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Application of staged biomass gasification for combined heat and power production

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Efficiency of electricity generation by various processes

$$\eta_{tot} = \eta_{CE} * \eta_{CU}$$

η_{CE} - cold gas efficiency which takes into account only the chemical energy of a gas

Type of power generation	Cold gas efficiency η_{CE}, %	Gas to electricity efficiency, η_{cu}, %	Overall el. efficiency $\eta_{t''}$, %	Inst. costs thousands czk /kW$_e$
1. Thermal plant with steam turbine (11 MW$_e$) (Zelený kotel, 33 MW$_t$), Plzeň	-	-	27,6	80
2. Thermal power station (35 MW$_e$) (Biomass combustion, 105 MW$_t$), Hodonín	-	-	~ 33	-
3. Two-stage gasifier prototype GP200 (0,2 MW$_e$) TARPO spol. s r.o., 2011	80–90	~ 32	~ 28*	90
4. Two-stage gasifier GP 750 (0,75 MW$_e$) TARPO spol. s r.o., AIR TECHNIC s.r.o., 2014	80–90	~ 36	~ 32**	100
5. Gasifier coupled with SOFC	~ 95	~ 45-65	~ 40-60	Very high

* Modified diesel engine: **6S160 ČKD Hořovice**

** Jenbacher AB, J316 GC (J320GC)

Principle of biomass gasification

Pyrolysis

Volatile matter combustion

Volatile matter: H_2, H_2O, CO, CO_2, CH_4, hydrocarbons
Tar precursors

Air

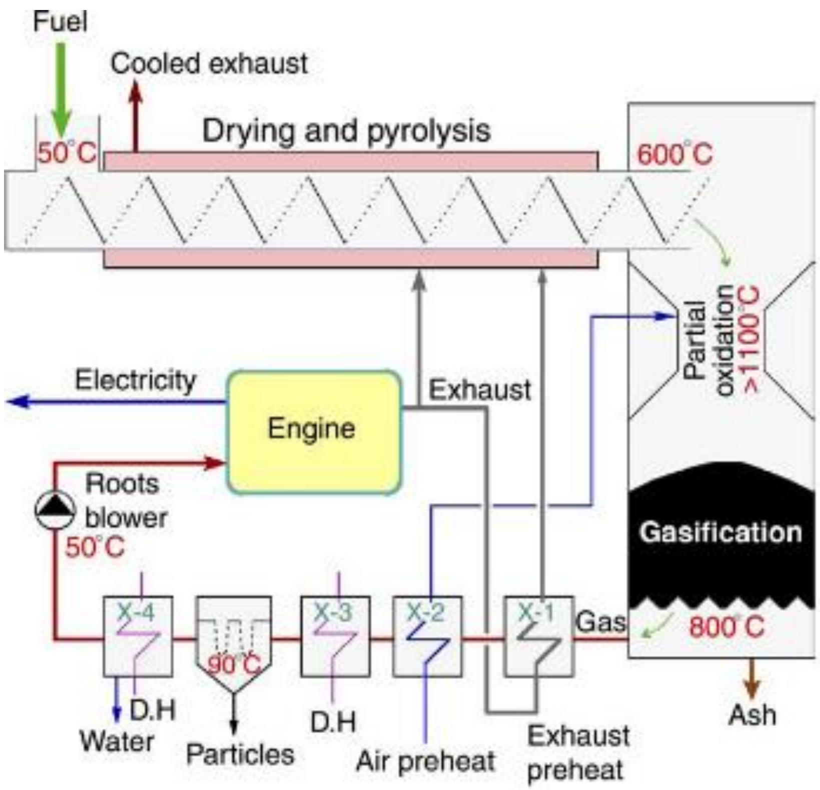
Char gasification

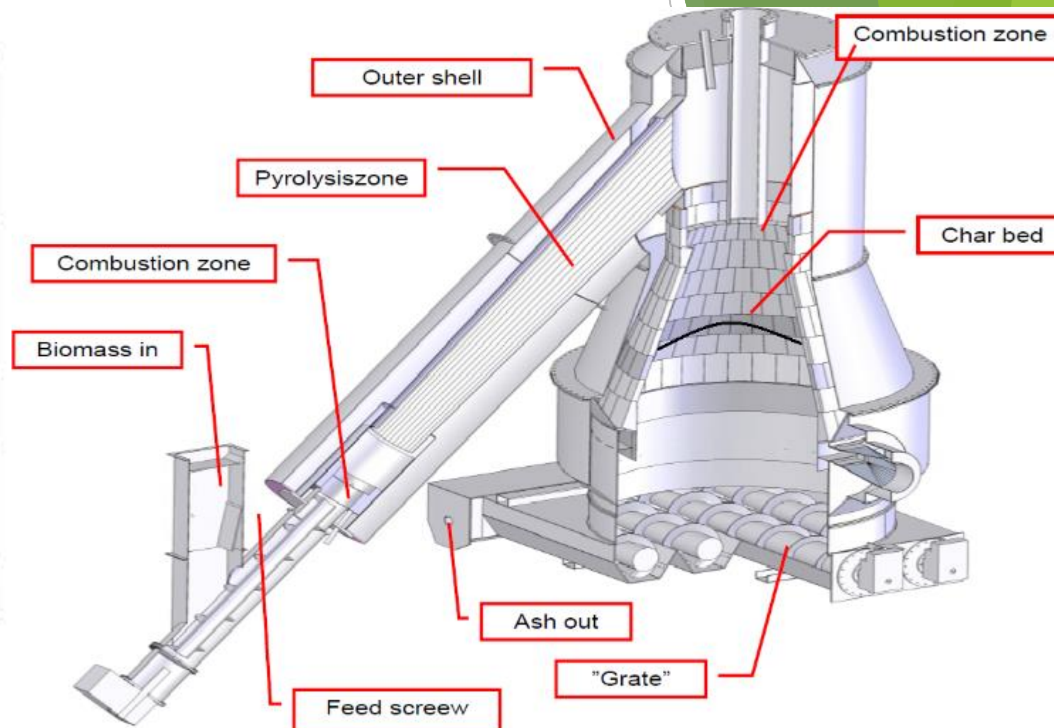
Heat

CO, H_2, CH_4, CO_2, H_2O, N_2

Tar definition according to the “Tar protocol” CEN/TS 15439:
Tar is mixture of organic substances with boiling point higher than benzene (80,1 °C, 101,325 kPa)

