MINERALS ENGINEERING 2014
UK Energy Symposium

Underground Coal Gasification in Poland. Experiences, results and future prospects.

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POLAND

GIG

Kegworth 15th May, 2014

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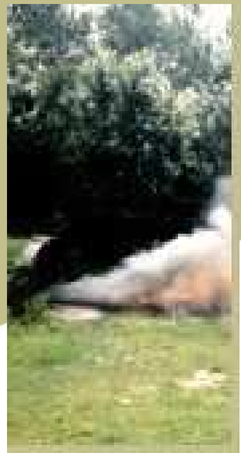



CENTRAL MINING INSTITUTE (GIG)
is a research and development organization related to the Upper Silesian mining industry and region since 1945

The Experimental Mine "Barbara"
in Mikołów was established 20 years earlier than the Institute and now constitutes its part

Poland, 40-166 Katowice, Plac Gwarków 1
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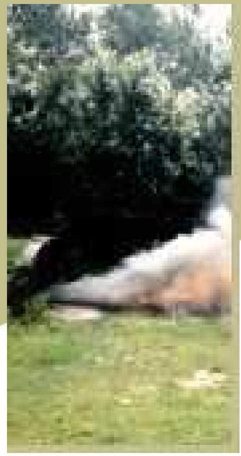




SCIENCE AND RESEARCH IN GIG

MINING AND GEOENGINEERING

SUSTAINABLE ENERGY TECHNOLOGIES (CLEAN COAL TECHNOLOGIES)

ENVIRONMENTAL ENGINEERING

HEALTH AND SAFETY IN INDUSTRY

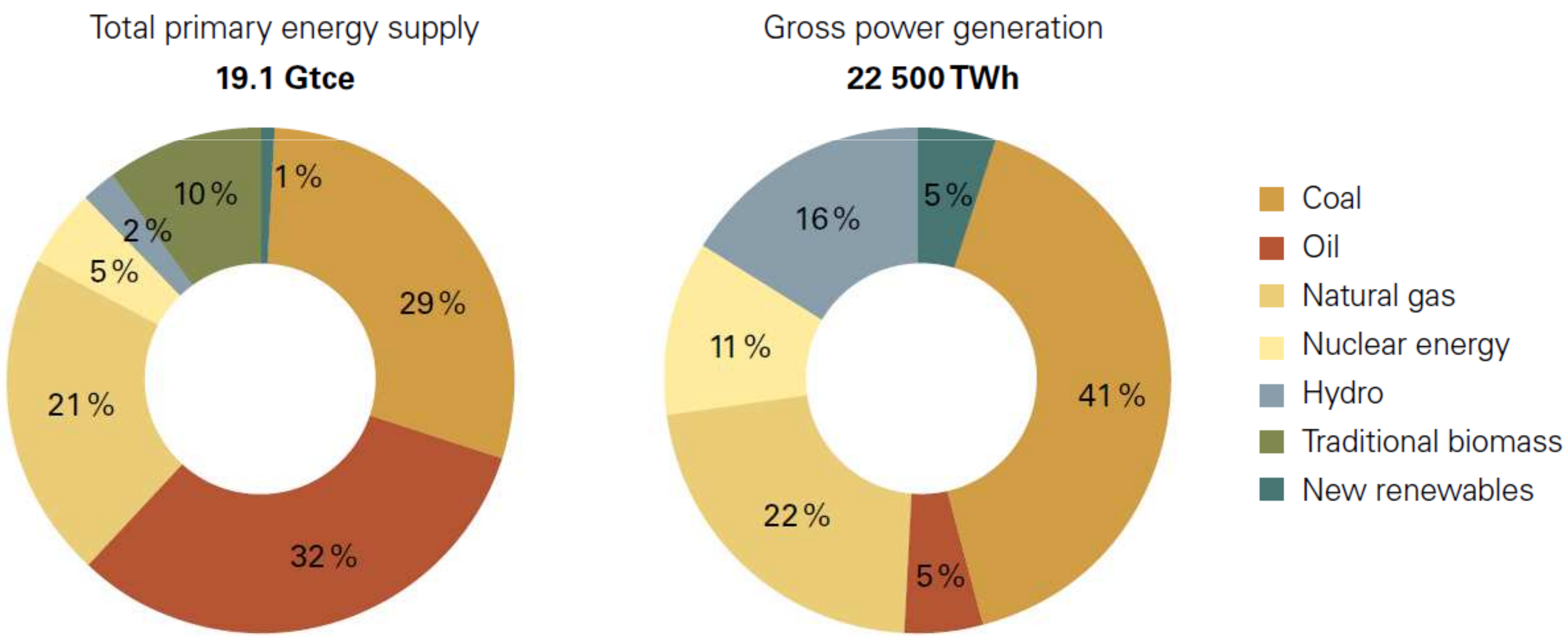
MATERIAL ENGINEERING

RADIOACTIVITY AND IONISING RADIATION

The future of coal

Why coal is such an important fuel?

Coal provides 29% of global primary energy needs and generates 41% of the world's electricity



Source: IEA, EURACOAL, 2013

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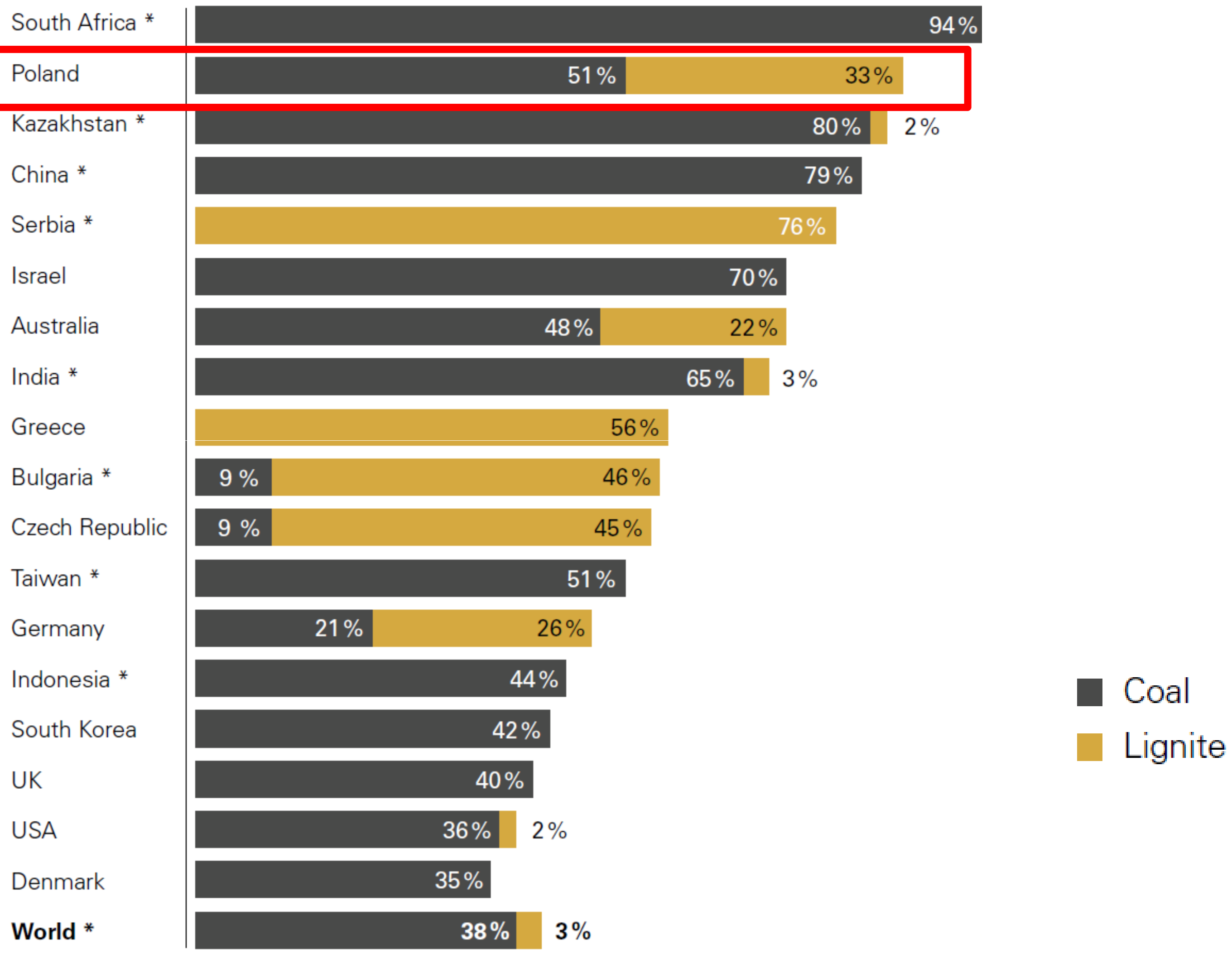
Coal-fired power generation in selected countries, 2012

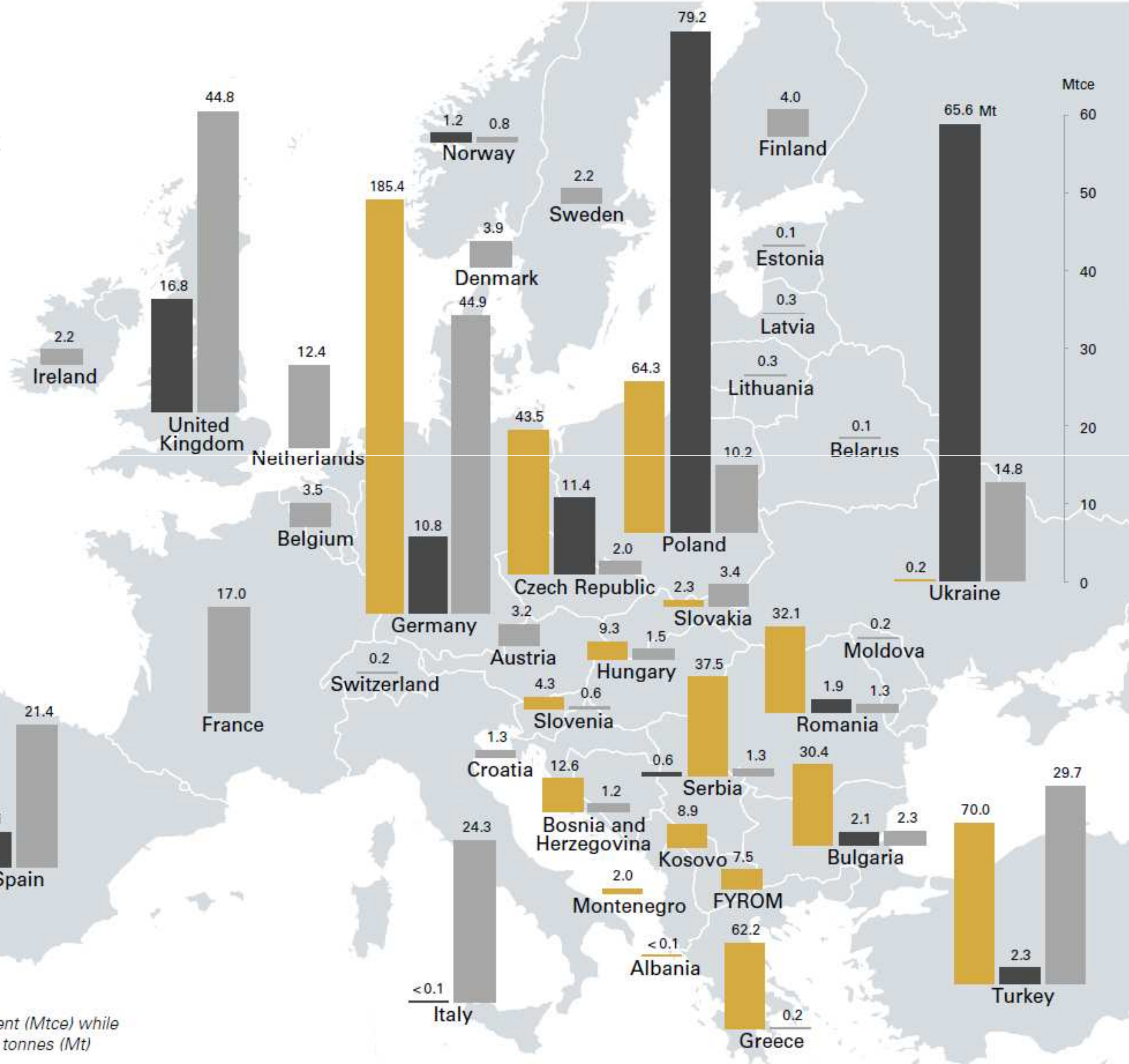


Source: *IEA, EURACOAL, 2013*
**2011 for non-OECD countries*

Coal in Europe 2012

EU - 28

■	Lignite production	434 Mt
■	Hard coal production	128 Mt
■	Imports	213 Mt

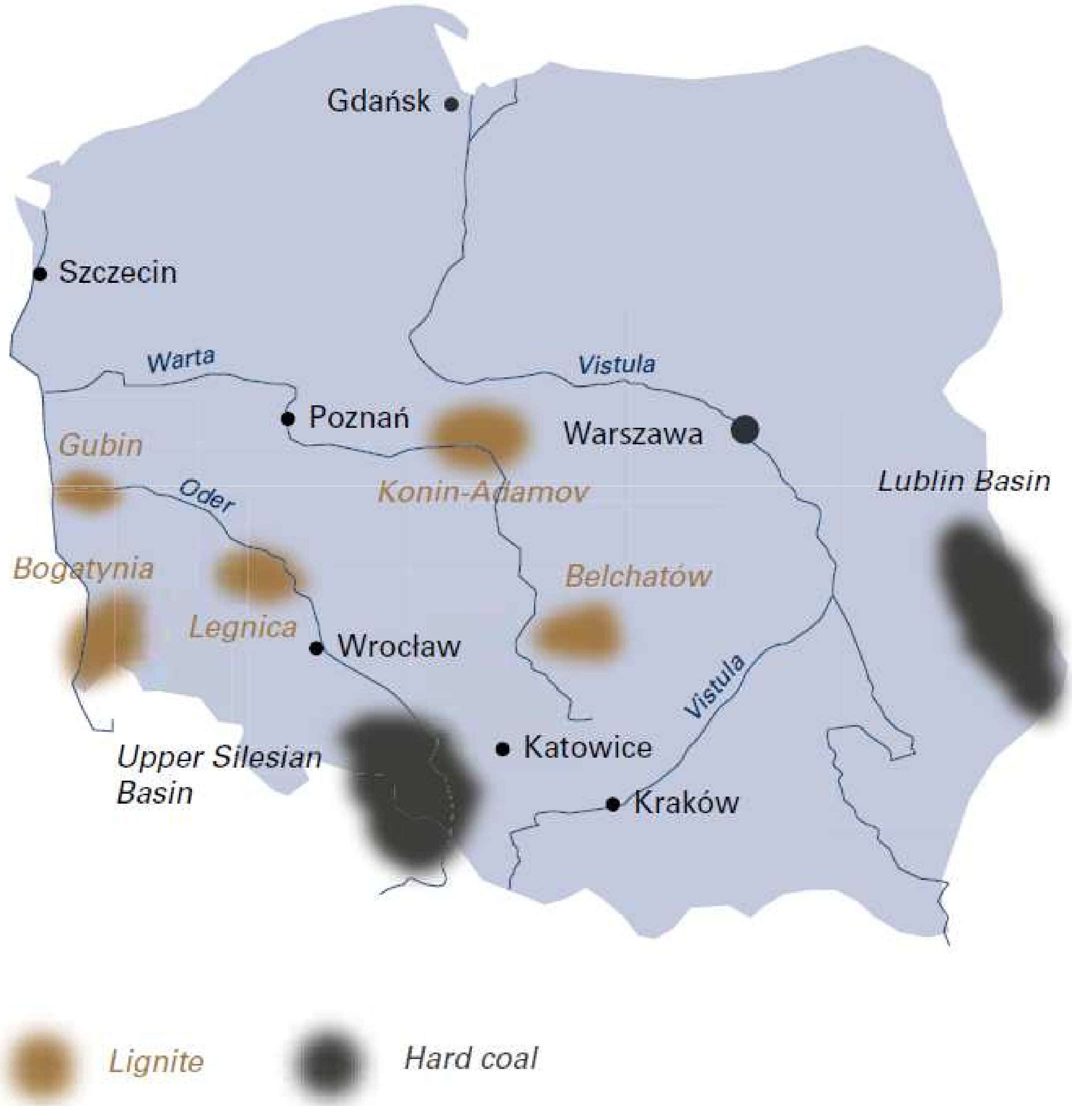


Source: EURACOAL members

Note: bars show million tonnes of coal equivalent (Mtce) while figures at top of bars show millions of physical tonnes (Mt)

