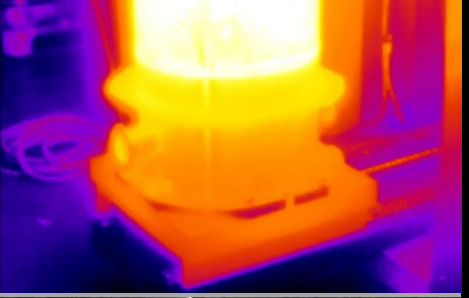

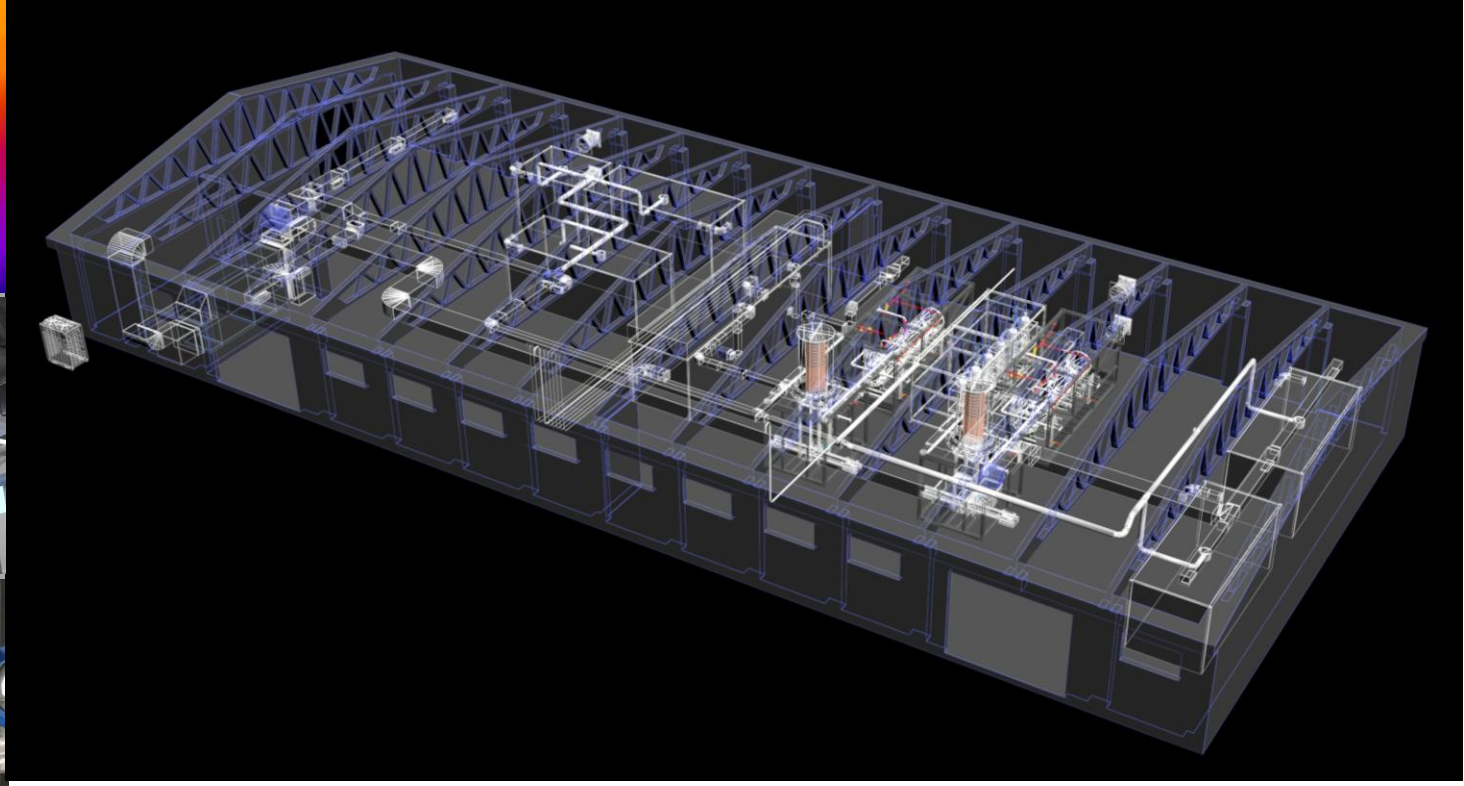

PLANT FOR THE PRODUCTION OF HYDROGEN-RICH GAS MIXTURES FROM METHANE AND BIOGAS BY PYROLYSIS

VERSION 1.2 // 30.03.2023

BRK Technologies

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IN: CH4 + [CO2]