Basic concepts of multi-stage gasifiers



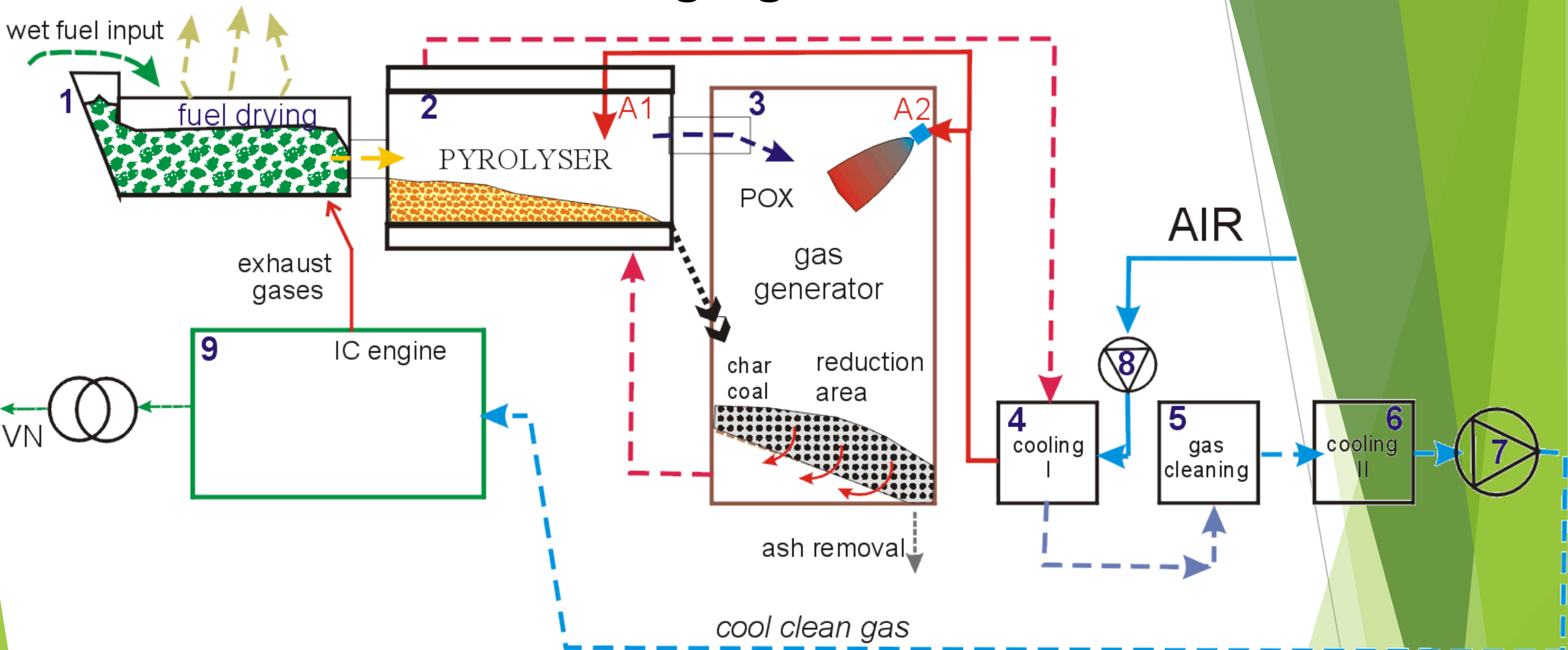


2000 DTU DK, Viking 17,5 $kW_{El.}$
2006 Hudsund DK, 200 $kW_{El.}$
Viking: $\eta_{CE.}$= 95% $\eta_{TOT.}$= 25 %
Tar content < 50 mg·m^{-3}
Complicated upscale of the pyrolysis zone

1996-2006, TK Energi, 75-140 $kW_{El.}$
Pyrolysis temperature 500-600 °C,
POX temperature1200-1300 °C
$\eta_{CE.}$= 85% $\eta_{TOT.}$= 22–26 %