Main coal basins in Poland

Lignite and hard coal



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Clean Coal Technology Centre (GIG)
Locations

Katowice – testing laboratories

- Basic research on coal processing processes
- Coal quality characteristics and geology
- Numerical modelling
- Environmental monitoring
- Laboratory research on CO_2 storage potential

Mikołów – technological unit

- Applied research on coal processing technologies
- Syngas processing and utilisation
- Coal-derived liquids
- Large scale experimental installations including UCG tests in real underground conditions

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Laboratory of Experimental Installations

Scope of activities

Conducting R&D works in the field of prospective chemical technologies of coal processing, including in particular:

- process of **underground**, pressure or non-pressure, **coal gasification** aimed at production of syngas with a high content of hydrogen and of gases for power use,
- pressure, **fluidized gasification** of solid fuels in surface conditions,
- **direct coal liquefaction** process aimed at the production of engine fuels and chemical raw materials,
- processes of **hydrogenation** and **refinement** of coal-derived substances,
- **separation** and **purification** of process gases using membrane techniques and methods of absorption and adsorption, including the pressure swing adsorption - PSA,
- **separation of CO_2** from process gases

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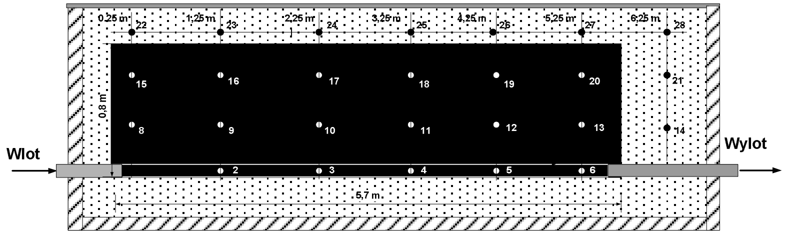
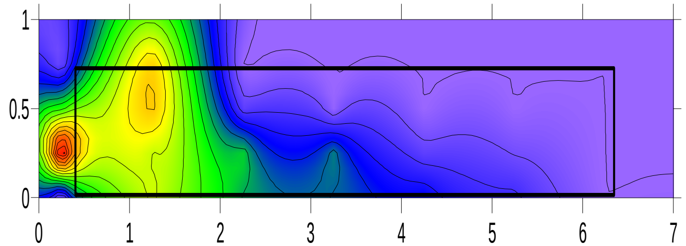
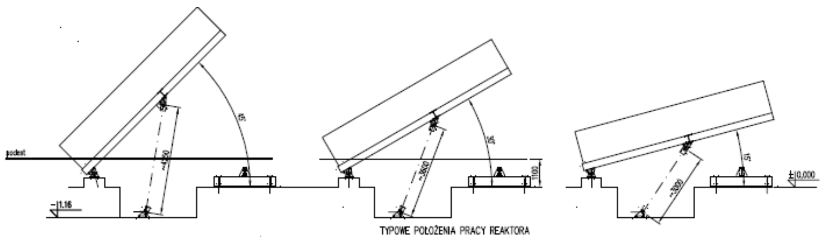
Ex-situ simulation of atmospheric pressure UCG

Technical parameters:

- coal type: lignite, hard coal
- coal seam length: 7 m
- gasification pressure: max 0.5 bar
- temperature: max 1600 ^{0}C
- coal seam inclination: 0, 15, 30 , 45 ^{0}







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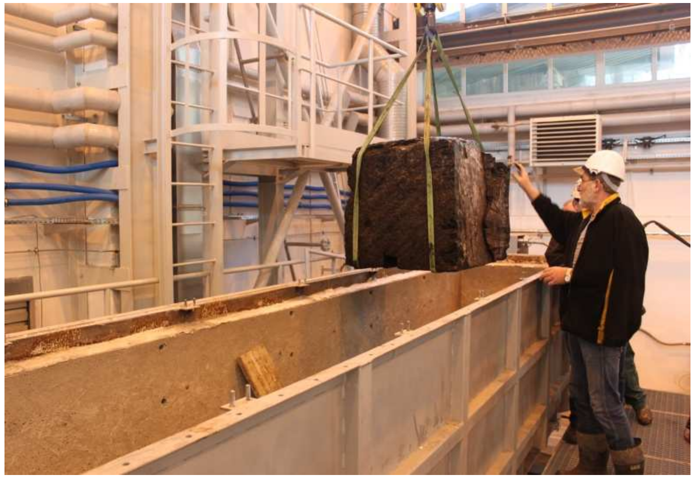
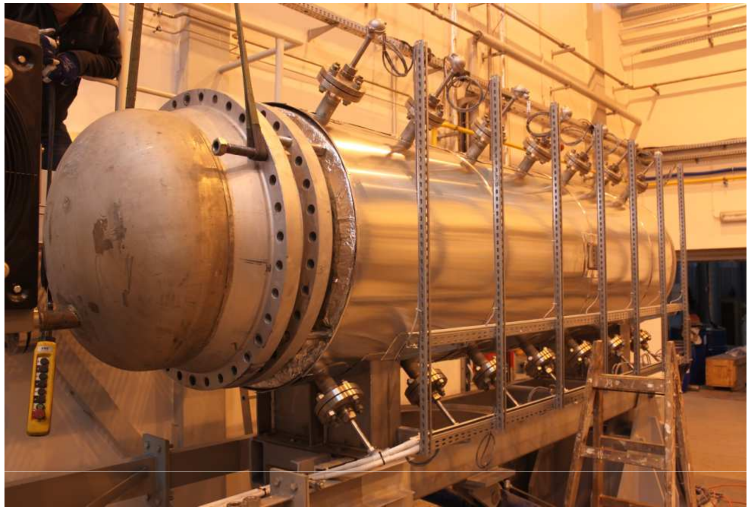
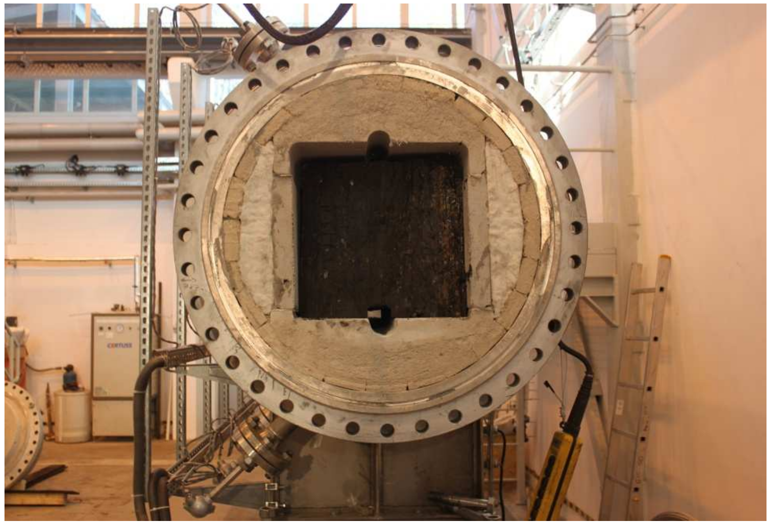
Atmospheric pressure UCG simulation
Preparation of artificial coal seam





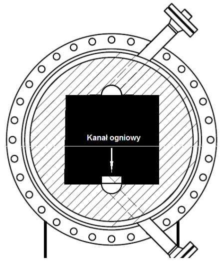

Ex-situ simulation of high-pressure UCG

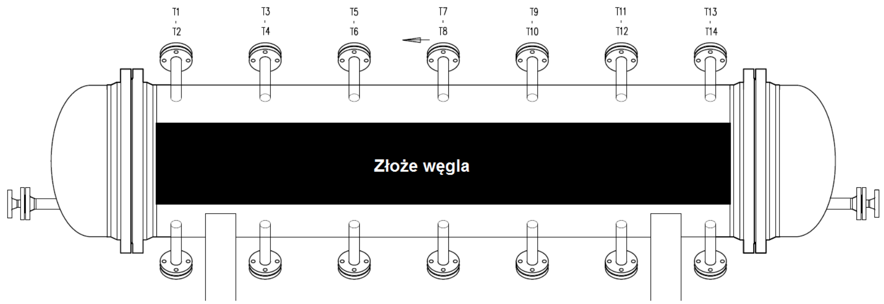


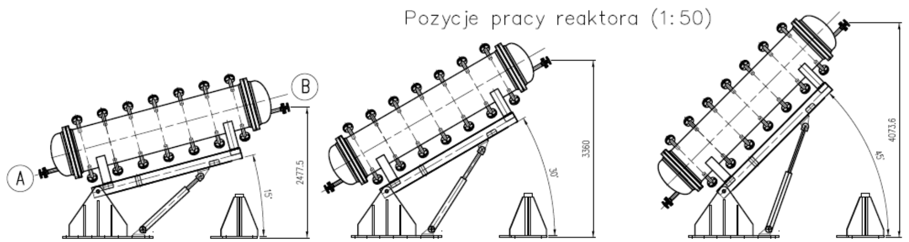


Technical parameters:

- coal type: lignite, hard coal
- coal seam length: 3.5 m
- gasification pressure: max 50 bar
- temperature: max 1600 ^{0}C
- coal seam inclination: 0, 15, 30 , 45 ^{0}







High - pressure UCG simulation

Preparation of artificial coal seam

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Pressurized surface gasifier

Technical parameters:

- feedstock: coal, biomass, wastes
- gasification pressure: max 50 bar
- temperature: max 1300 ^{0}C
- capacity: 10 kg of coal/hour

Gas purification and separation module

Absorption/adsorption vessels

Pressure Swing Adsorption - PSA

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Direct coal liquefaction (hydrogenation)

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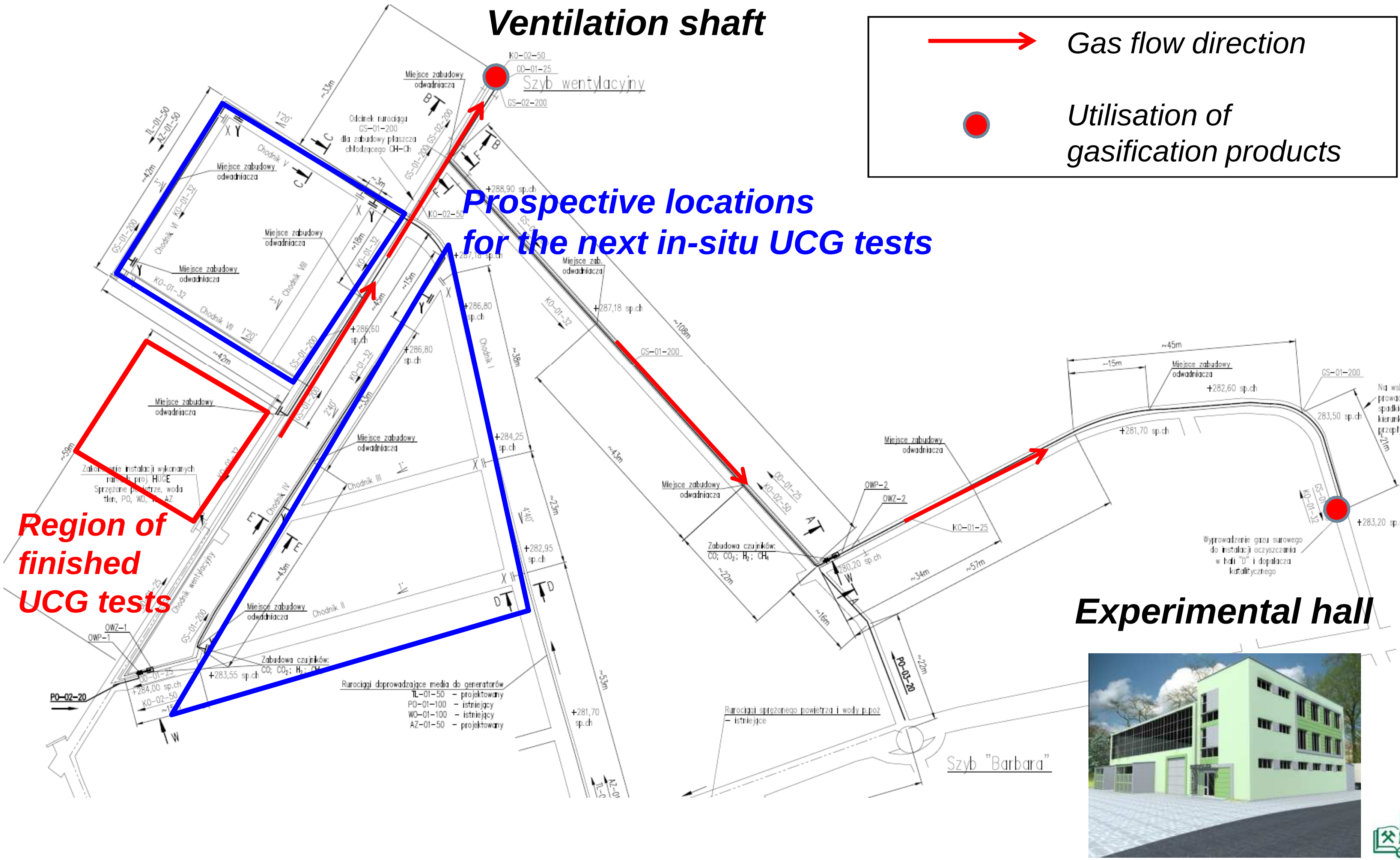
The UCG Underground Test Ground in EM „Barbara”



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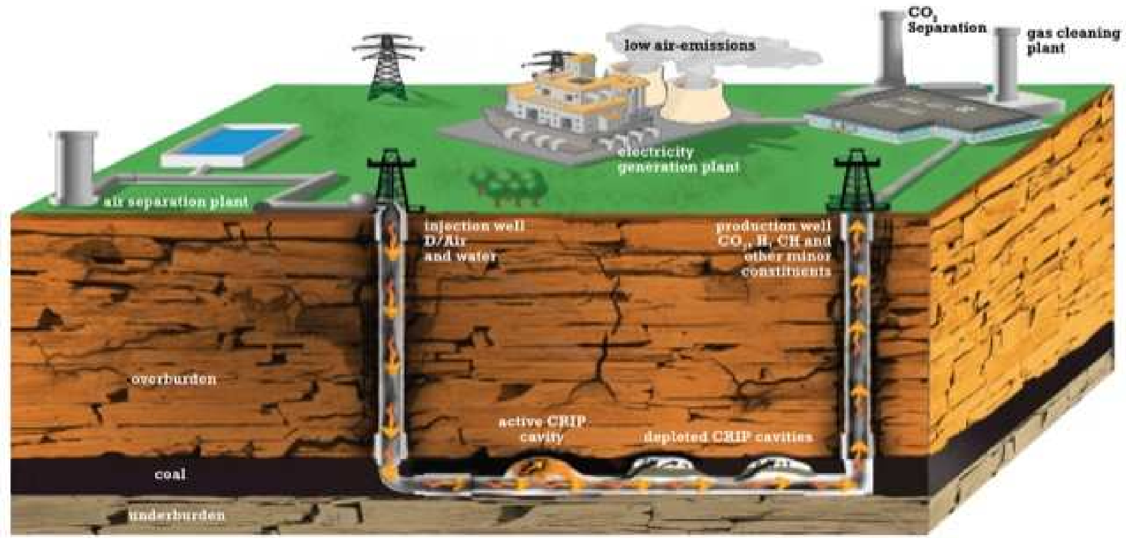
Underground coal gasification

- *Underground Coal Gasification is the process of in-situ conversion of coal deposits to combustible gaseous products (H_2, CO, CH_4)*
- *It is not a new technology but one that has evolved*
- *In recent years it has undergone a transformation due to technical advances, specific research and sharing of knowledge and information*



UCG methods

- ***LVW*** *–Linked vertical well*
- ***CRIP*** *– Controlled retractable injection point*
- ***„Longwall''*** *method*