OUT: H2 + CH4 + (↘ CO2) + C↓

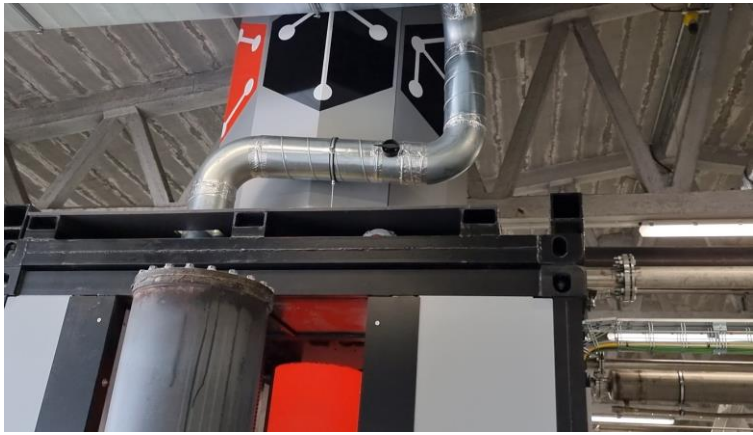
The plant allows to produce hydrogen by methane pyrolysis in an induction reactor without CO2 emissions, to reduce the CO2 content in the initial biogas, to prepare chromatographically verified hydrogen-containing mixtures.

The process is a thermodynamically more advantageous alternative to blending hydrogen produced by electrolysis into a pipeline network. Provides direct preparation of a gas mixture as a result of a thermal process.

The design of the industrial plant provides for easy replacement of catalysts and inhibitors, as well as the elimination of solid carbon, which is a product of methane pyrolysis, from the process.

When operating on biogas, the unit allows to reduce the CO2 content in the initial mixture due to the Sabatier reaction, which makes the process carbon-negative.

The system makes it possible to produce hydrogen-containing gases (HCG), separate pure hydrogen from HCG, and prepare HCG of a given quality from separated fractions.



PROCESS

Natural gas processing

Methane Pyrolysis for CO_2-Free H_2 Production

$$CH_4 = C\downarrow + 2H_2$$

Products

Green Hydrogen

H_2

Hydrogen-enriched methane gas of GC-verified stable quality with no further methanation required. CO_2 reduction in feedstock gas.

H_2 CH_4

Carbon black

C

Biogas processing

Methane Pyrolysis for CO_2-Free H_2 Production

$$CH_4 = C\downarrow + 2H_2$$

Sabatier reaction

$$CO_2 + 4H_2 = CH_4 + 2H_2O$$

Products

Hydrogen-enriched methane gas of GC-verified stable quality with no further methanation required. CO_2 reduction in feedstock gas.