Tar content 10-80 mg·m^{-3}

Brandt, P. et all.; Tar Reduction in a Two-Stage Gasifier: A review. *Energy Fuels*. **2000**, 14, (4), 816-819
Thomas, K.; Biomass Gasification with low tar production: Staged gasification. *Escola de combustado*, **2007**

Scheme of two-stage gasifiers used in the CR



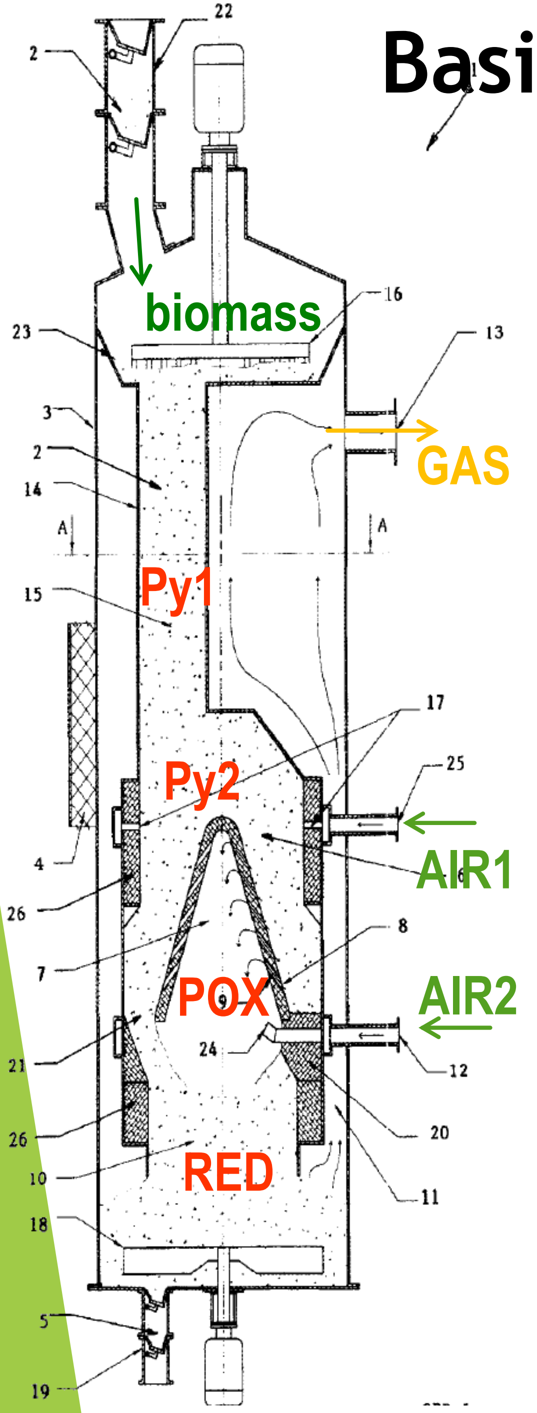
Main parameters of GP750 unit used in Kozomín:

Nominal electric power	**710 kW**
Nominal wooden chips consumption (dry)	550 kg/h.
Chips dimension	6 to 50 mm
Biomass moisture (dryer input)	up to 60 wt. %
Overall efficiency (calculated from LHV)	**32 %**
Nominal fuel (dry) consumption	**0,7 kg/kWh**
Nominal electric output	**1,4 kWh /kg**

Installations of two-stage gasifiers

Locality	Engine type	Year of start-up Generator type	Installed power output	Current state
Kněževes	ČKD, 2x6S160	2011- 2013 GP200	2x100 kW$_e$	2014 Replaced by pyrolysis unit
Odry	Jenbacher, 2xJ316	Od 2012 2xGP500	2x400KW$_e$	Operating at lower output: 2x400 kW$_e$
Dobříš	Guascor, FBLD560	1xGP750	630 kWe	Experimental unit
Kozomín	Jenbacher, 3xJ320	07/2014 5xGP750	2,1 MWe (3x710 kWe) 4,2 MW$_t$ (gas)	Pilot operation of five GP750 units
Handlová	Guascor, FBLD560, FBLD480	06/2014 2xGP750	570 kW$_e$ 430 kW$_e$	Operating from 4/2015
Olešnice	ČKD, 2x6S160	2013 GP200 03/2015 GP200XL	2x100 kW$_e$	Transformed to twin-fire

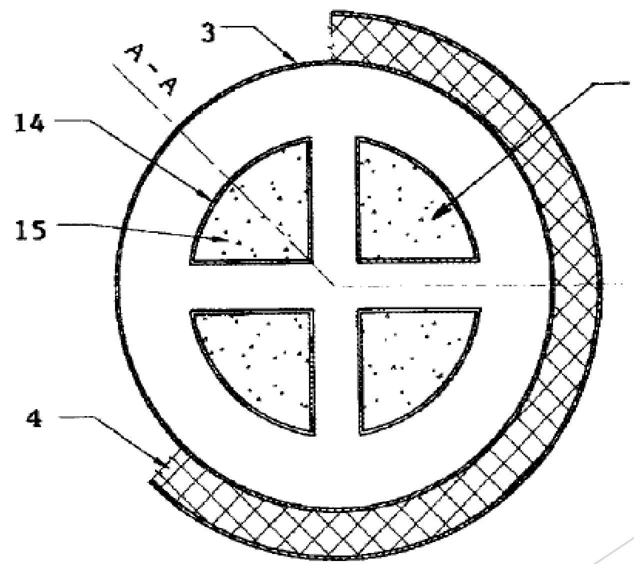
Basic description of GP750 gasifier



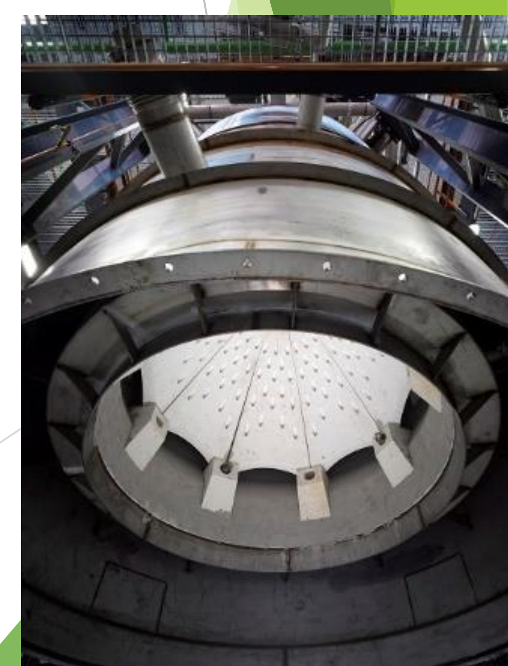
Impact of scale-up

Gasifier	Dimensions of POX chamber		Volume	Flow*	Residence time*
	D,m	H,m	m^3	m^3/h	s
GP200	1,0	1,1	~0,3	~400	~2,5
GP500	1,6	2,1	~1,5	~900	~5,5
GP750	2,5	2,3	~4,0	~1300	~10