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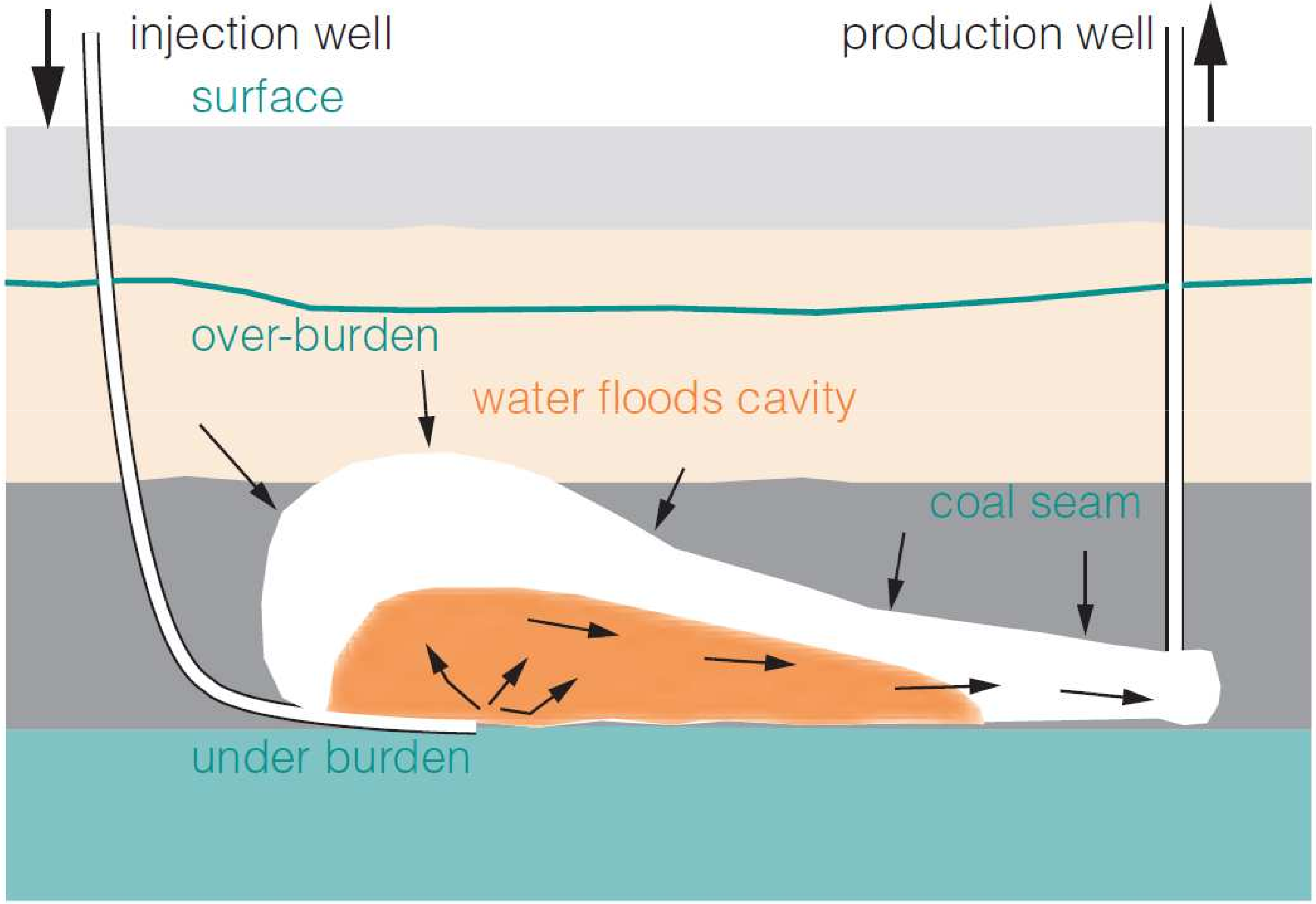
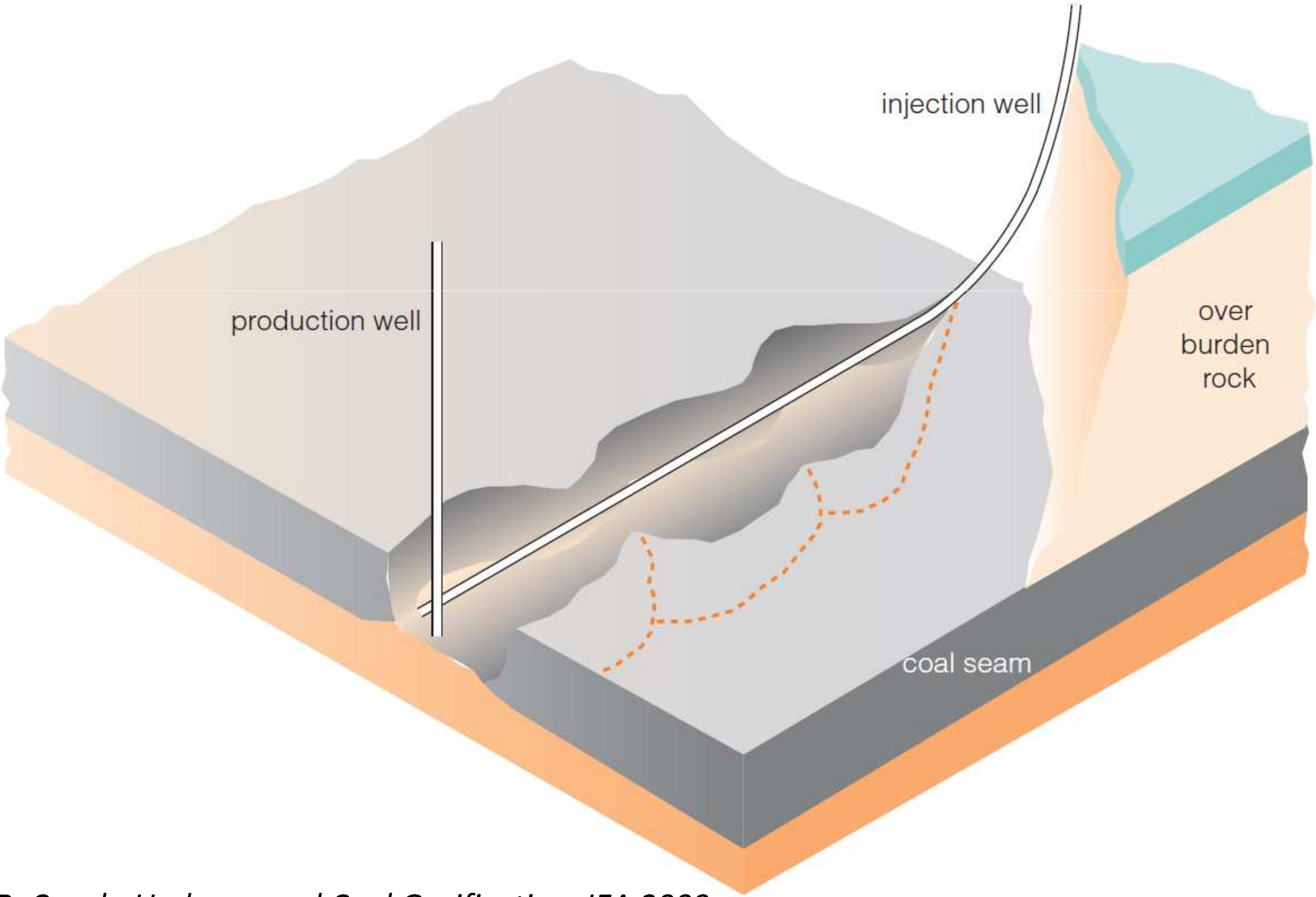
Linked vertical well (LVW)



Source: G.R. Couch, Underground Coal Gasification, IEA 2009

Controlled retractable injection point (CRIP)

The CRIP process retracts the oxidants injection point to control the location of the combustion front



Source: G.R. Couch, Underground Coal Gasification, IEA 2009

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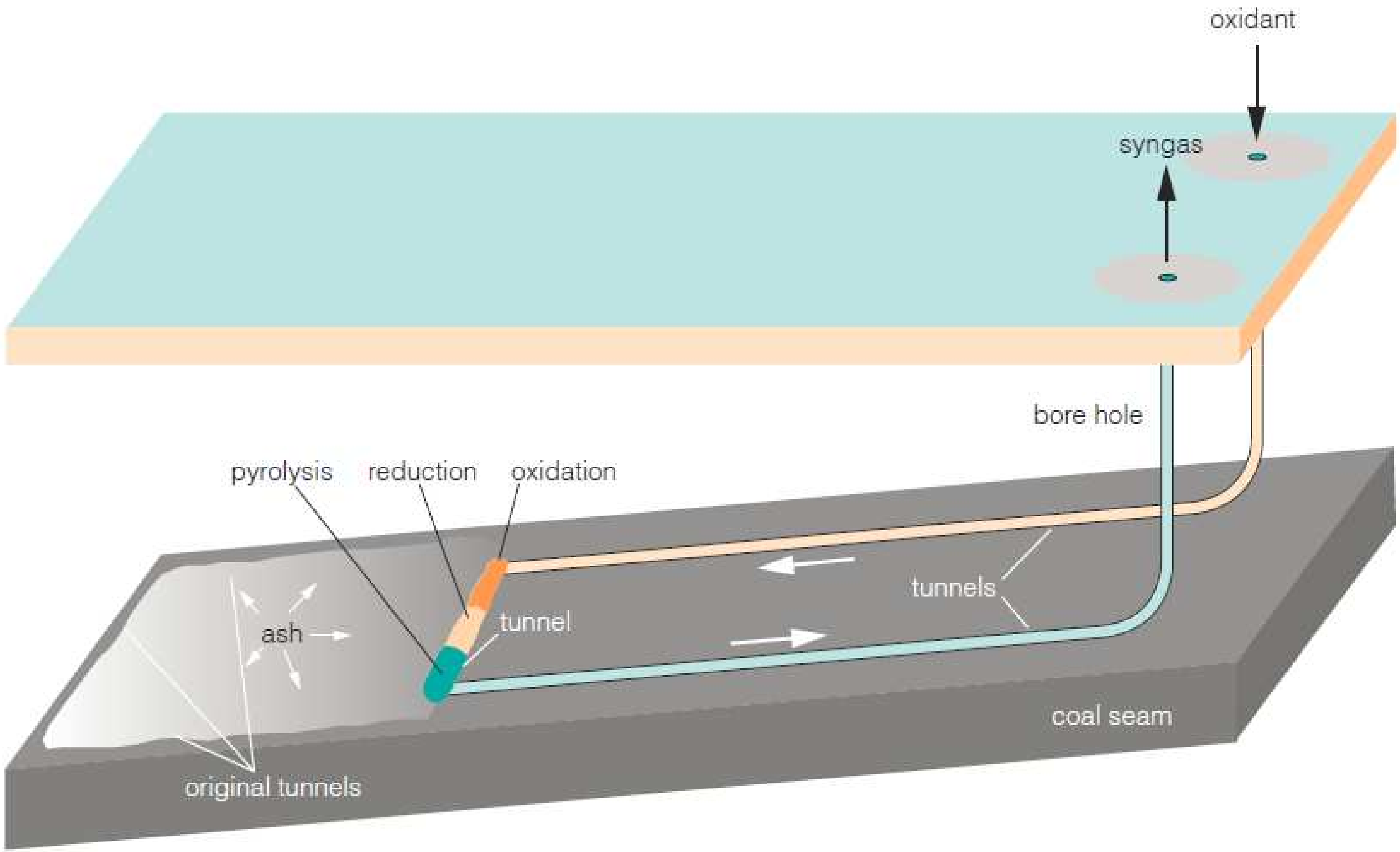
„Longwall" UCG method



<u>Source:</u> G.R. Couch, Underground Coal Gasification, IEA 2009

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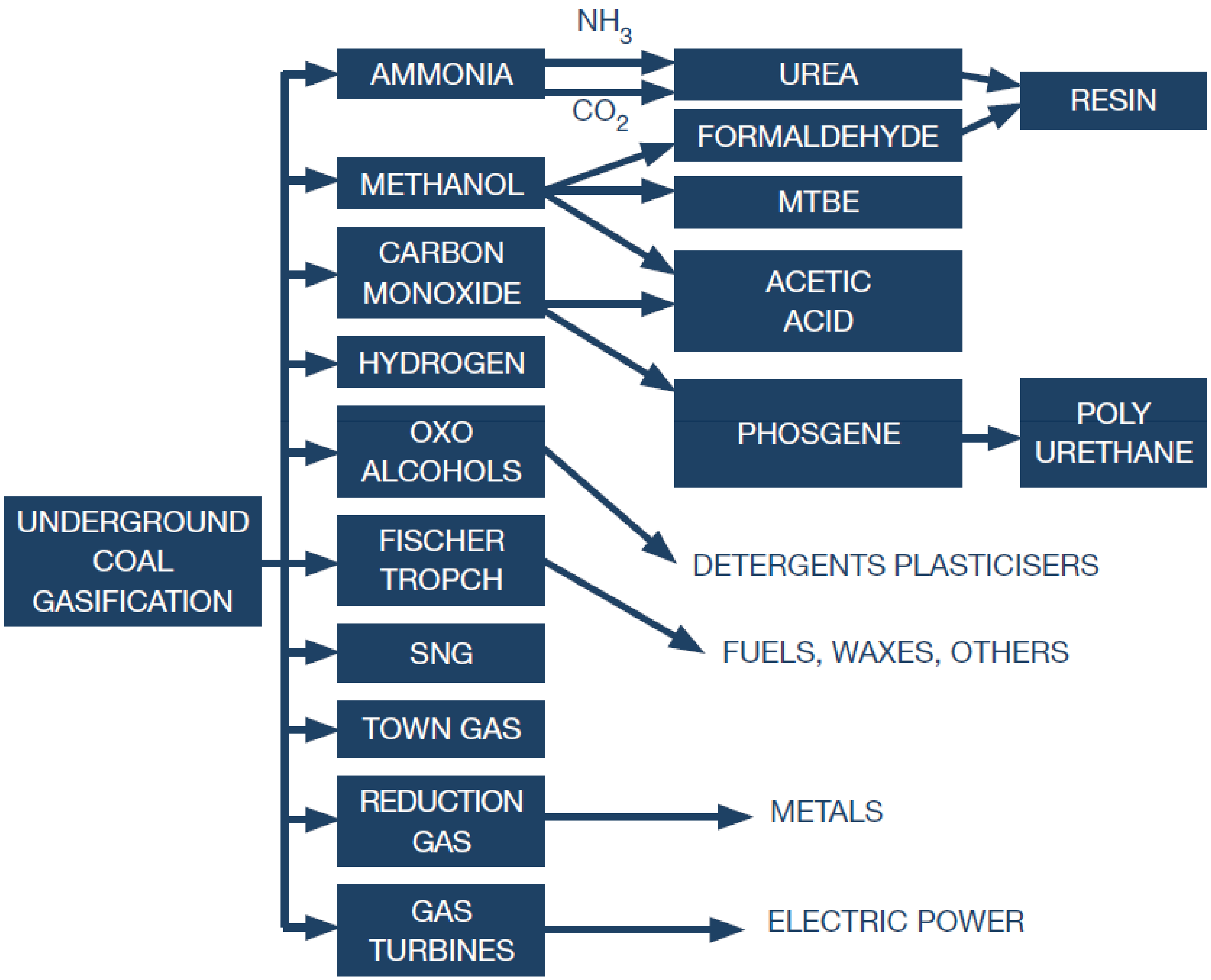
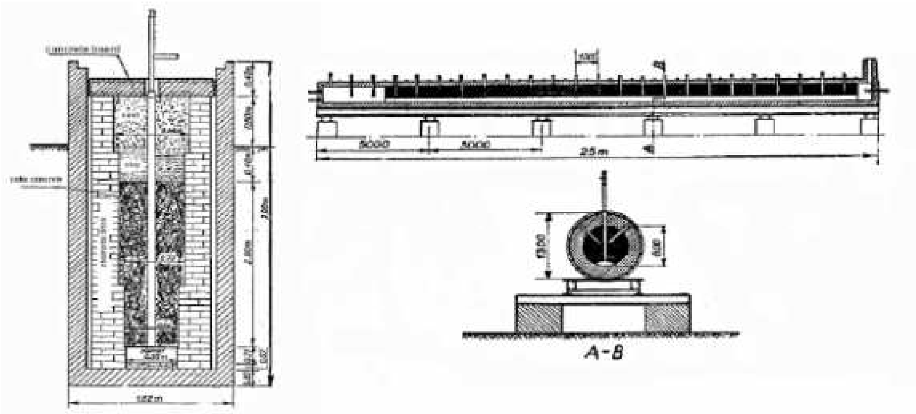
Possible applications of the UCG product gas



Former Polish UCG developments by GIG

The first Polish research programme on UCG (1945 – 1975)

- ***Laboratory and industrial scale research***
- ***Filed-scale UCG experiments in Mine „Mars" mainly with air as gasification agent***