H_2 CH_4

Carbon black

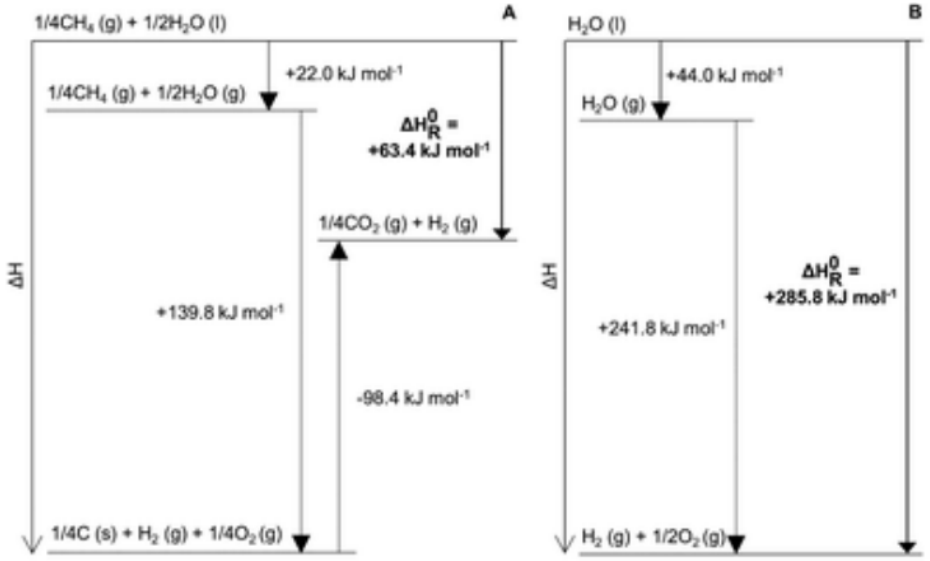
C

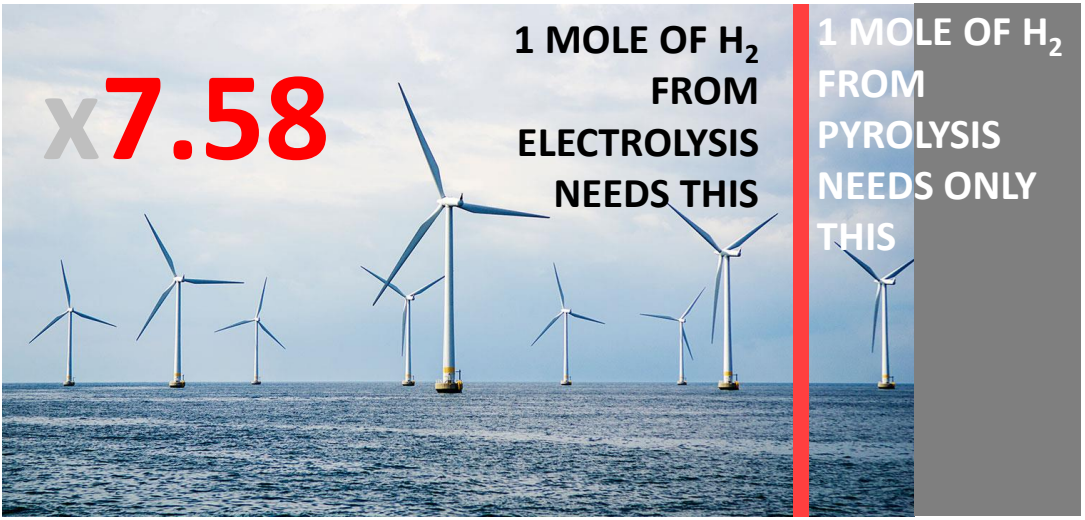
THERMODYNAMICS

Methane pyrolysis is a more thermodynamically favorable method of hydrogen production than water electrolysis.

Energy consumption for the production of 1 mole of hydrogen:

- Steam reforming: **63** kJ/mol
- Electrolysis: **286** kJ/mol
- Pyrolysis: **38** kJ/mol





GAS DECARBONIZATION EFFECT

At 10% hydrogen concentration in the methane mixture, emissions are reduced by 75 g of CO2 for each cubic meter of fuel gas used.

The CO2 concentration in the feed biogas is reduced from 30% to 15% by the Sabatier reaction, making the process carbon negative.

The calorific value of the proceed gas increases.

Input gas			Planned change, %
Component	**Concentration**	**Unit**	
Methane	60.28	% mol.	
Ethane	1.70	% mol.	
Propane	0.33	% mol.	
n-Butane	0.08	% mol.	
i-Butane	0.06	% mol.	
n-Pentane	3.00	% mol.	
i-Pentane	2.00	% mol.	
neo-Pentane	1.00	% mol.	
Hexane	0.05	% mol.	
Carbon dioxide	30.00	% mol.	-12
Nitrogen+Oxygen	1.50	% mol.	
Hydrogen	0.00	% mol.	10
Parameter	**Value**	**Unit**	
Calorific value (vol., sup., 25/20)	32.785	MJ/m3	
Volume (total)	1	nm3	
Moles (@20C)	41.57		
CO2 content after combustion	39.72	moles	
	0.9553	nm3	
	1747.9	g	

