (IN), kg h$^{-1}$ | 29.56 | 29.3 | 29.04 | 28.5 |
| Steam flow (IN), kg h$^{-1}$ | - | 6.1 | - | 7.4 |
| ER | 0.267 | 0.265 | 0.25 | 0.25 |
| S/Lig | - | 0.34 | - | 0.42 |

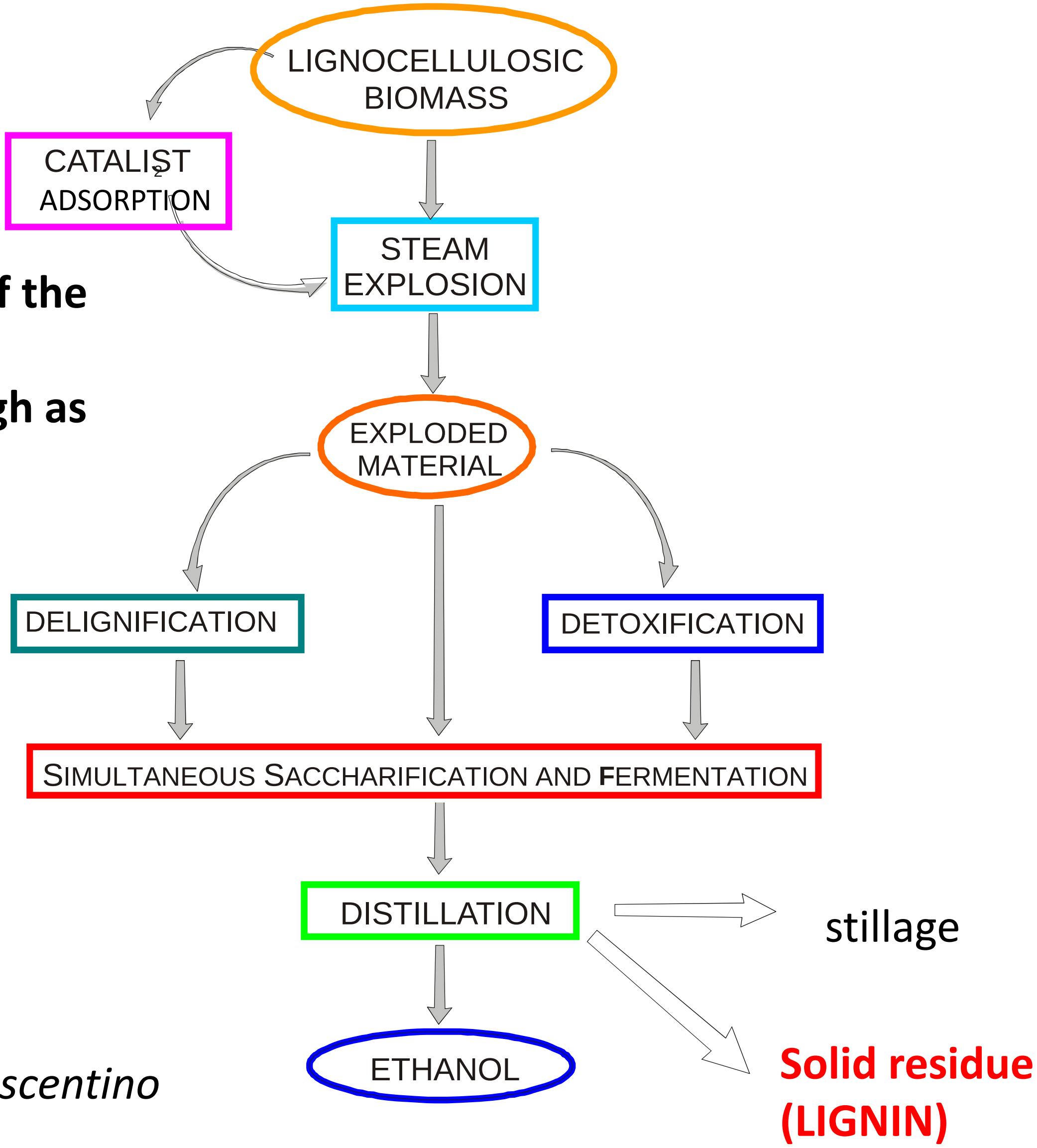
# Ethanol from lignocellulosic

## via pretreatment enzymatic hydrolysis and fermentation

**From 3 kg of biomass =**
**1.1 kg of residue (hydrolytic lignin)**
**1 kg of ethanol**

**In Italy from the substitution of 10% of the liquid fuels with 2nd gen. ethanol the production of lignin is estimated as high as 7,5 Mt/y.**