Experimental systems used by „old masters" in UCG tests in GIG in 1956-1960, Dziunikowski (1956)

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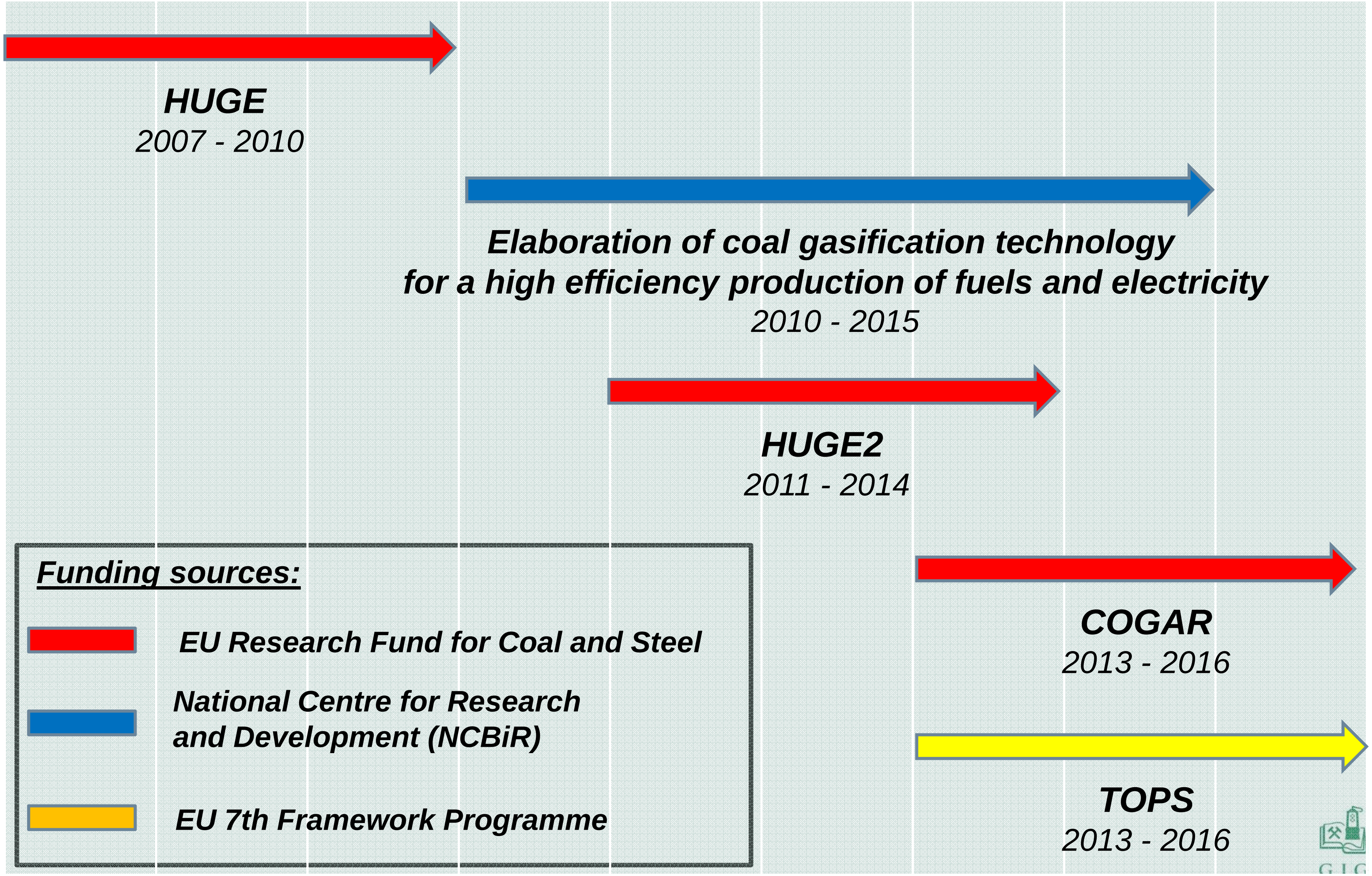
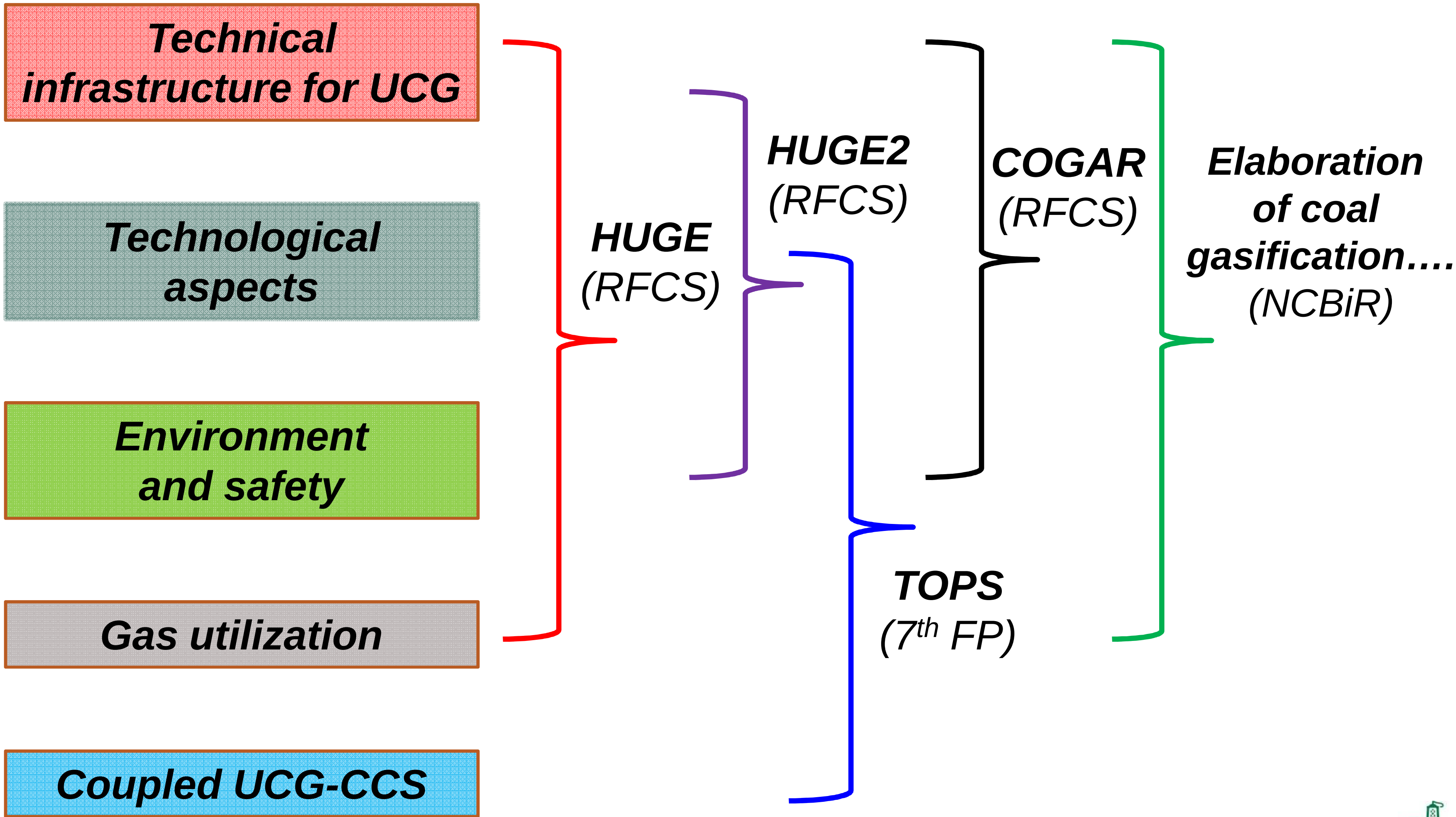
Recent UCG projects in Central Mining Institute (GIG)



UCG aspects under study



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Projects HUGE & HUGE2

***H**ydrogen Oriented **U**nderground Coal **G**asification for **E**urope*

Aims:

*Theoretical and experimental exploration of the possibilities of in-situ production of **hydrogen-rich** gas through the **underground coal gasification (UCG)** technique*

***HUGE 2** – Safety and Environmental Aspects*

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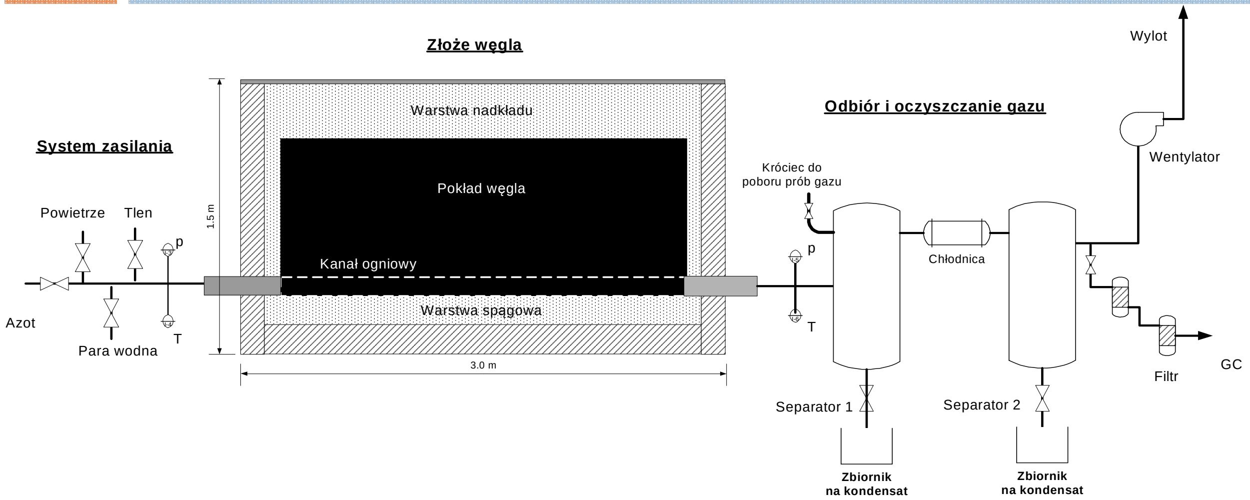
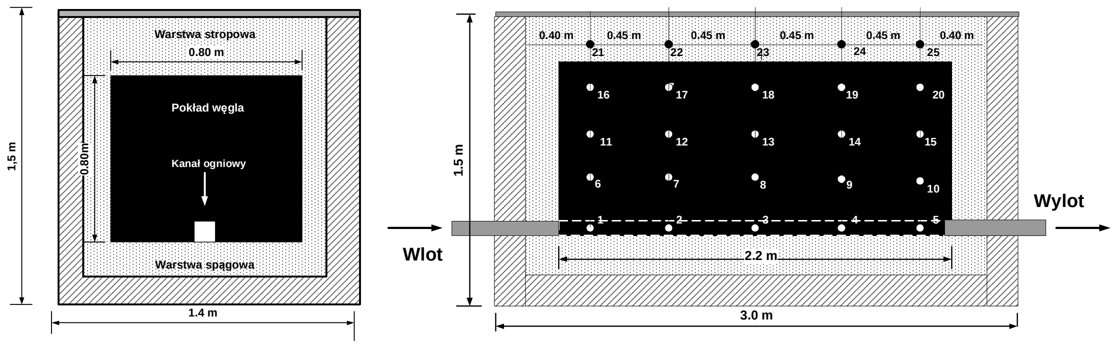
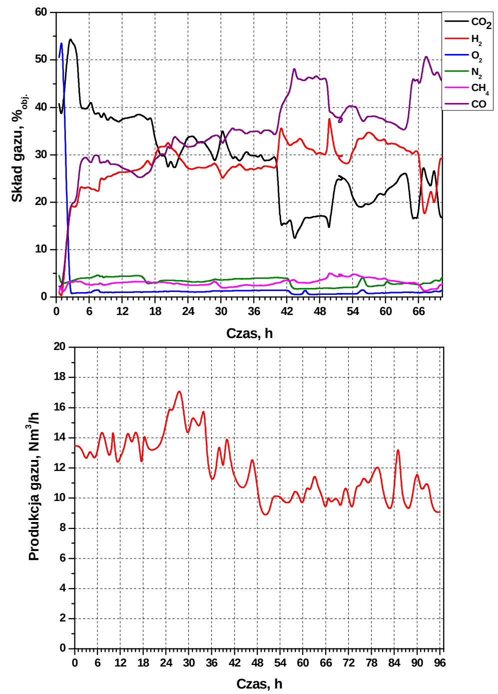
Ex-situ experimental installation

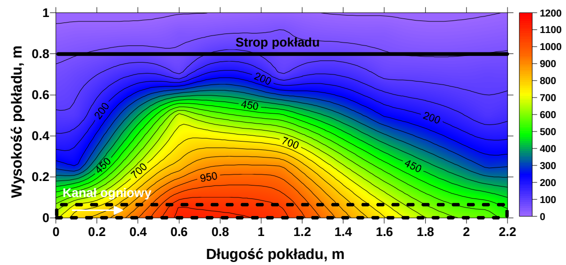




Gas quality control



Temperature control



Installation parameters	
Coal seam dimensions	2,5 x 0,8 x 0,8 m
Gasification agent	Oxygen, air, steam
Gasification temperature	up to 1600^{0}C
Gasification pressure	atmospheric

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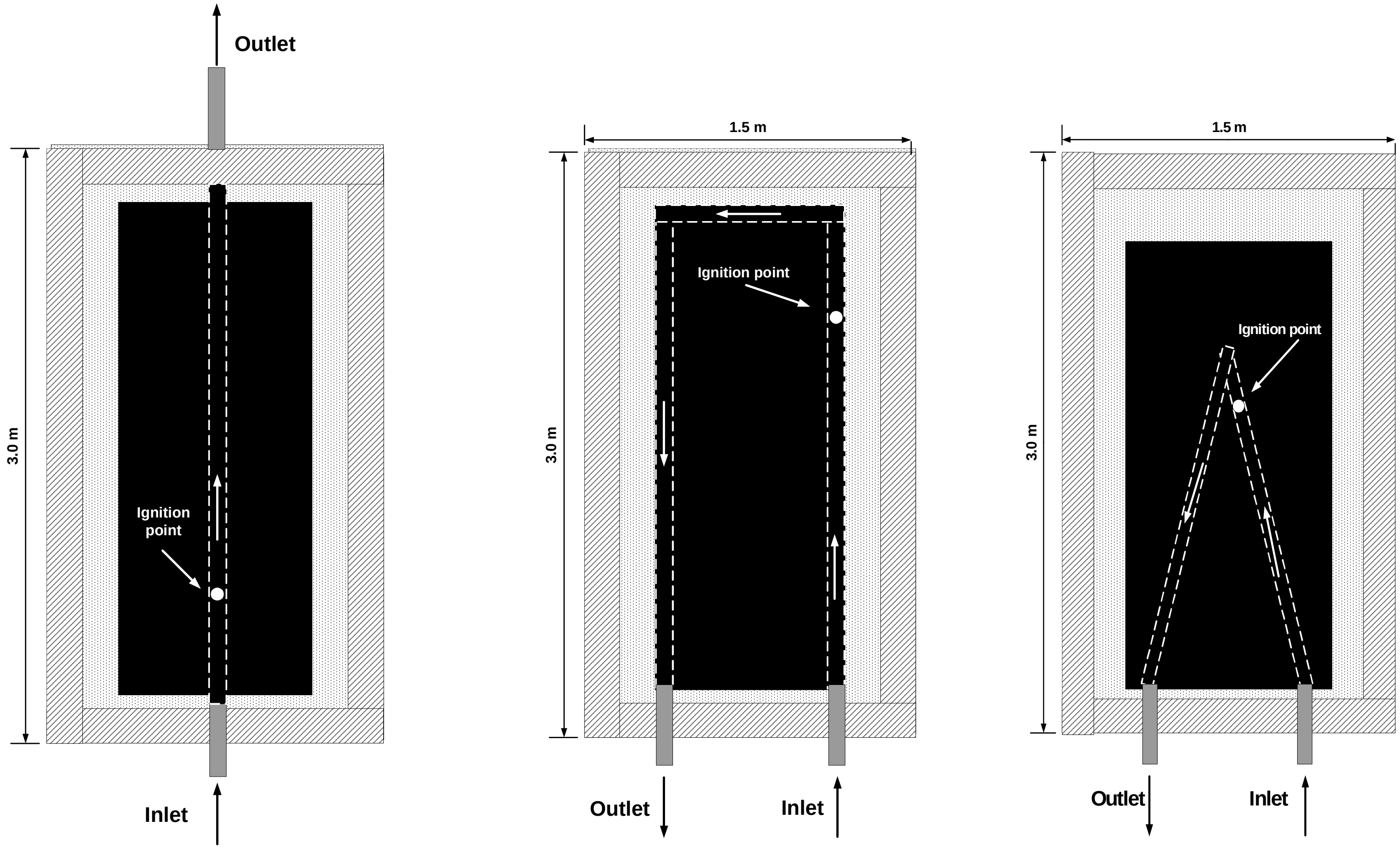
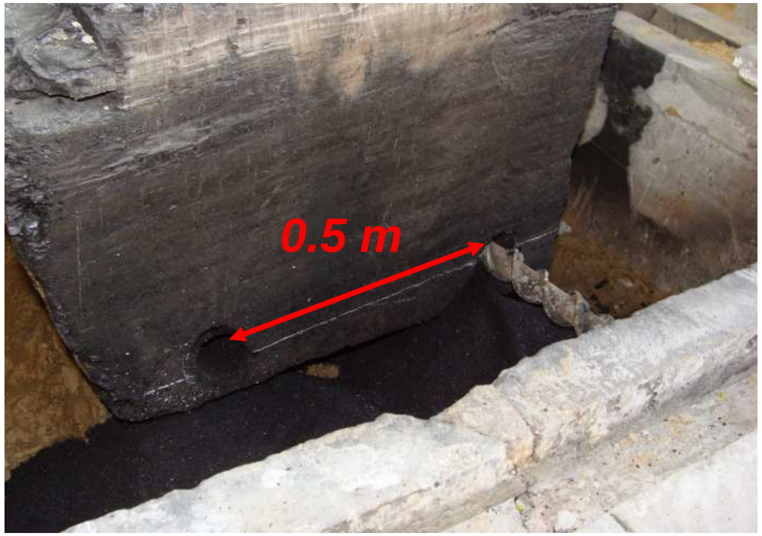
Gasification channel
Tested configurations