Output gas			
Component	**Concentration**	**Unit**	**kg/J20**
Methane	66.25	% mol.	0
Ethane	1.53	% mol.	0
Propane	0.30	% mol.	0
n-Butane	0.07	% mol.	0
i-Butane	0.05	% mol.	0
n-Pentane	2.70	% mol.	0
i-Pentane	1.80	% mol.	0
neo-Pentane	0.900	% mol.	0
Hexane	0.05	% mol.	0
Carbon dioxide	15.00	% mol.	0
Nitrogen+Oxygen	1.35	% mol.	0
Hydrogen	10	% mol.	10.7856
Parameter	**Value**	**Unit**	**Δ, %**
Calorific value (vol., sup., 25/20)	35.137	MJ/m3	**7.18**
Volume (total)	1	nm3	**0.93**
Moles (@20C)	41.57		
CO2 content after combustion	40.73	moles	**2.56**
	0.97977	nm3	
	1792.6	g	
Volume compensated	**1672.61**	**g**	**-4.31**

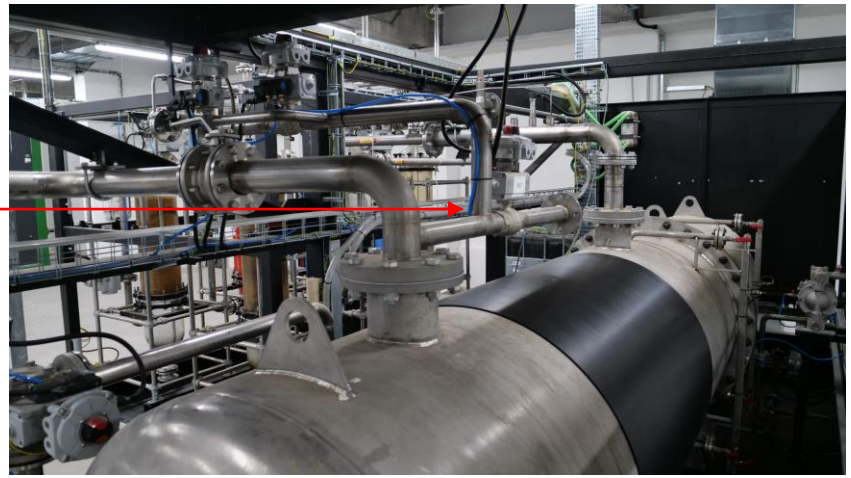
Capacity		
1,200	nm3/day	
CO2 economy, g/1m3		CO2 economy (total), kg
75		**90.30**

Only the thermal processing effect is considered in this table.
Further gas separation is ensured via the next process stages.