*2nd gen Ethanol plant 40.000 t/y operating in Italy, Piemonte Region Crescentino*



# The fate of lignin: soluble and insoluble

***Supernatant liquid*** **: many molecules from soluble lignin**

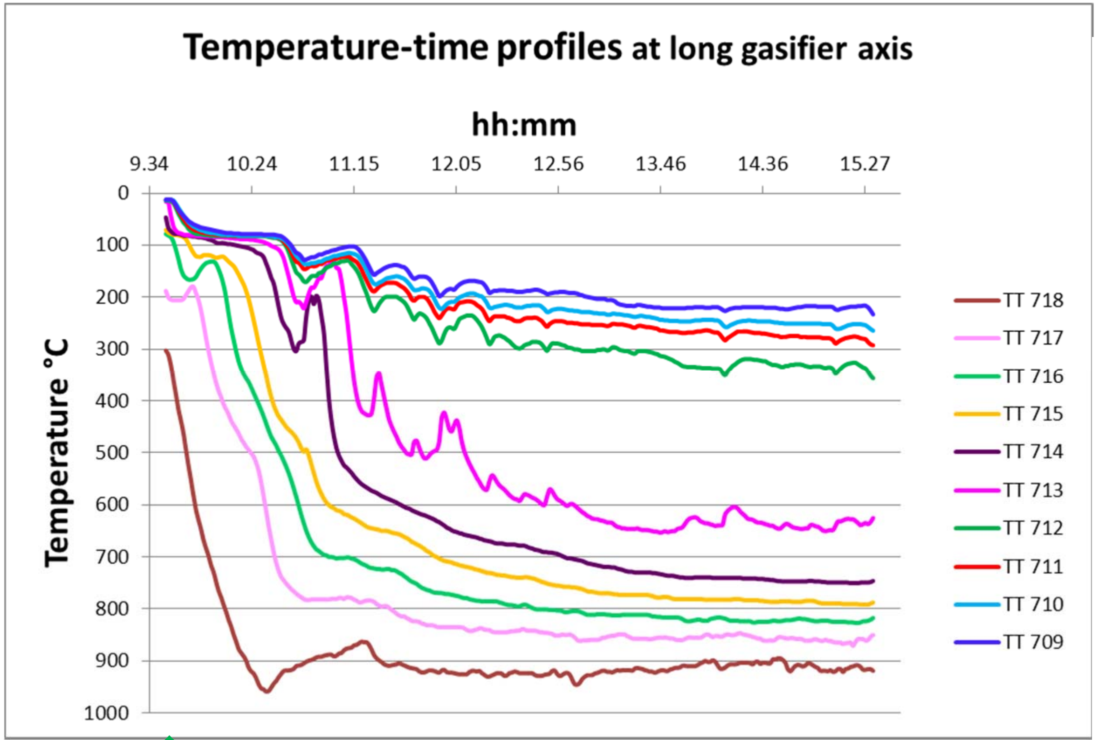
Main degradation products detected in a typical fermentation broth from steam exploded biomass.

| **Name** | ***Molecular formula*** |
|---|---|
| *2-Furan methanol* | $C_5H_4O_2$ |
| *Benzeneacetic acid, 4-hydroxy-3-methoxy-(homovanillic acid)* | $C_9H_{10}O_4$ |
| *Furfural* | |
| *Phenol* | $C_6H_6O$ |
| *Formic acid* | $HCO_2H$ |
| *benzenethanol, 4 hydroxy* | $C_8H_{10}O_2$ |
| *5-hydroxymethyl-2-furaldehyde (HMF)* | $C_6H_6O_3$ |
| *Vanillylil alcohol* | $C_8H_{10}O_3$ |
| *4-allylil-2,6 dimethoxyphenol* | C11H14O3 |
| *Syringaldehyde* | $C_9H_{10}O_4$ |
| *2,6-phenol dimethoxy* | $C_8H_{11}O_3$ |
| *-2methoxy phenol (guaiacol)* | $C_7H_8O_2$ |
| *Eugenol* | $C_9H_{10}O_2$ |
| *Benzaldehyde, 4-hydroxy-3 methyl (vanillin)* | $C_8H_8O_3$ |