Examples of large coal samples



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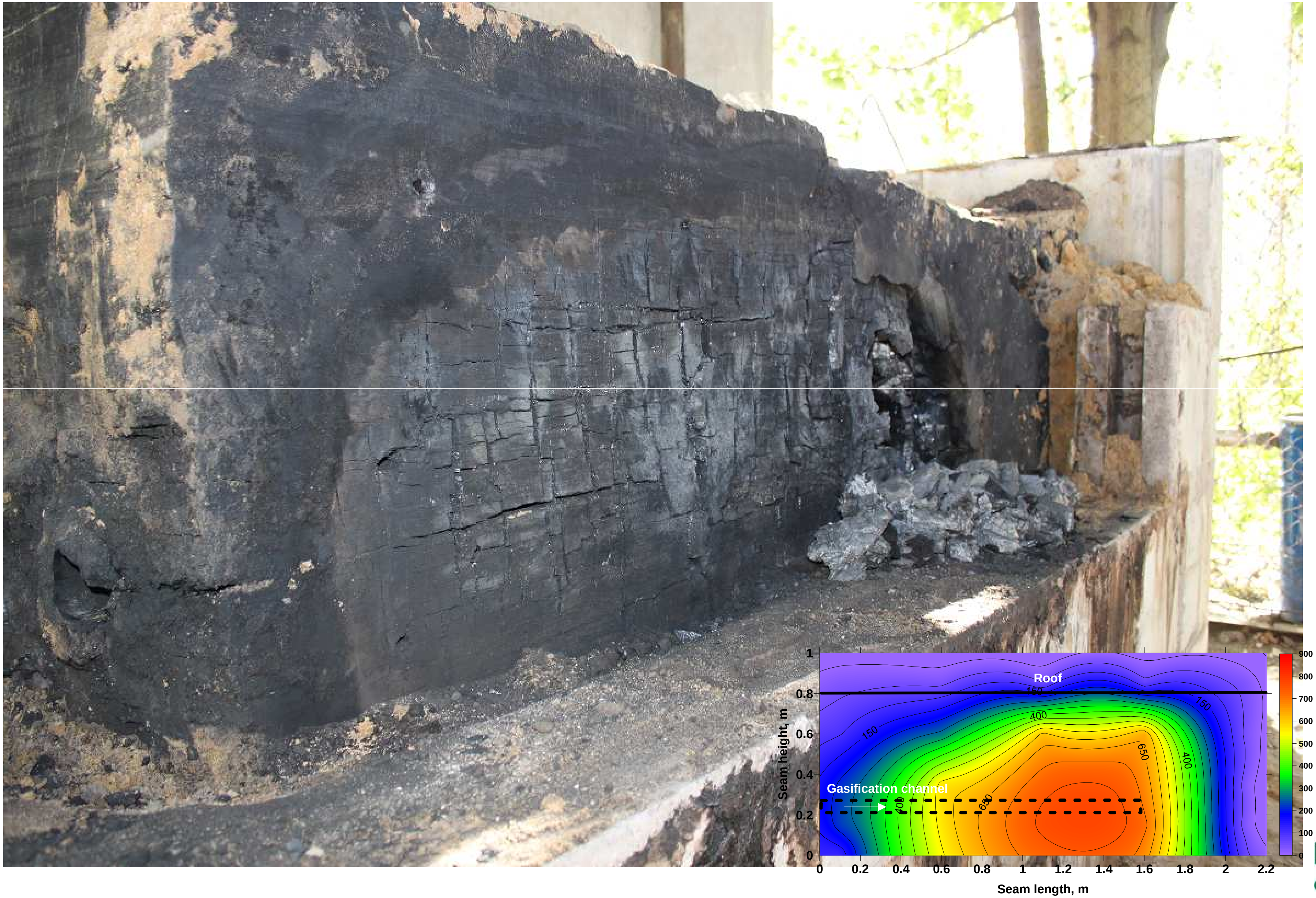
Post-gasification studies

Cavity shape



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Ex-situ UCG experiments

Results

Type of coal	Gasification agent	Average gas composition, $\%_{vol}$					Heating value, MJ/m^3
		CO_2	H_2	N_2	CH_4	CO	
Hard coal	Oxygen	31.7	**26.7**	3.3	1.5	32.1	8.5
	Oxygen + steam	36.1	**28.2**	4.2	5.5	25.0	8.2
	„Two stage" Oxygen cycle	57.0	**15.3**	5.1	3.1	17.6	5.0
	Steam cycle	14.0	**53.8**	4.7	9.8	15.8	11.5
Lignite	Oxygen	70.4	**14.3**	5.1	1.5	5.6	3.1

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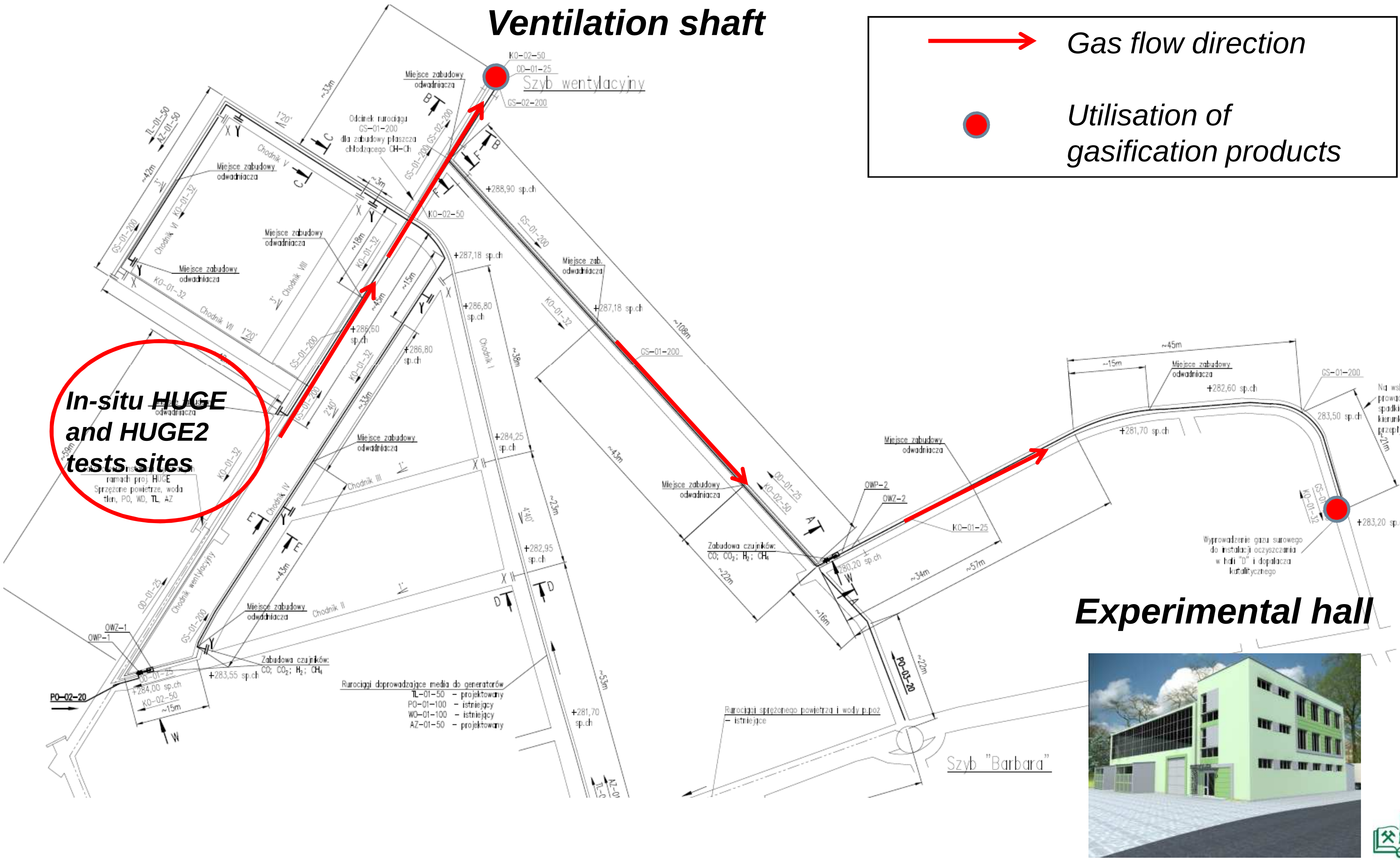
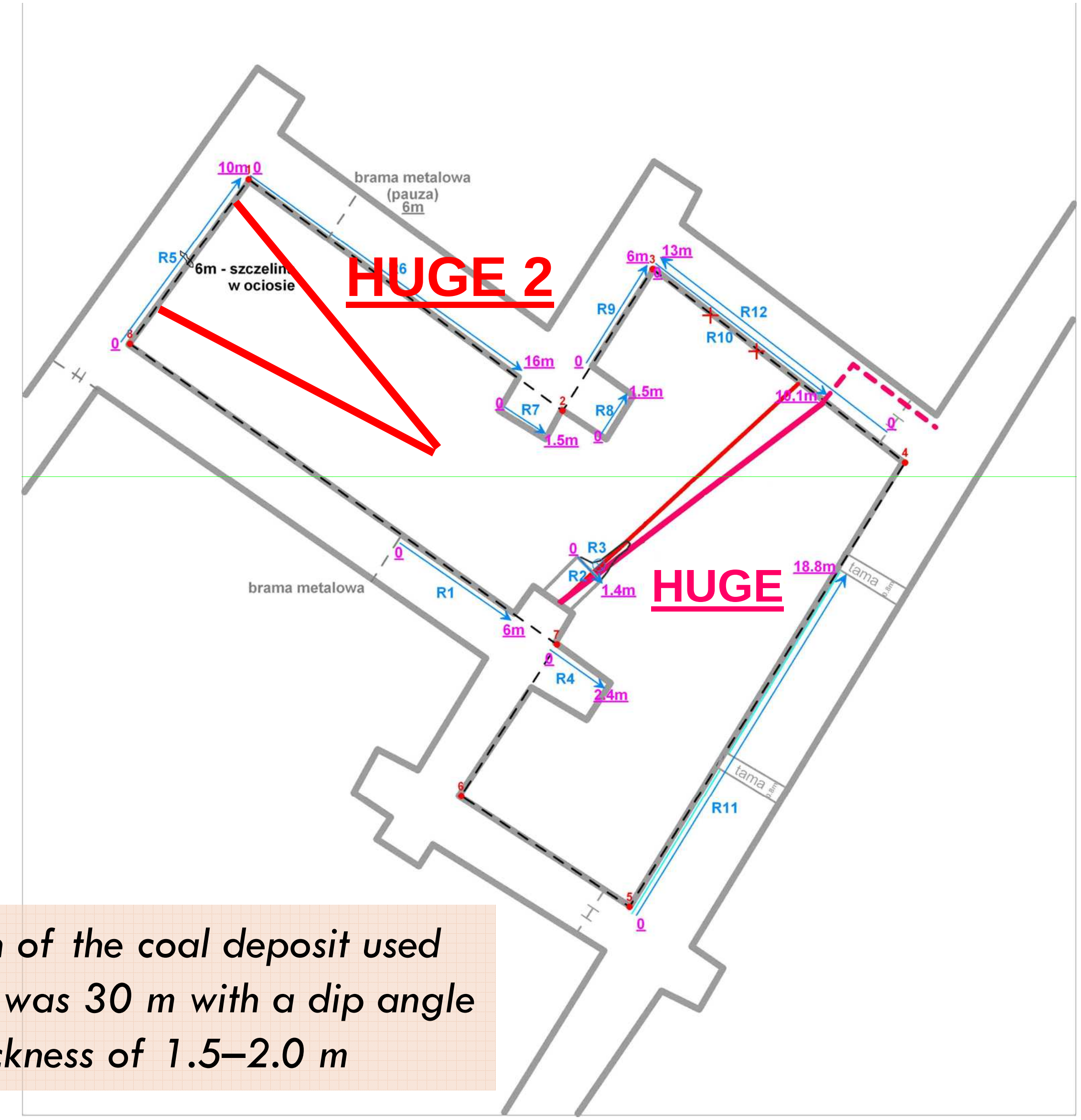
Experiments on underground coal gasification process (UCG) in natural conditions

In situ UCG experiments
Test sites



Location of HUGE and HUGE2 underground gasifiers and tested configurations of gasification channels



The average depth of the coal deposit used in the experiments was 30 m with a dip angle of 4–6° and a thickness of 1.5–2.0 m

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Barbara Mine

Coal characteristics

No.	Coal parameter	Value
	As received	
1	Total moisture [%]	11.8
2	Ash [%]	15.6
3	Total sulphur [%]	0.5
4	Calorific value [kJ/kg]	21 708
	Analytical	
5	Moisture [%]	6.4
6	Ash [%]	16.5
7	Volatiles [%]	29.8
8	Calorific value [kJ/kg]	23 019
9	Total sulfur [%]	0.5
10	Carbon [%]	57.95
11	Hydrogen [%]	3.7
12	Nitrogen [%]	0.9

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Coal seam No. 301 before gasification