MODULES

Induction heated reactor

Contact gas cooling system

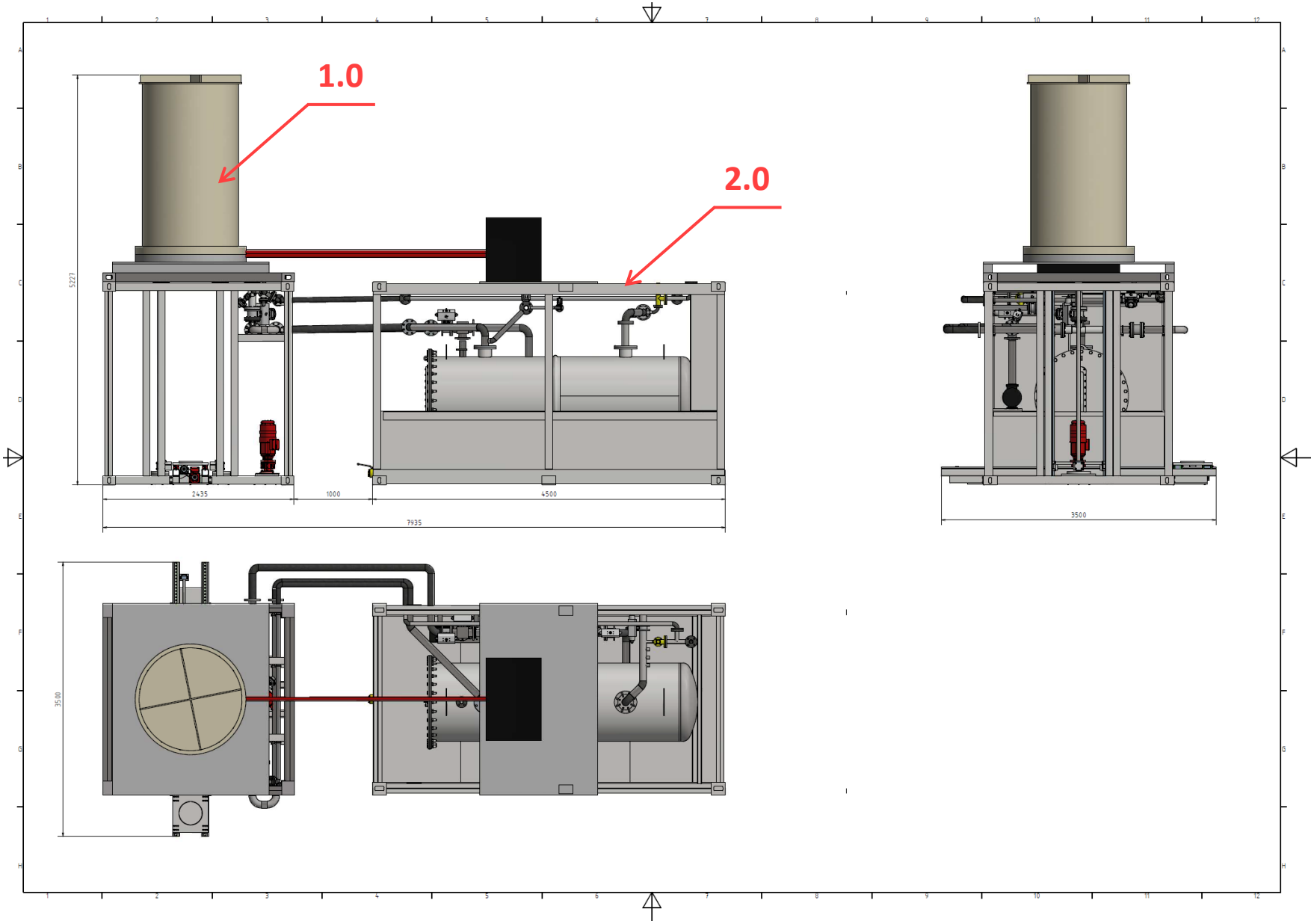


Process gas chromatograph

Gas draying, compression, separation (optional), and controlled mixing

1.0 Induction heated reactor

2.0 Gas cooling system



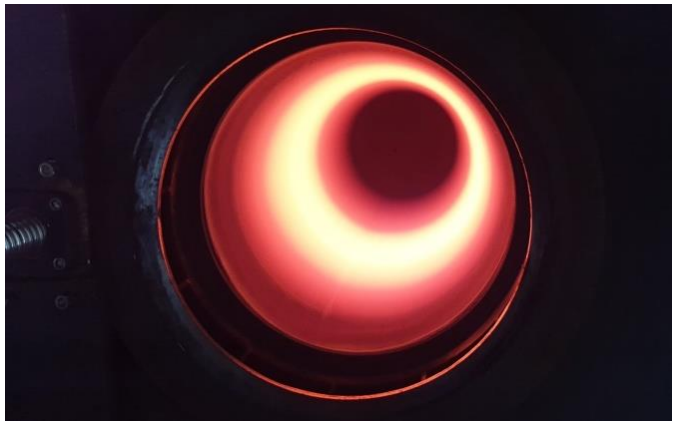
PYROLYSIS REACTOR

The pyrolysis of methane takes place in a reactor with induction heating in a reducing atmosphere at a temperature of 750 to 1000°C.

The reactor is a system of gas-tight stainless steel cylindrical vessels in ceramic insulation with an induction heating and temperature control system.