Pyrolysis zone

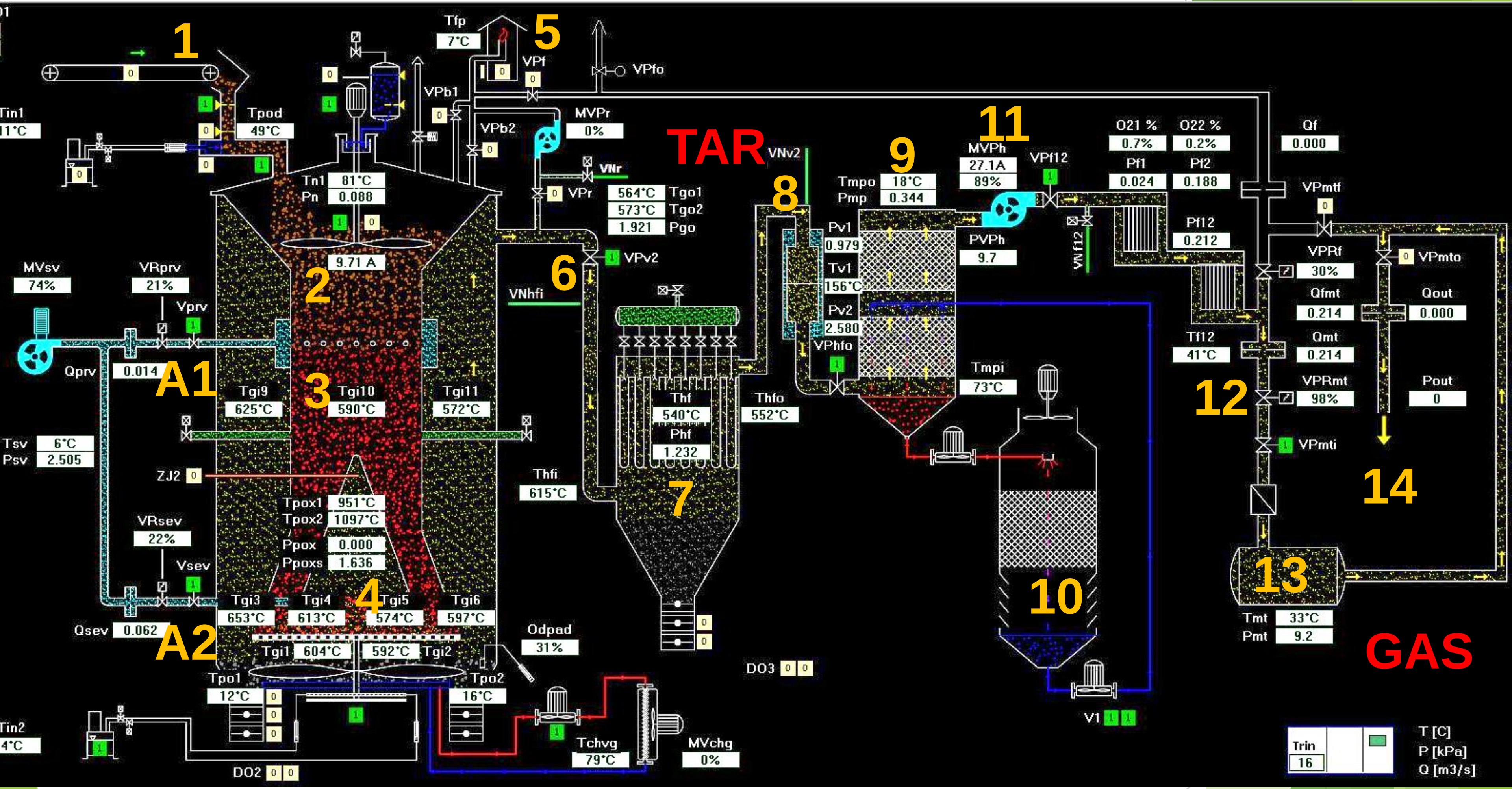


POX chamber



* Standard temperature and pressure

Flow sheet of Kozomín gasification unit

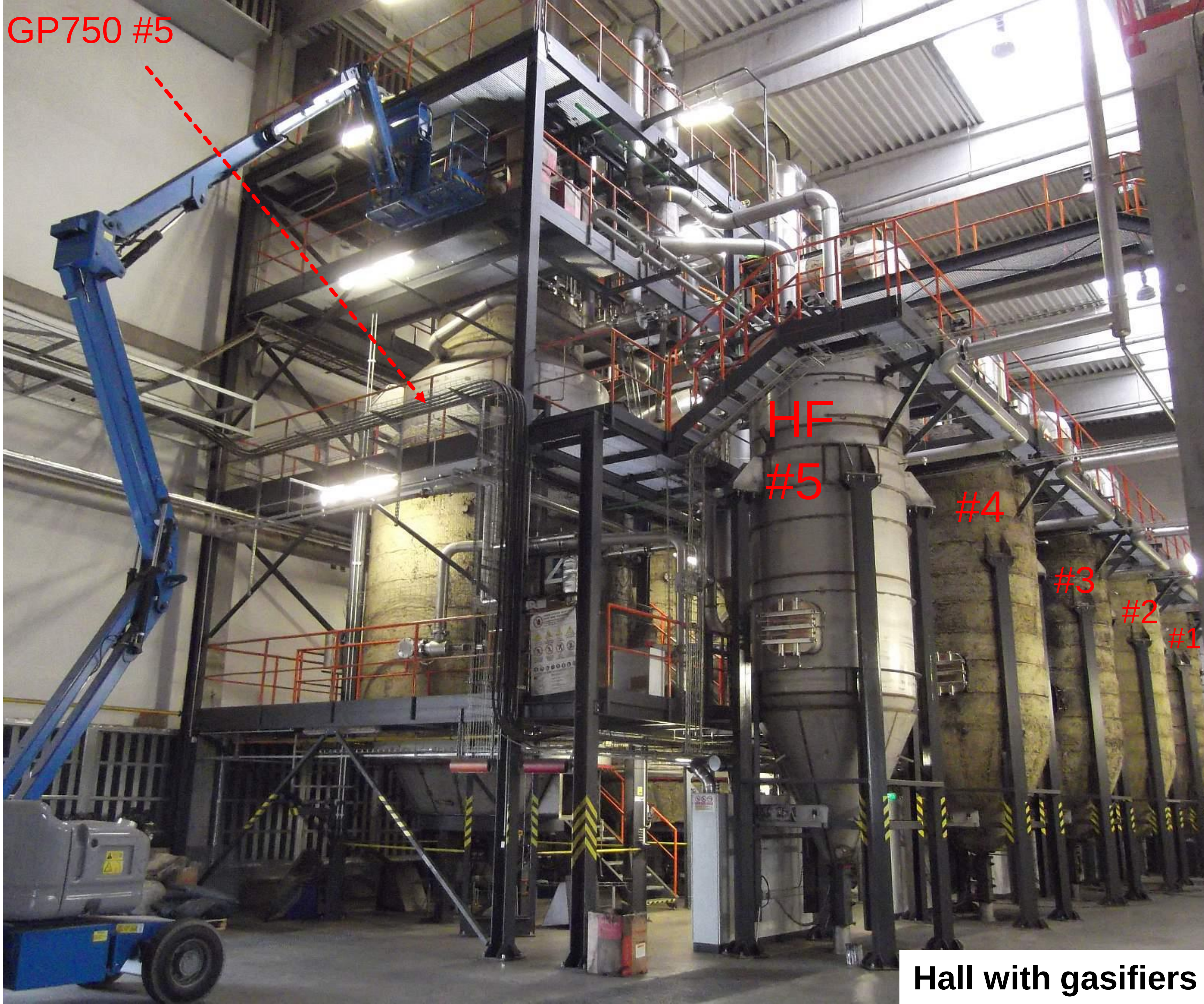


1 - entry of fuel into the GP750, 2 - allothermal pyrolysis section, 3 - autothermal pyrolysis section, 4 - POX section, 5 - combustion flare, 6 - gas output, 7 - bag filter, 8 - heat exchangers (gas/water), 9 - contact water cooling, 10 - cooling tower, 11 - gas blower, 12 - gas flow measurement , 13 - mix tank, 14 - pipe to IC motor.