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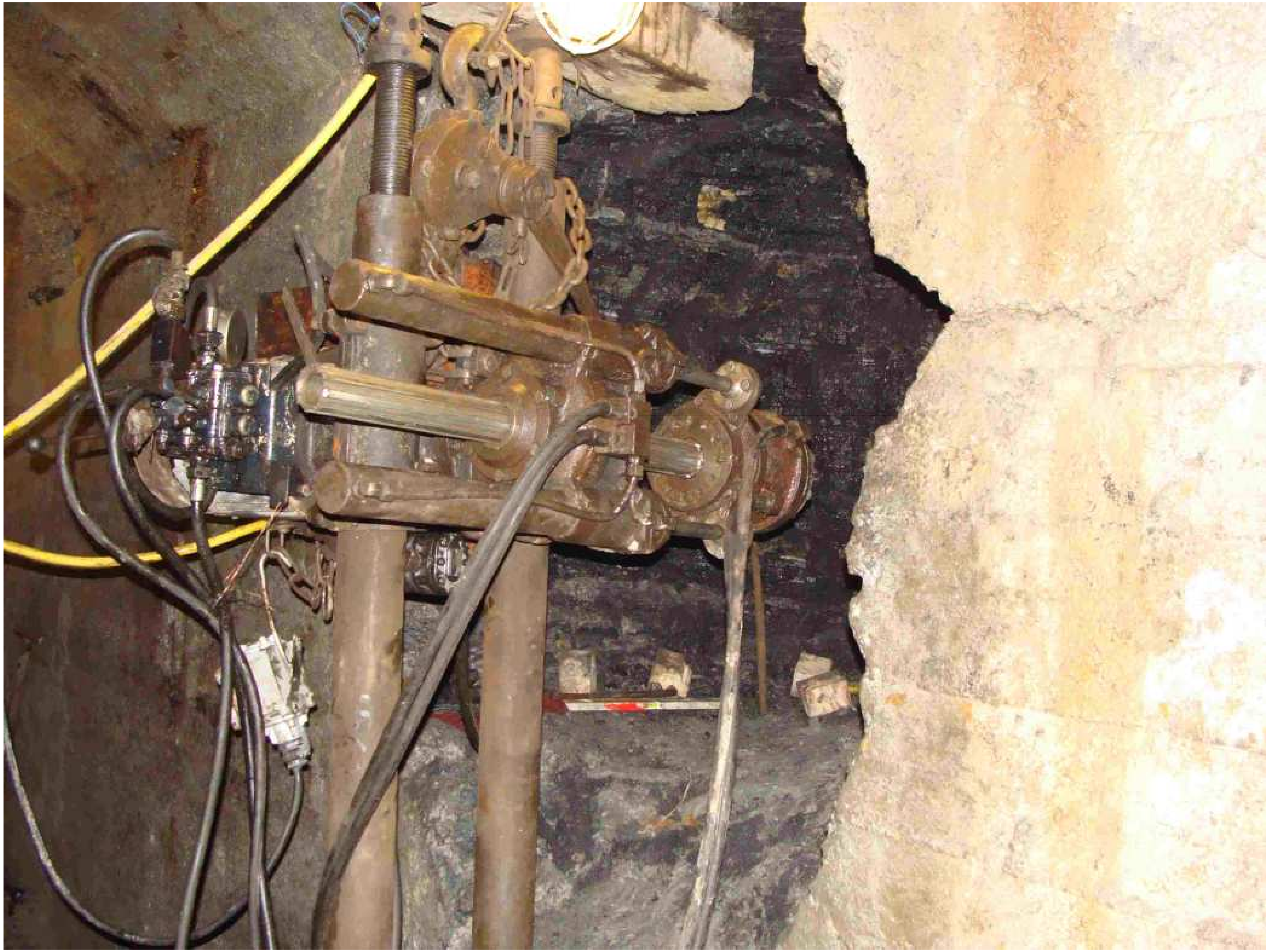
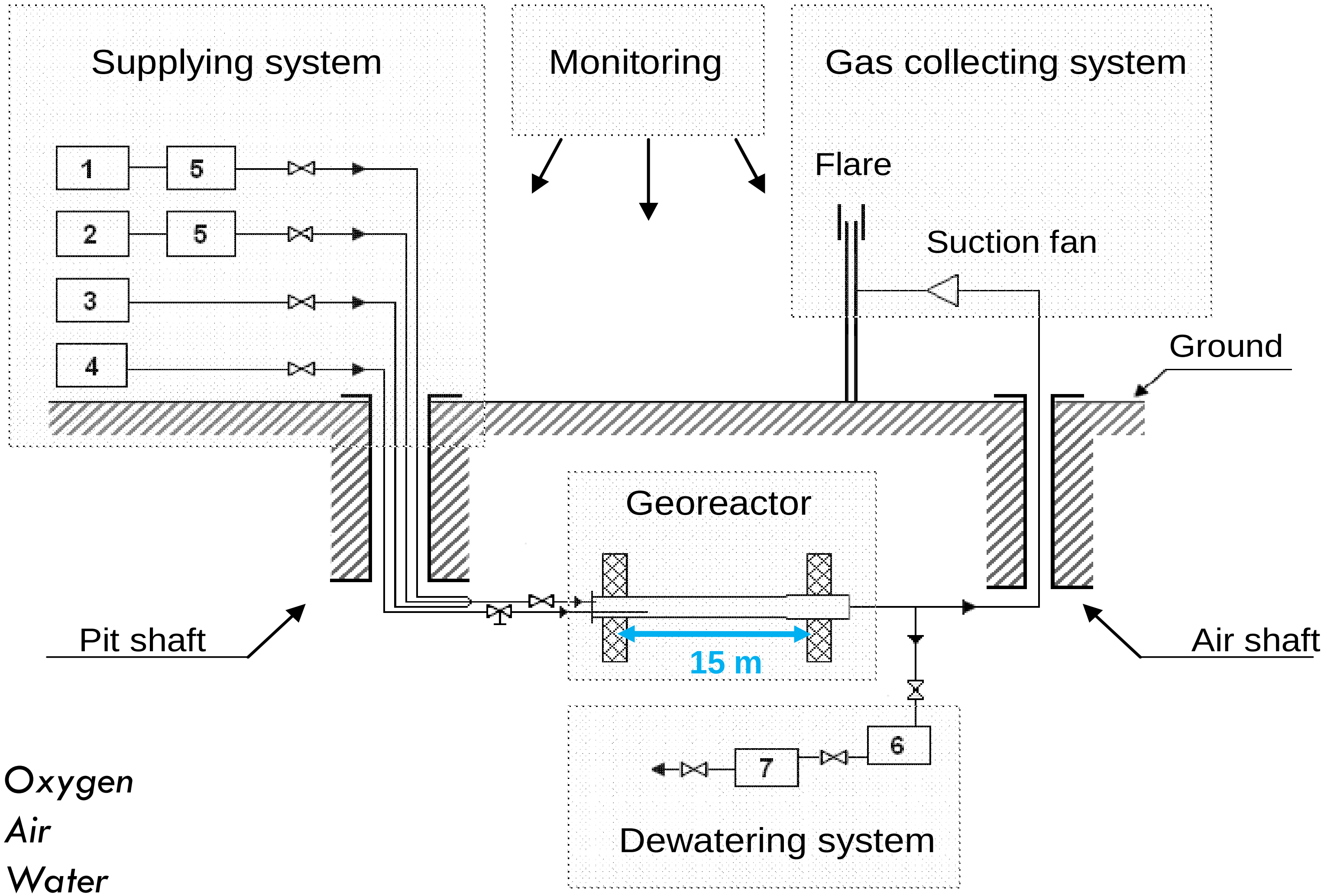
Preparation of gasification channels



Scheme of the in-situ installation



1. Oxygen
2. Air
3. Water
4. Nitrogen

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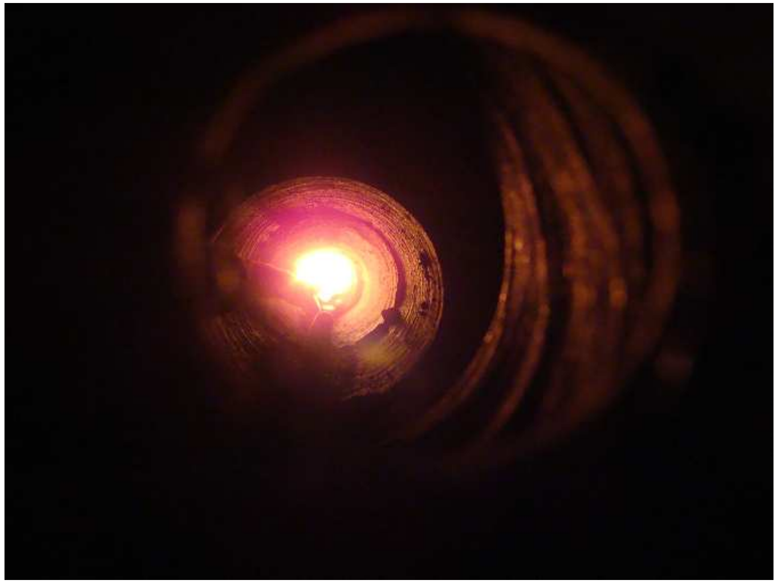
Coal seam ignition



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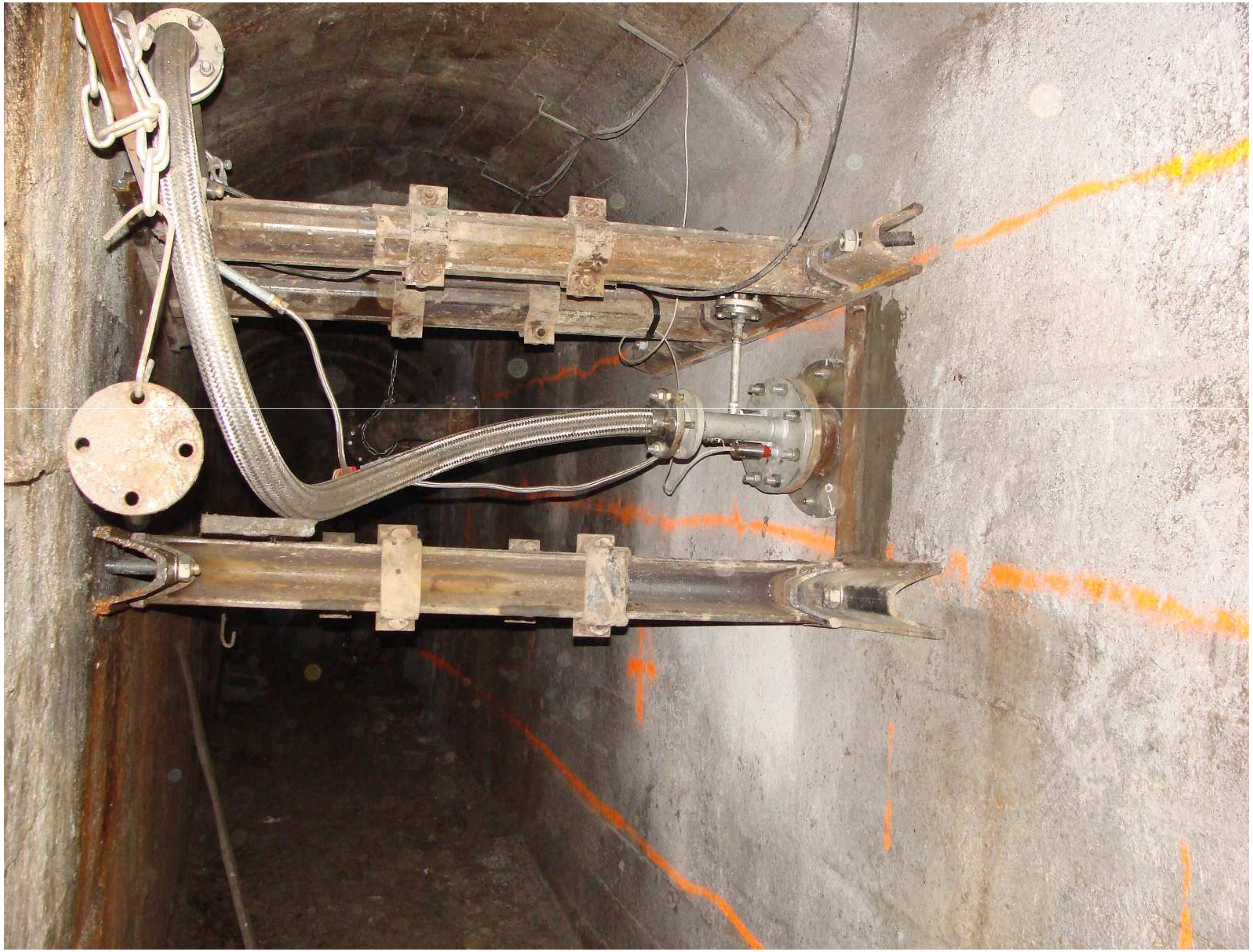
UCG reactor inlet



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UCG product pipelines

UCG product pipelines

Gas composition and safety monitoring

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Oxygen source – mobile criogenic tank

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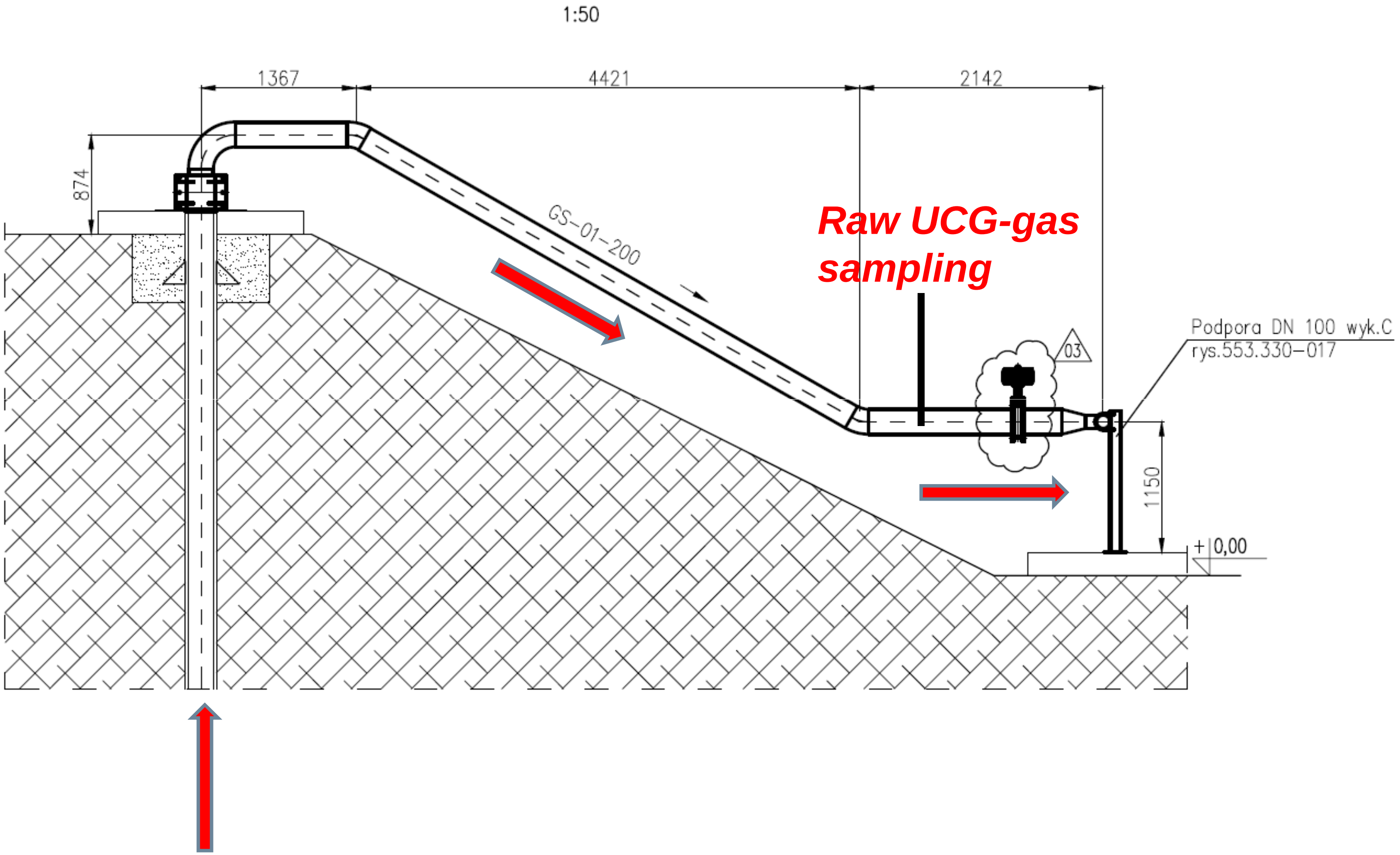
UCG gas combustion
Thermal combustor

Flame of UCG-derived gas

UCG gas combustion
Flare stack (alternative)