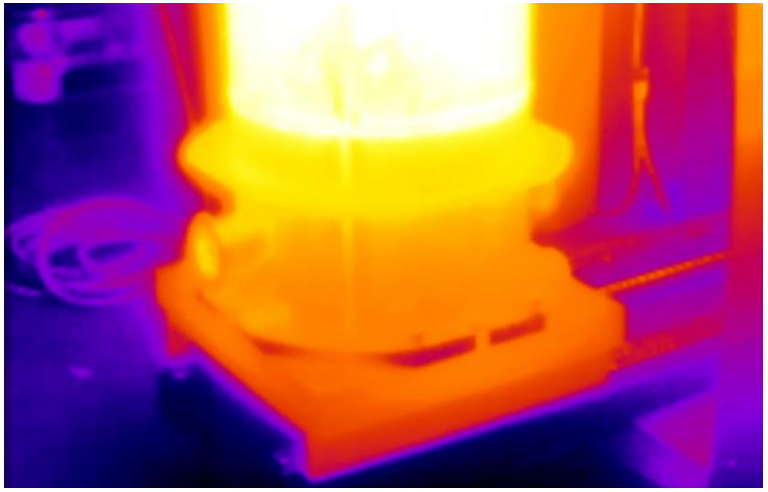
Reactor cartridge with feed and lock system allows for easy replacement of catalysts, inhibitors and removal of solid carbon from the process.

		UNIT	NUMBER
1.0	Pyrolysis module		
1.1	induction unit (power: 70 KVA, overall dimensions: 1050x820x916 mm, range: KHz)	PCS	1
1.2	inductor (inner diameter: 620 mm, copper, profile 32x20x3 mm, height: 1900 mm)	PCS	1
1.3	inductor water cooling system	SET	1
1.4	water cooling system of the induction unit	SET	1
1.5	dome reactor with ceramic insulation (temperature 750 - 1000C)	SET	1
1.6	reactor cartridge (dimensions for loading catalysts: height 1670 mm, diameter 444 mm, usable volume 258 l)	PCS	2
1.7	reactor cartridge feeding and fixing system	SET	1