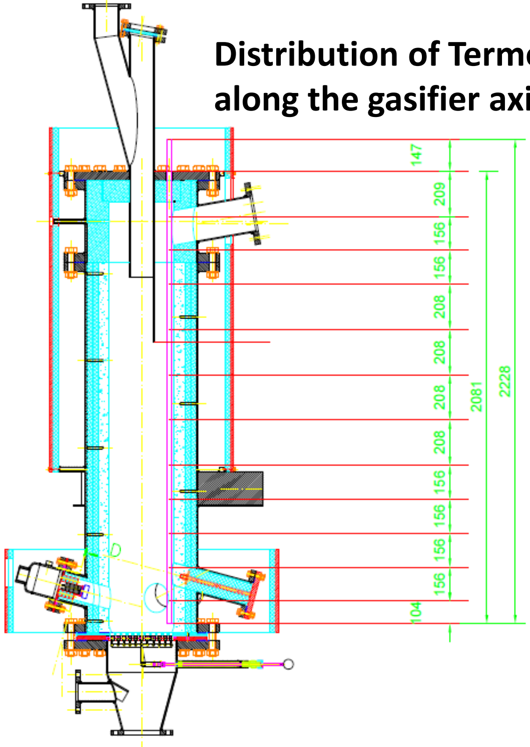
***The solid residue*** (~ LIGNIN+UNCONVERTED FIBRES+YEAST+ENZYMES…) 20-50% DM


***Hydrolytic lignin from lignocellulosics via steam explosion+enzymatic hydrolysis+fermentation+distillation - Pressed and dried***

# Gasification of lignin: process control




**Distribution of Termocouples along the gasifier axis**



Stationary state reached after one hour

Start of trial: cold gasifier

Sampling of producer gas from the top of the gasifier for tar determination

# Gasification of lignin: results

| | Lig1 | | Lig2 | |
|---|---|---|---|---|
| **Gasification medium** | **Air** | **Air+steam** | **Air** | **Air+steam** |
| **Raw gas composition** | | | | |
| CO, vol% | 29.3 | 17.6 | 32.3 | 23.8 |
| $H_2$, vol% | 15.9 | 21.3 | 15.5 | 21.4 |
| $CH_4$, vol% | 2.3 | 1.7 | 2.1 | 1.68 |
| $CO_2$, vol% | 9.3 | 17.02 | 5.9 | 11.6 |
| LHV, $MJ/Nm^3$ | 6.25 | 5.13 | 6.48 | 5.92 |
| **Performance p** | | | | |
| Superficial velocity (gasifier), $m\ s^{-1}$ | 0.175 | | | |
| Specific gasification rate, $kg\ h^{-1}\ m^{-2}$ | 297 | | | |

| | Lig1 | Lig2 |
|---|---|---|
| | | |
| $LHV_{lignina}$ MJ/kg | 17.9 | 18.5 |
| Ash, | 13.73 | 6.77 |