Contaminants monitoring system

Tar compounds in raw UCG gas



Raw UCG-gas from underground

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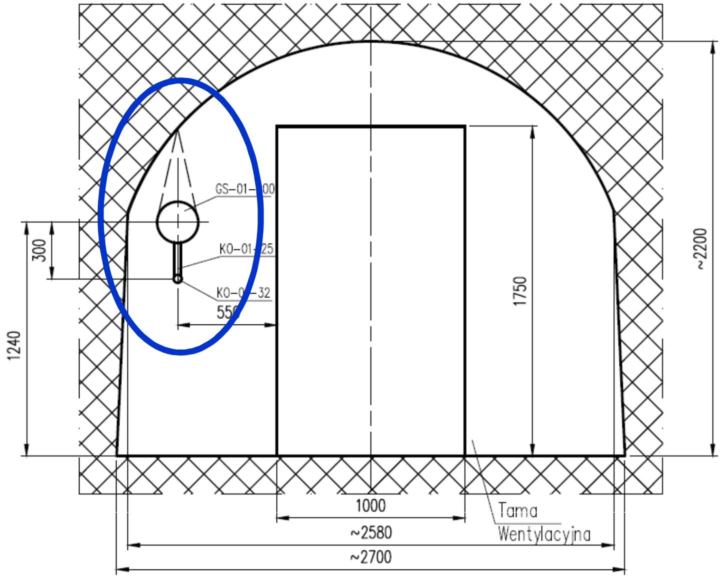
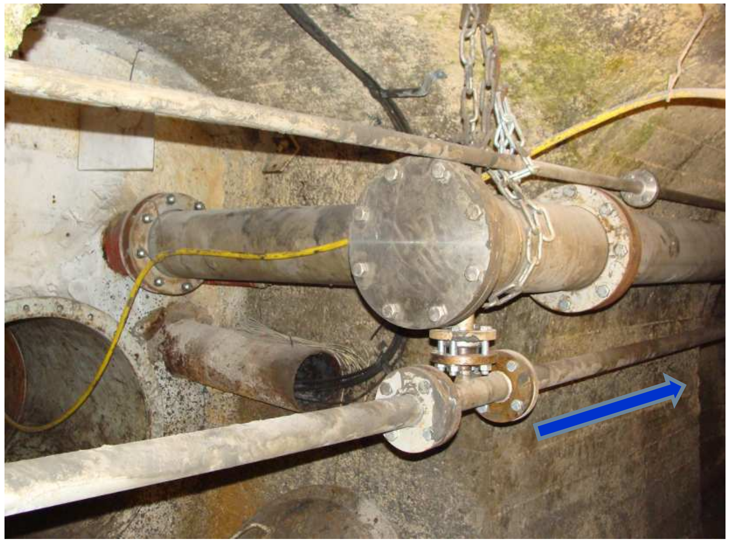
Contaminants monitoring system

Post-processing water (condensate) collection system





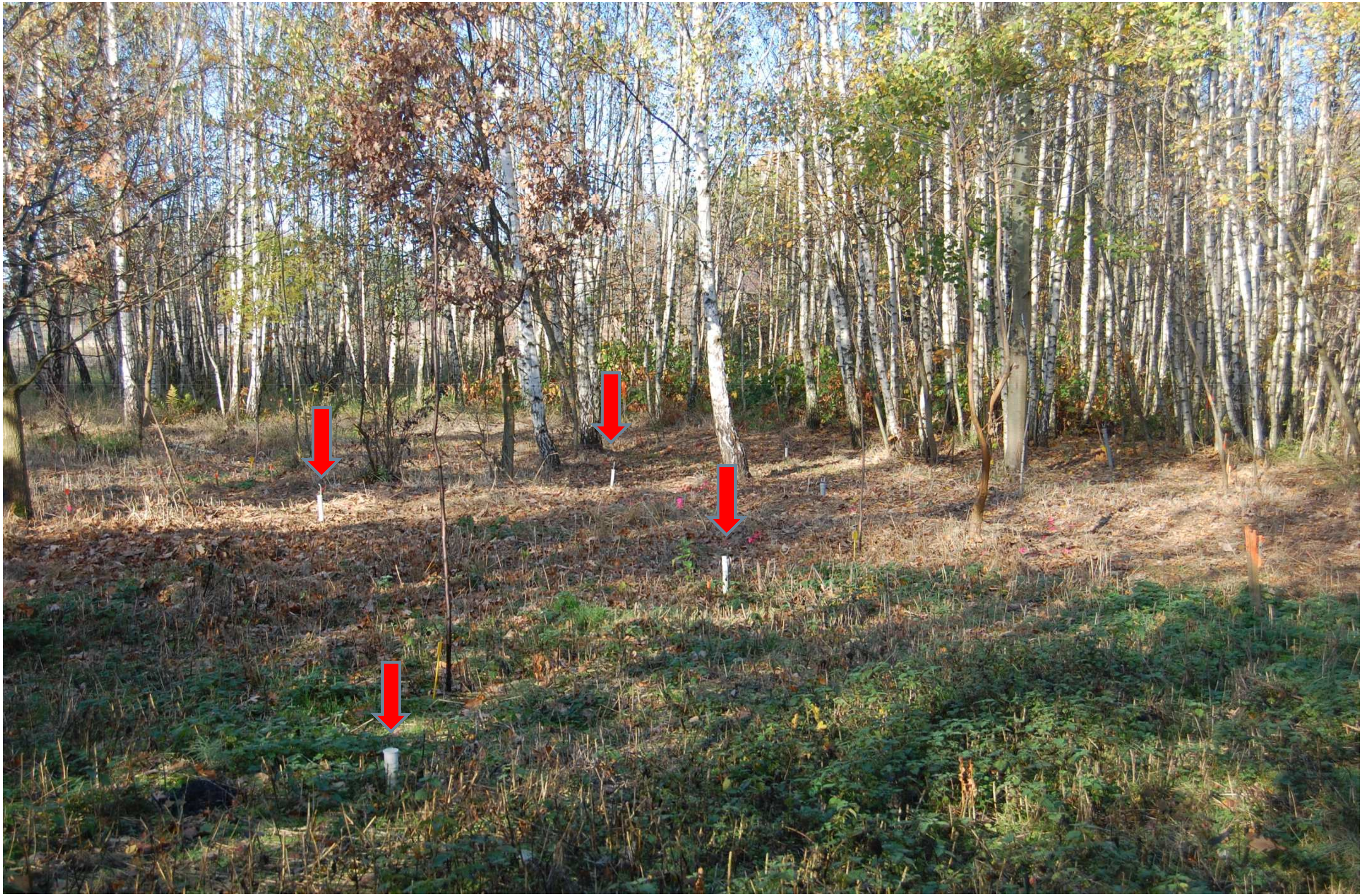
Groups of tar compounds determined in raw gas

Compound/group of compounds	Sampling method	Determination method
BTEX: Benzene, Toluene, Ethylbenzene, Xylenes (o-, m- p- isomers)	Sampling on sorbent tube with activated carbon (SKC Anasorb CSC, 600 mg) Two samples in parallel	Gas chromatography with FID detector (AGILENT 7890A)
15 PAHs: Naphthalene (NaP), Acenaphthene (AcP), Fluorene (Flu), Phenanthrene (Phe), Anthracene (AnT), Fluoranthene (Fla), Pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Dibenzo(a,h)anthracene (DBA), Benzo(g,h,i)perylene (BghiP), Indeno(1,2,3-cd)pyrene (IND)	Sampling on sorbent tube with polymer rasin (SKC XAD-2, 600 mg) Two samples in parallel	Gas chromatography with MS detector (AGILENT 7890A)
Phenols: Phenol (hydroxybenzene) o – Cresol m – Cresol p – Cresol	Sampling on sorbent tube with silica gel(SKC Silica Gel, 600 mg) Two samples in parallel	Gas chromatography with FID detector (AGILENT 7890A)

Groundwater monitoring
Sampling vertical wells

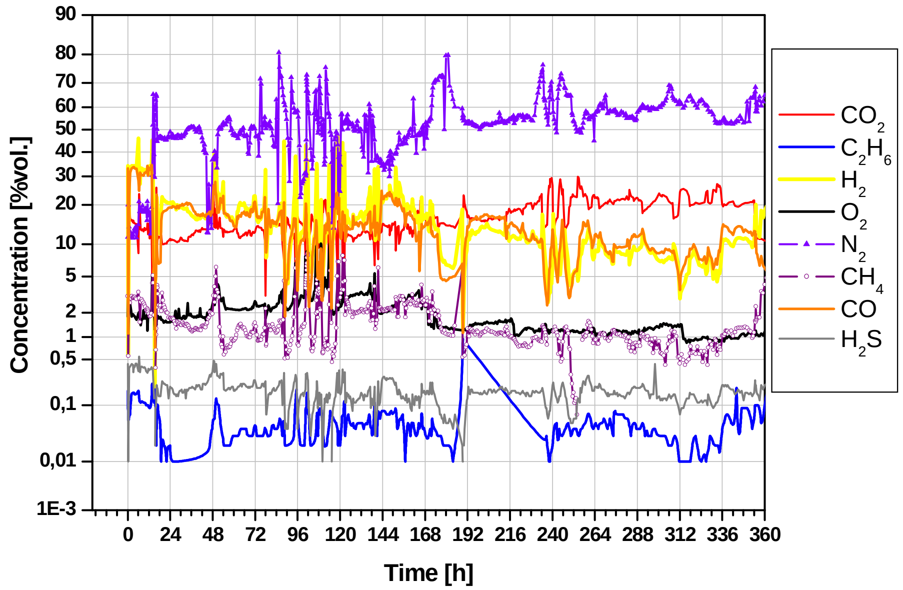
Groundwater monitoring

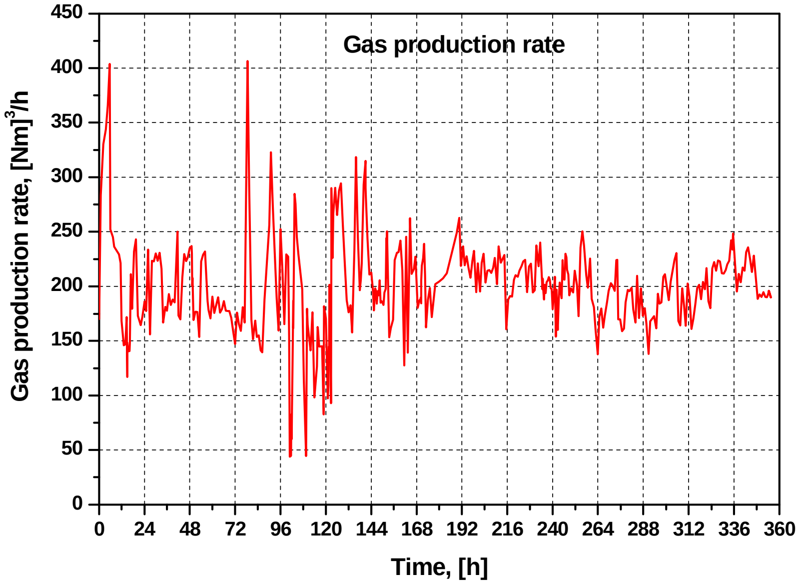
Sampling vertical wells



General results

In-situ experiment HUGE (straight configuration)





Parameter	Value
Gasification agent	oxygen
Oxygen supply rate, Nm^3/h	10 - 40
Experiment duration, hours	355
Average gas production, Nm^3/h	202
Average gas composition, %:	
CO_2	16.4
H_2	14.7
CH_4	1.5
CO	13.4
N_2	52.9
Average gas heating value, MJ/Nm^3	3.75
Total coal consumption, kg	22 100
Process energy efficiency, %	56

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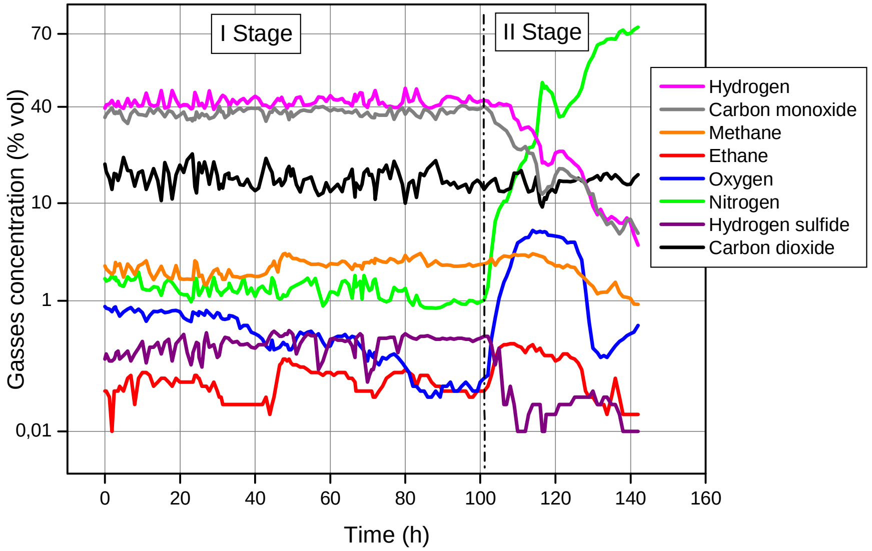
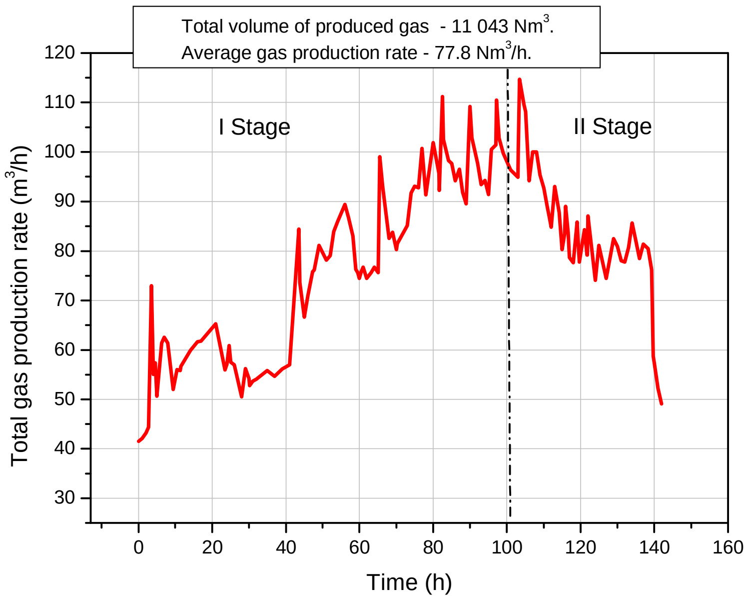
General results

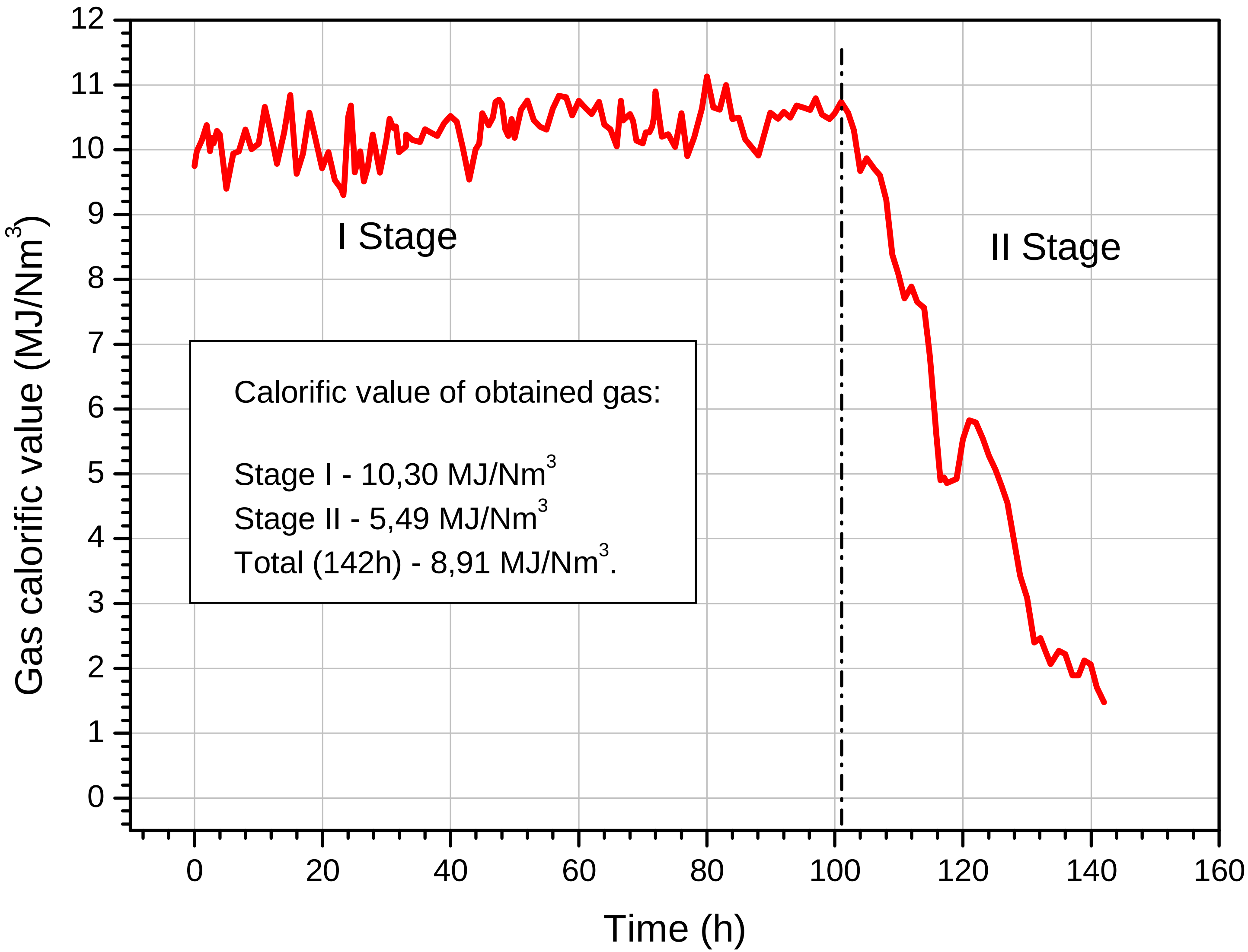
In situ experiment HUGE2 (V-shaped configuration)