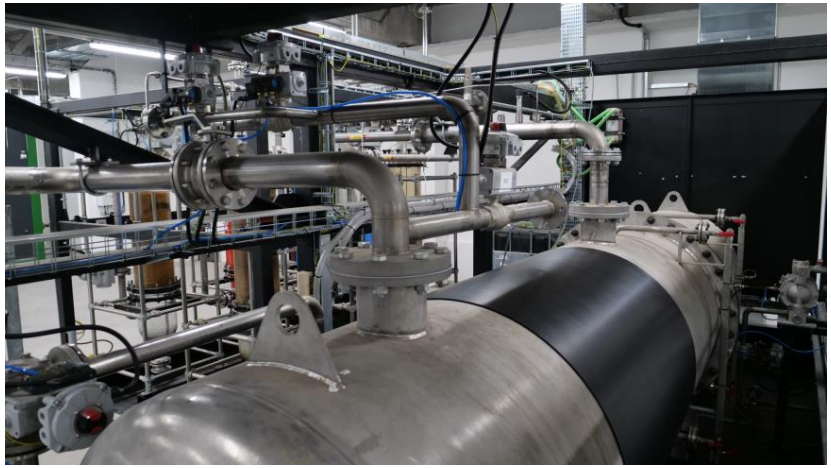


PYROLYSIS REACTOR SPECS

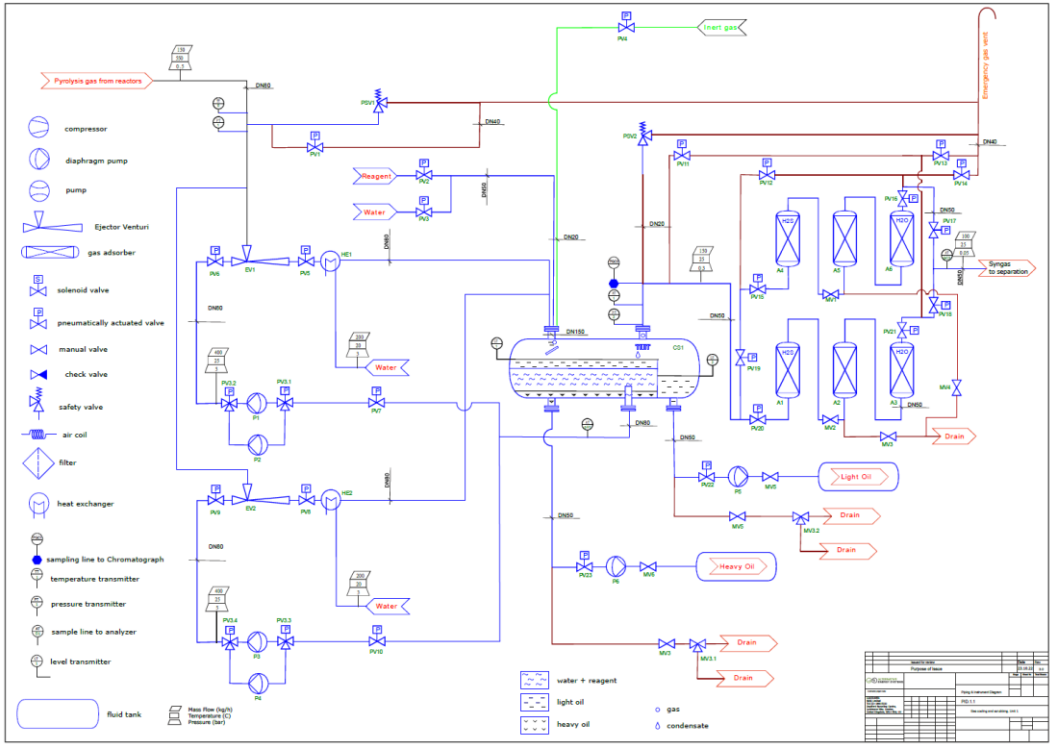
Induction Reactor Power (KW)	80
Maximum temperature in the reactor zone, °C	1000
Maximum hydrogen capacity (kg/h)	Up to 15
Maximum capacity for methane (kg/h)	Up to 60
Height (m)	1,67
Inner diameter (m)	0,44
Internal volume (m3)	0,26



GAS COOLING SYSTEM



The system provides effective contact cooling of the pyrolysis gas, the removal of water, which is the product of the Sabatier reaction, prevents the formation of undesirable components of the gas mixture.



Gas draying, compression, separation (optional), and controlled mixing system

The system provides drying, separation (optional), mixing (if necessary, blending of gas from external sources can be provided for), and gas compression for storage at pressures up to 200 bar.

The system can be directly used as an in-house H2-CNG filling station.

PROCESS GAS CHROMATOGRAPH

The Automatic Complex is designed for online analysis of composition of gaseous products of pyrolysis followed by calculation of its physical-chemical properties including calorific value and methane number.

Flammable Components

Component		Molar concentration, %
H_2 2.016	Hydrogen	1.660124
CH_4 16.042	Methane	56.926792
C_2H_2 26.04	Acetylene	0.049106
CO 28.01	Carbon monoxide	0.000000
C_2H_4 28.052	Ethylene	13.113622
C_2H_6 30.068	Ethane	6.151433
H_2S 34.076	Hydrogen sulfide	0.000000
C_3H_4 40.065	Propadiene	0.010464
C_3H_6 42.078	Propylene	5.631370
C_3H_8 44.094	Propane	1.196340
C_4H_8 56.104	Butenes	4.972113
C_4H_{10} 58.12	i-Butane	0.341992
C_4H_{10} 58.12	n-Butane	0.146875
C_{5+} >60.05	Pentanes+	1.631251
Subtotal Flammable Components		91.83%

Non-flammable Components

Component		Molar concentration, %
H_2O 18.016	Water	0.040090
N_2 28.02	Nitrogen	0.000000
O_2 31.998	Oxygen	1.714311
CO_2 44.01	Carbon dioxide	6.895570
Subtotal Non-Flammable Components		8.65%

Energy

- Mass calorific value (MJ/kg)
- Volume calorific value (MJ/m3)
- $W=\frac{Q}{\sqrt{\rho_{gas}/\rho_{air}}}$ [MJ/Nm3] — Wobbe index (MJ/m3)