A1-primary air inlet, A2- secondary air supply

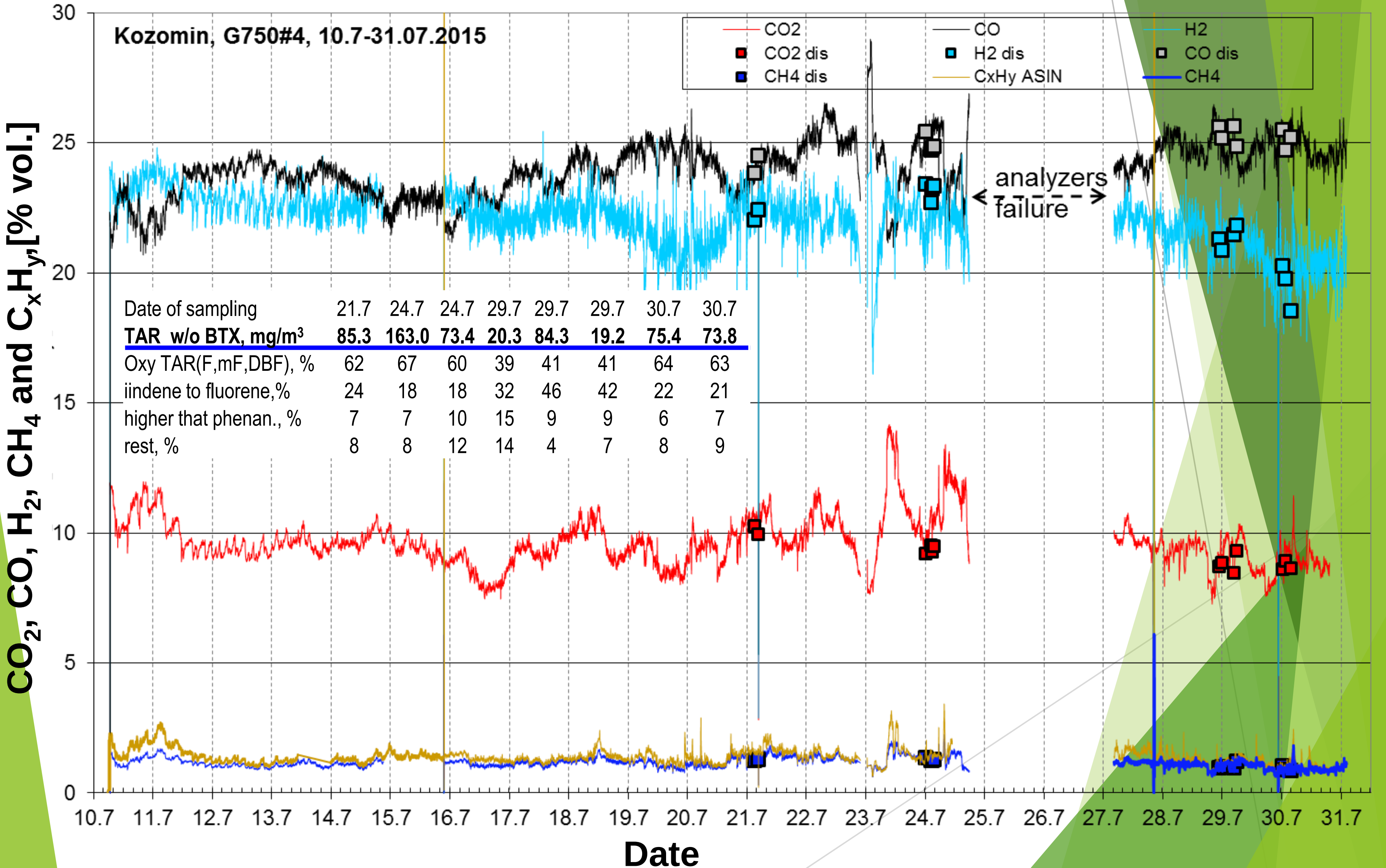
GAS - point for gas quality sampling (on-line, off-line), TAR - point for gas sampling according to Tar Protocol