Parameter	Value
Gasification agent	oxygen
Oxygen supply rate, Nm³/h	10 - 20
Experiment duration, hours	142
Average gas production, Nm³/h	78
Average gas composition, %:	
CO_2	15.2
H_2	36.3
CH_4	2.45
CO	31.7
N_2	12.3
Average gas heating value, MJ/Nm³	8.9
Total coal consumption, kg	5 300
Process energy efficiency, %	70.14

UCG gas (HUGE2)
Calorific value



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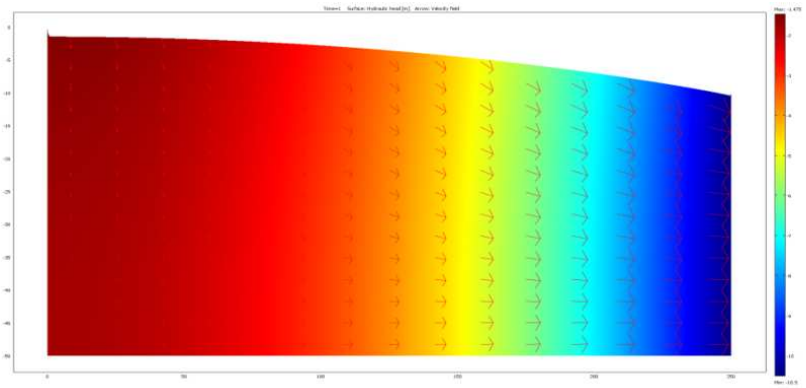
Numerical modeling of UCG hydrogeology – EM Barbara

Groundwater flow model (2D)

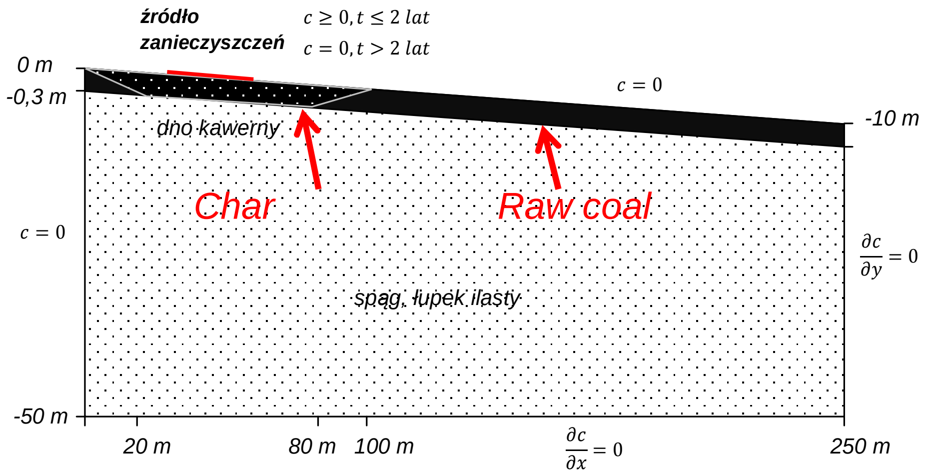


<u>Darcy's law:</u>

$$u = -K\nabla H$$

$$S\frac{\partial H}{\partial t} + \nabla \cdot [-K\nabla H] = Q_s$$

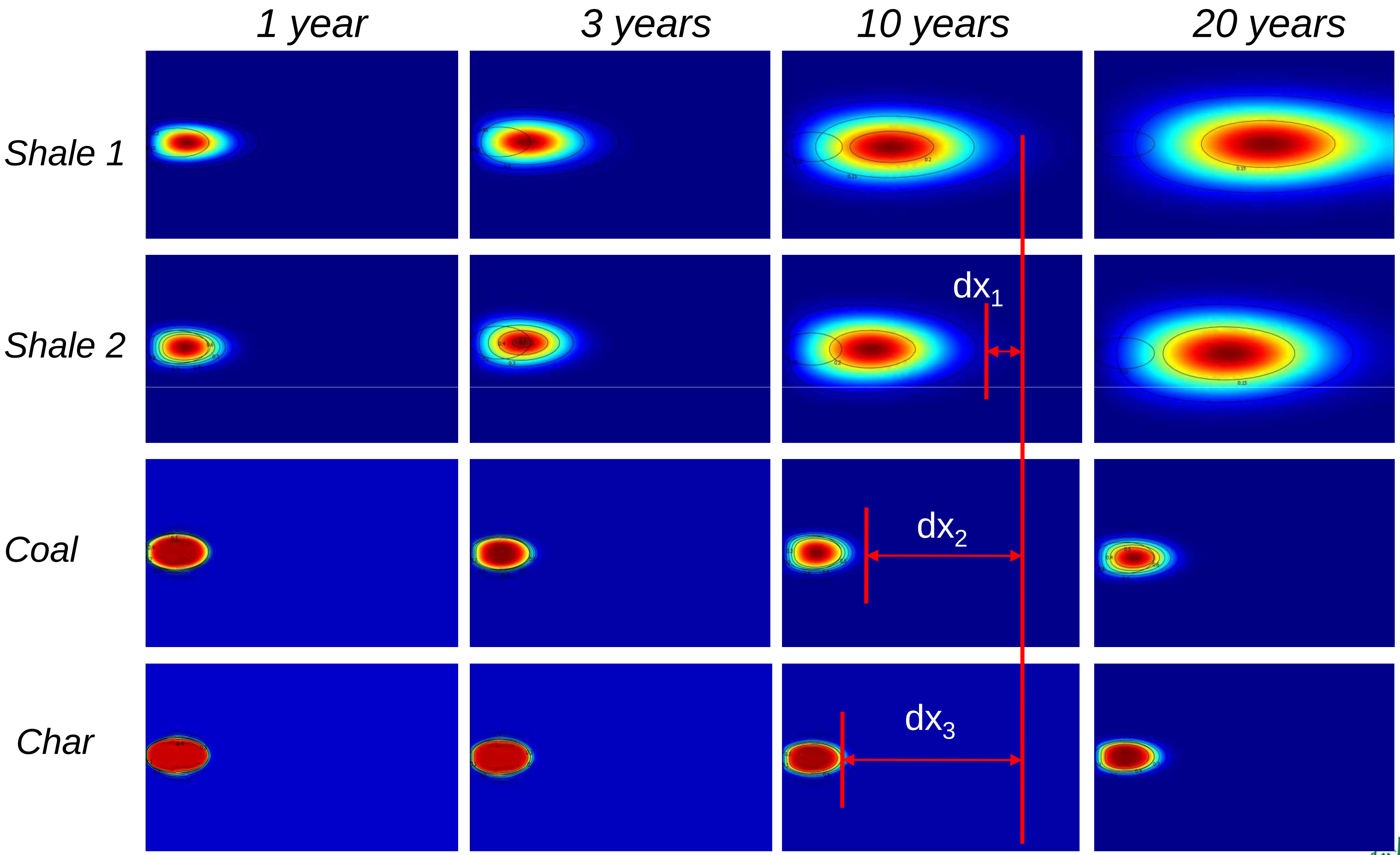
Contaminant transport model



<u>Advective – dispersive transport:</u>

$$\frac{\partial C}{\partial t} + \nabla \cdot (-\theta D\nabla C + uC) - \lambda R\theta C = 0$$

Contaminant transport in coal seam and selected rocks



Normalized isolines of naphtalene *(c/c_0)*

Post-gasification studies

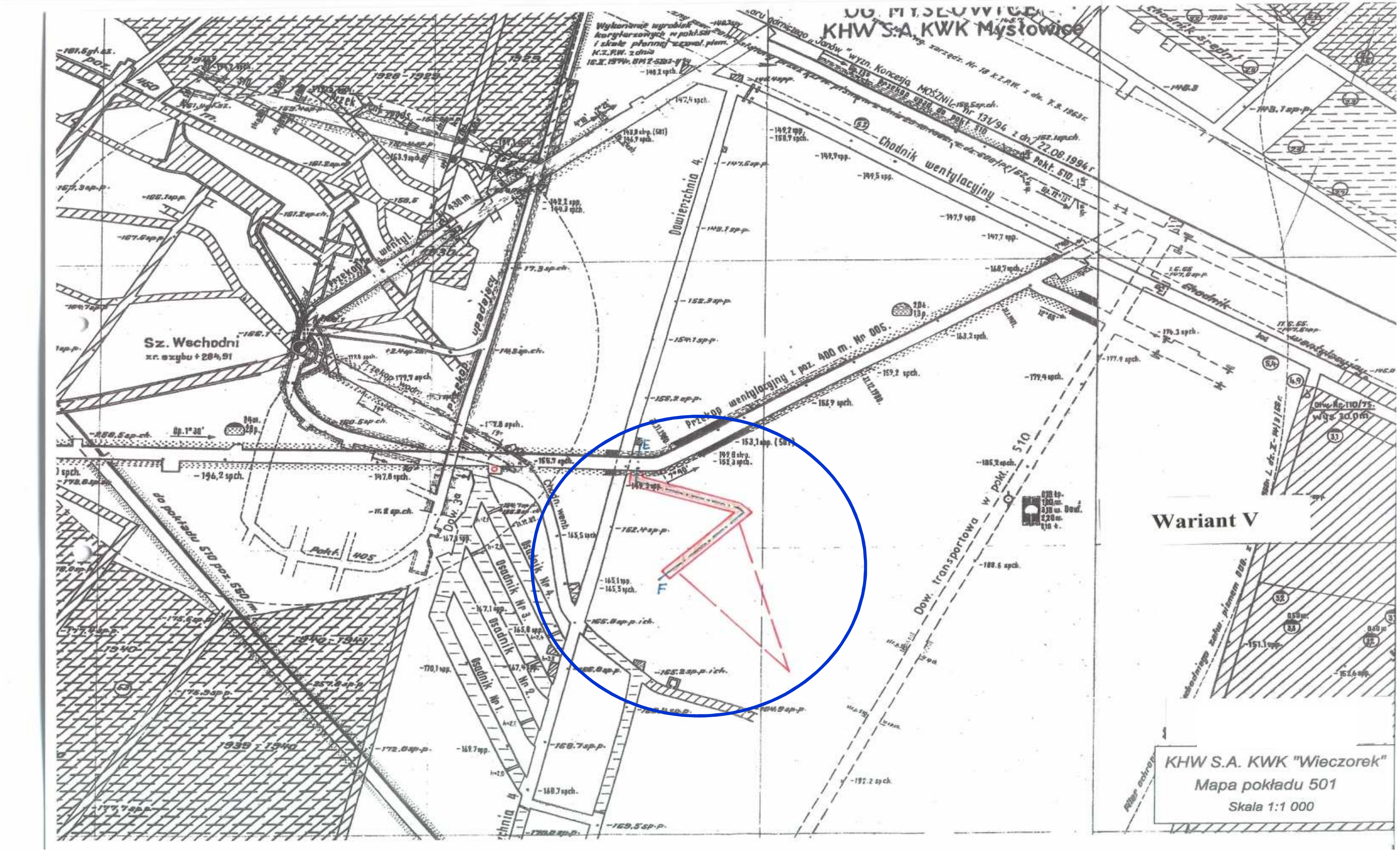
GIG

Post-gasification cavity (HUGE)

UCG pilot plant at Coal Mine „Wieczorek"

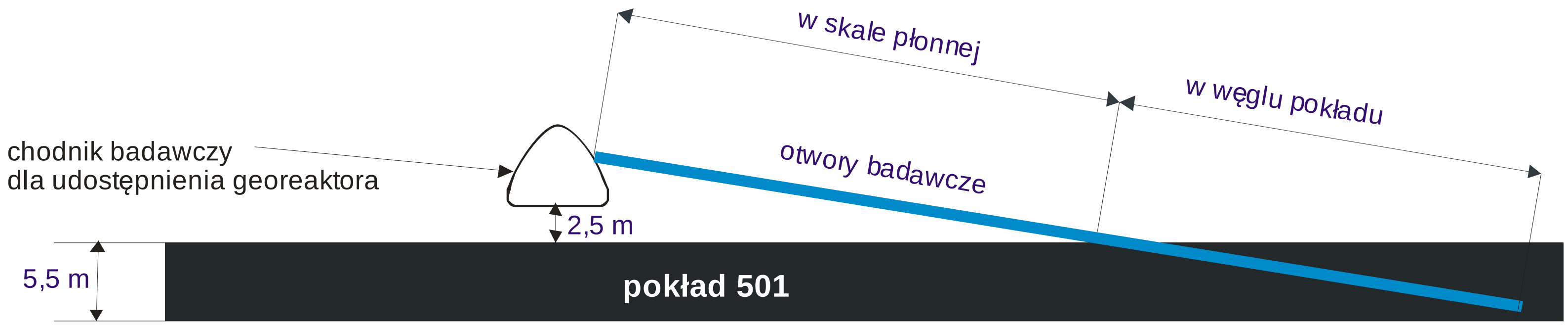
UCG pilot plant „Wieczorek"

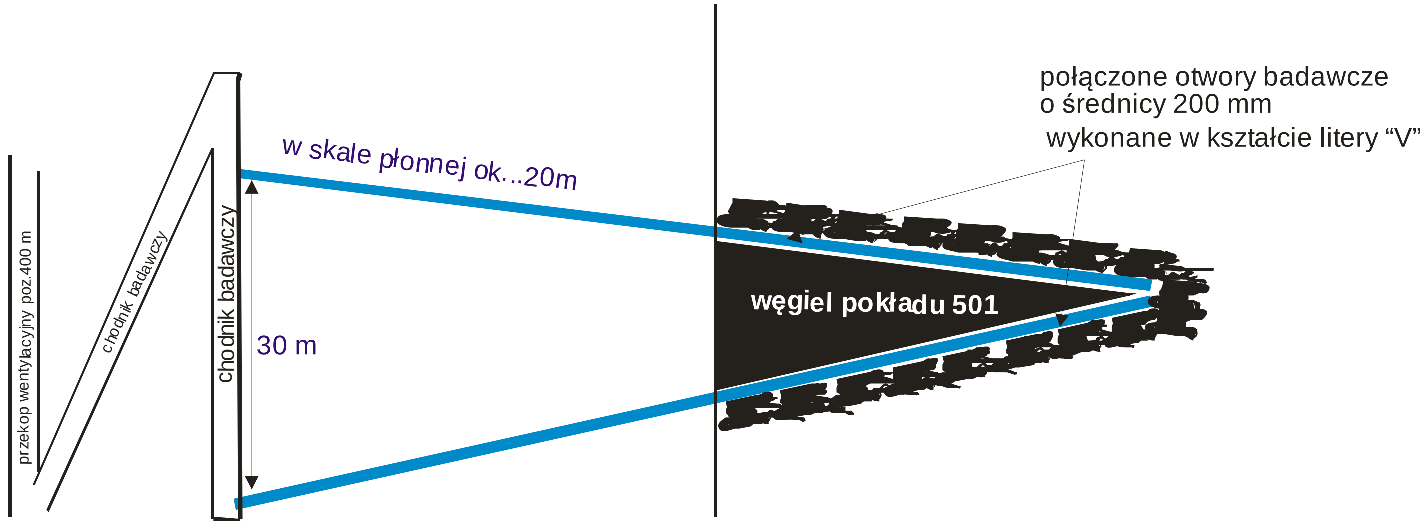
Site selection



UCG pilot plant „Wieczorek"

Geometries of gasification channels





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UCG pilot plant „Wieczorek"

Underground gallery

UCG pilot plant „Wieczorek"
Drilling works

UCG pilot plant „Wieczorek"
Surface UCG gas purification module

Thank you for your attention

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