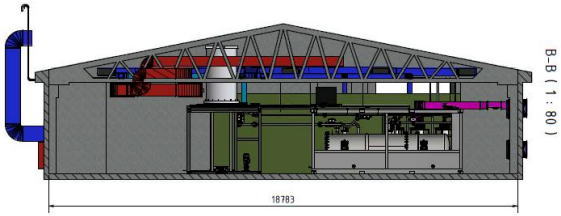
Parameters

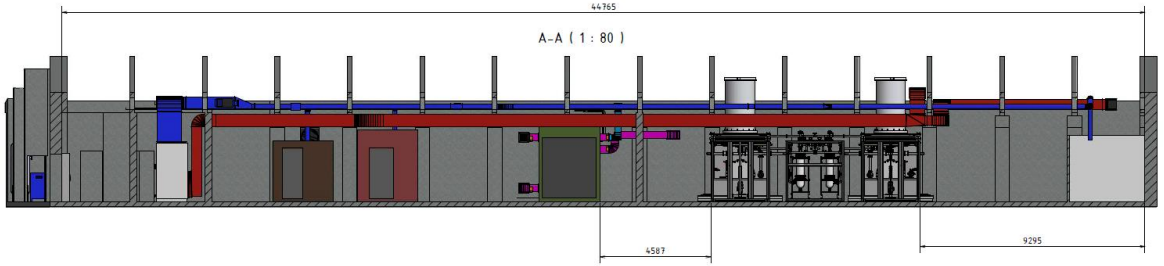
- Methane number
- Molecular weight (kg/kmole)
- Water Dew-Point (°C)

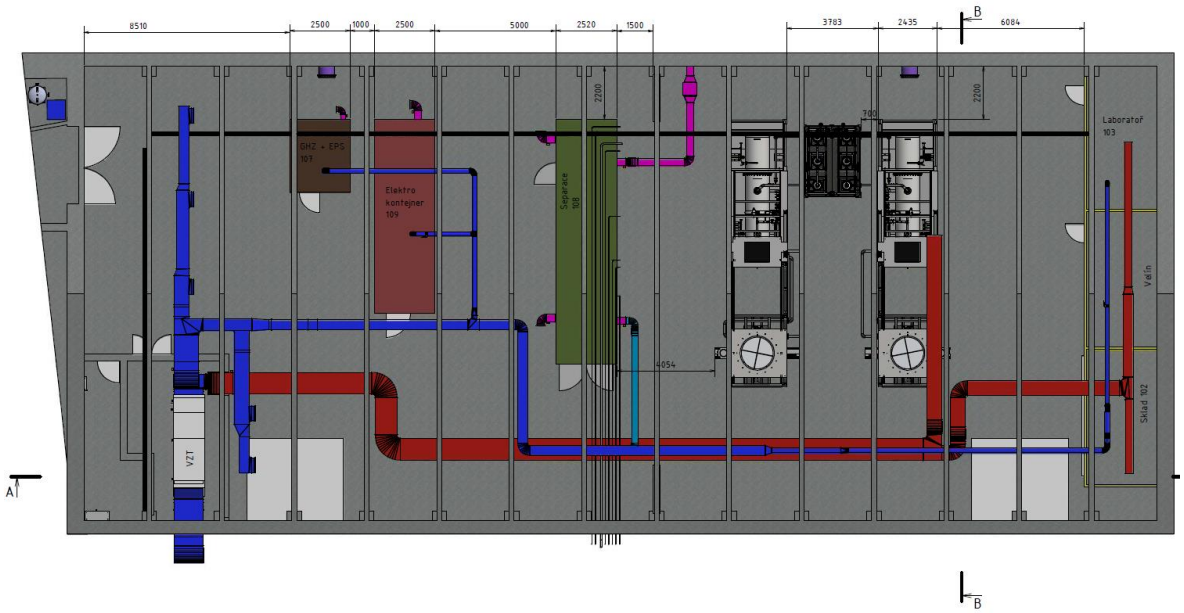
Density

Relative density
Density (kg/m3)
Compression factor

SAMPLE PLANT LAYOUT







PYROLYSIS PLANT IN VLKOS, PREROV, CZECH REPUBLIC