Combined heat and power plant in Kozomín



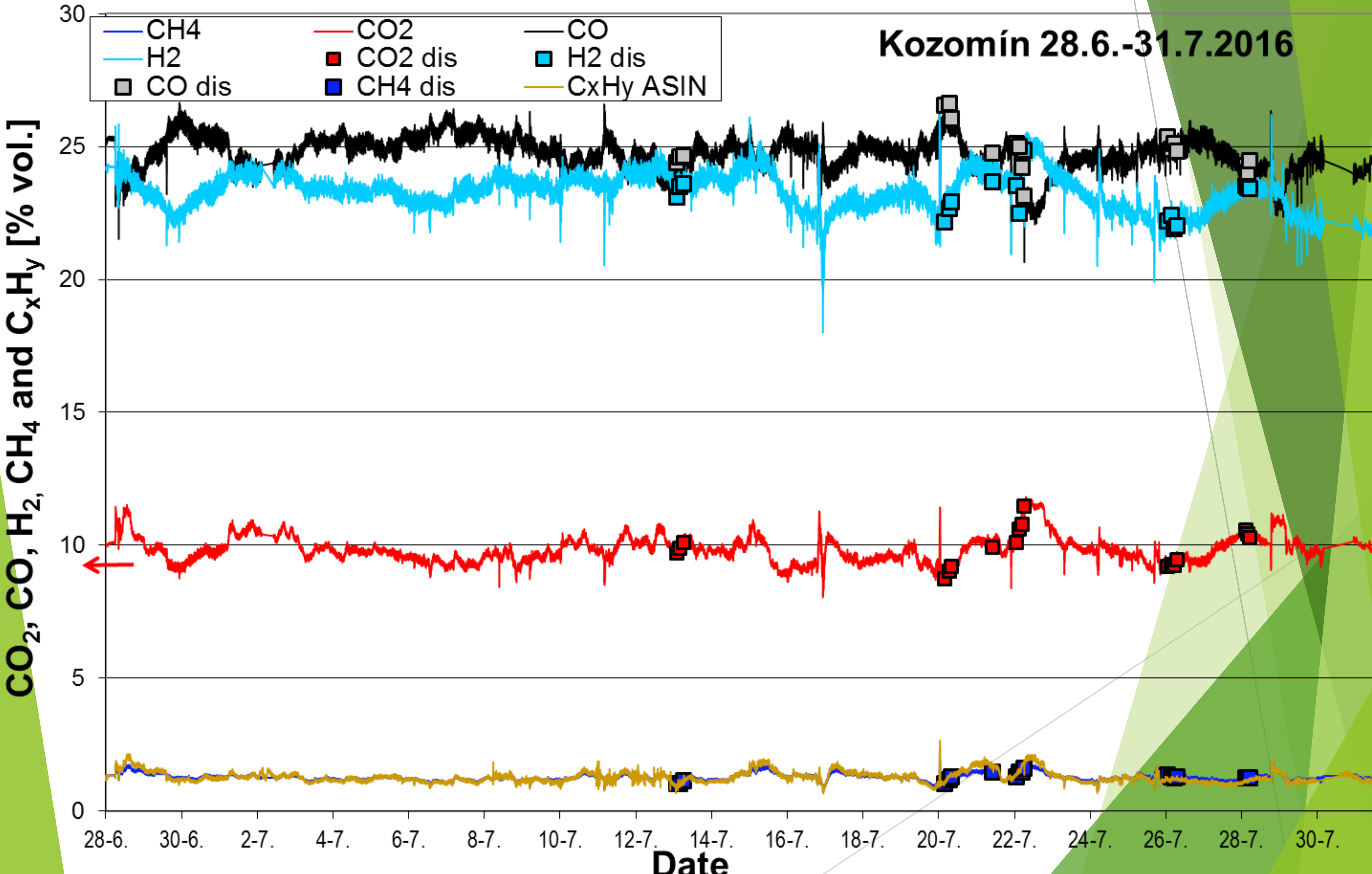
Hall with gasifiers

Gas composition from 3*GP750 in Kozomín 2015



Date of sampling	21.7	24.7	24.7	29.7	29.7	29.7	30.7	30.7
TAR w/o BTX, mg/m³	**85.3**	**163.0**	**73.4**	**20.3**	**84.3**	**19.2**	**75.4**	**73.8**
Oxy TAR(F,mF,DBF), %	62	67	60	39	41	41	64	63
iindene to fluorene,%	24	18	18	32	46	42	22	21
higher that phenan., %	7	7	10	15	9	9	6	7
rest, %	8	8	12	14	4	7	8	9

Gas composition from 3*GP750 in Kozomín 2016



Typical gas composition from downdraft and staged gasifiers

	Downdraft Imbert	Downdraft GP300	Viking DTU 75 kW_t	GP200	GP500	GP750
Biomass moisture, wt.	<10	<10	35-45	<10	<10	<10
CO	25,5	24,6	19,6	26,7	25,0	25,3
H_2	17,2	16,4	30,5	23,0	22,3	22,7
CH_4	***3,0***	***2,2***	***1,2***	***1,1***	***2,0***	***1,3***
CO_2	9,6	9,6	15,4	8,0	9,5	9,7
N_2	***43,5***	***46,1***	***33,2***	***40,6***	***41,1***	***40,9***
Other	1,2	1,1	0,1	0,6	0,2	0,1
Tar content, mg/m^3	**1000-2000**	**1300-2000**	**<5**	**0,5-2,0**	**5,0-40**	**20-200**
Q_i (15 °C) MJ/m^3	6,3	5,7	5,6	5,9	5,9	5,8

Average fuel consumption in July 2016

Electric power, kW	3·606	Overall efficiency (LHV)	31,4 %
Fuel consumption (dry), kg/h	3·500	Overall efficiency (HHV)	26,7 %
Moist fuel consumption, t/month	1795	Overall efficiency – biochar (HHV)	32,7 %
Biochar production, t/month	20	Fuel consumption (dry), kg/kWh	0,823

Average fuel composition in July 2016 aafter drying

Weight %	Raw	Dry
Water content	6,55	0
Combustible	92,36	98,84
Ash content	1,08	1,16
Volatile matter	71,05	76,03
Fixed carbon	21,31	22,81

Thank you for attention

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