**Cold gas efficiency:**

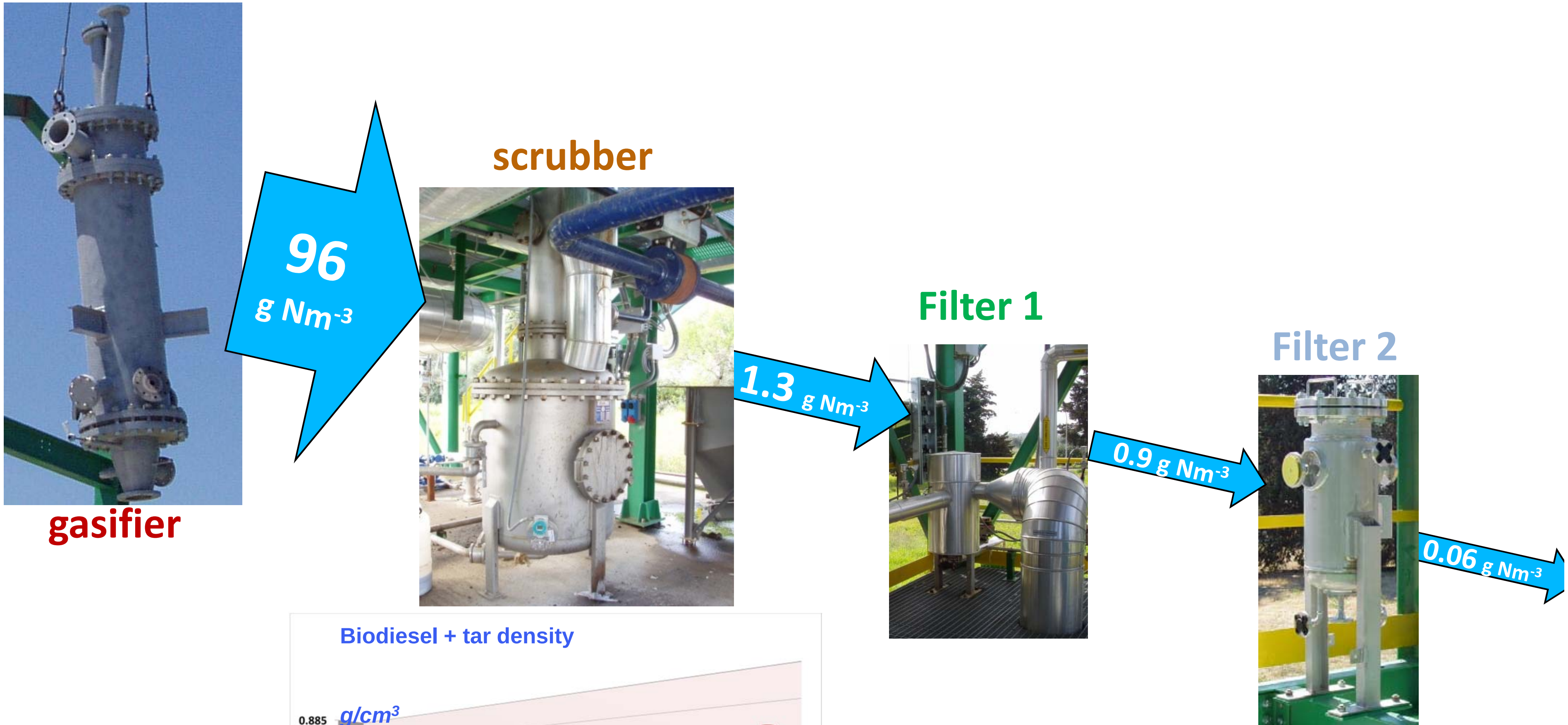
$$\frac{\text{LHV of clean gas [kJ/h]}}{\text{LHV of feedstock [kJ/h]}}$$

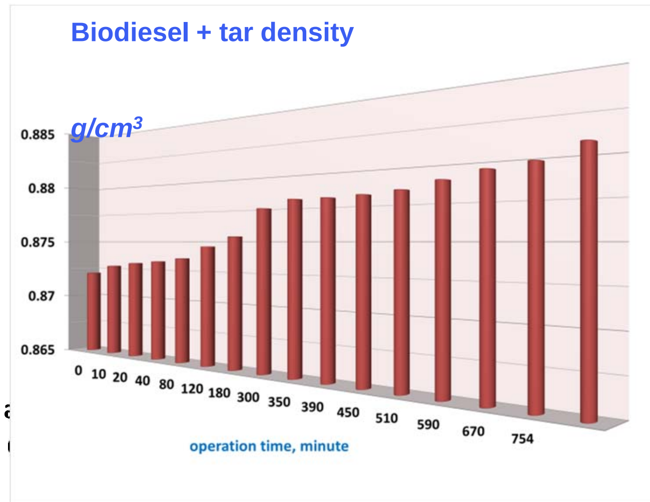
**0.75**

Loaded pieces of lignin and pyrolyzed (withdrawn at the end of the trial)


**The loading system permits the optimal feeding of the lignin in the reactor**

# Gasification of lignin: results




**The tar concentration a** … **ency of 98-99%$_{wt}$.**

**Biodiesel scrubbing is** … **pounds, including both polar and non-polar molecules.**

# Gasification of lignin: Future work

- To optimise of gasification parameters (equivalence ratio, Steam /Biomass, feeding rate)
- To improve the analytics of tar determination
- To maximize the hydrogen content (HENRI will be also used on train)
- To modell in ChemCad the process by using the kinetic parameters (TGA) and comparison with experimental output

# THANK YOU