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POLNOR CCS: Negative CO_2 emission gas power plant
Acronym: nCO2PP

Prof. Dariusz Mikielewicz, Principal Investigator (GUT)
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Prof. Halina Pawlak-Kruczek, WP3 Leader (WUST)
Prof. Ivar S. Ertesvåg , WP4 Leader (NTNU)
Prof. Paweł Madejski, WP5 Leader (AGH)
Prof. Tomasz Ochrymiuk, WP6 Leader (IMP)

Kraków, 1-2 February 2024

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SINTEF Energi AS

IASE - Institute of Power Systems Automation Sp. z o.o.

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POLNOR CCS: Negative CO_2 emission gas power plant nCO2PP – glance at project

Principal Investigator (PI): prof. Dariusz Mikielewicz (GUT)

WP1: Technical feasibility study of a novel concept of negative CO_2 emission power plant (WP leader: Paweł Ziółkowski (GUT)) – From Task 1 to Task 2

WP2: Integrated assessment of negative emission power plant using sludge as fuel - industrial research (WP leader: Chao Fu (SINTEF)) – From Task 1 to Task 6

WP3: Enabling technology 1: Thermal valorisation of sewage sludge (HTC) and conversion to syngas (WP leader: Halina Pawlak-Kruczek (WUST)) – From Task 1 to Task 6

WP4: Enabling technology 2: Efficient wet combustion of syngas (WP leader: Ivar S. Ertesvåg (NTNU)) – From Task 1 to Task 5

WP5: Enabling technology 3: Critical process components (WP leader: Paweł Madejski (AGH)) – From Task 1 to Task 3

WP6: Experimental and numerical analysis of the work of the combustion chamber, spray-ejector condenser and other cycle devices towards the optimal (WP leader: Tomasz Ochrymiuk (IMP PAN)) – From Task 1 to Task 4

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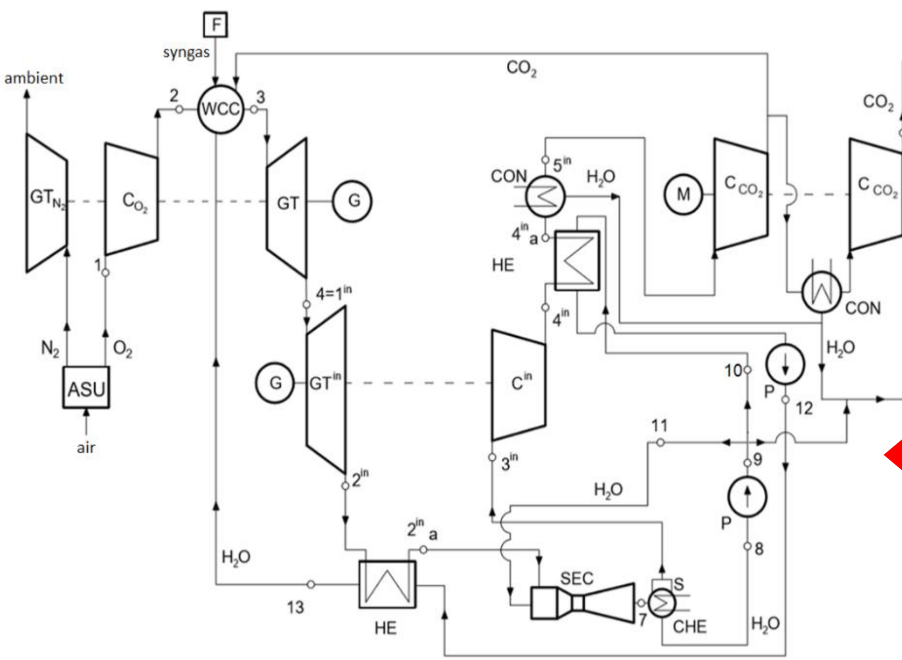
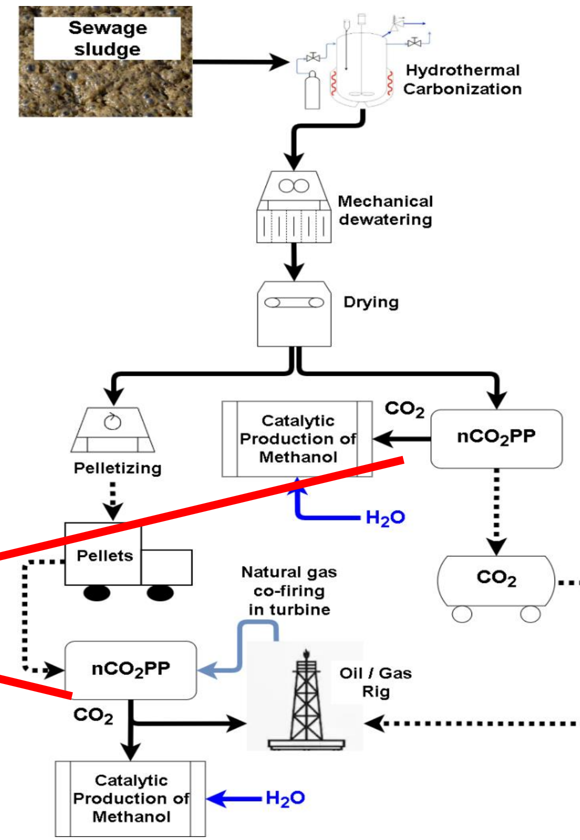
POLNOR CCS: Negative CO_2 emission gas power plant nCO2PP – General concept



The compact (nCO_2PP) high-efficiency negative-emission power plant cycle, where: WCC – wet combustion chamber, GT+GT^{in} – gas and steam turbine divided into two parts, SEC – spray ejector condenser.



Scheme of two routes for novel negative CO_2 emission gas power plant (nCO_2PP) coupled with sewage sludge gasification.

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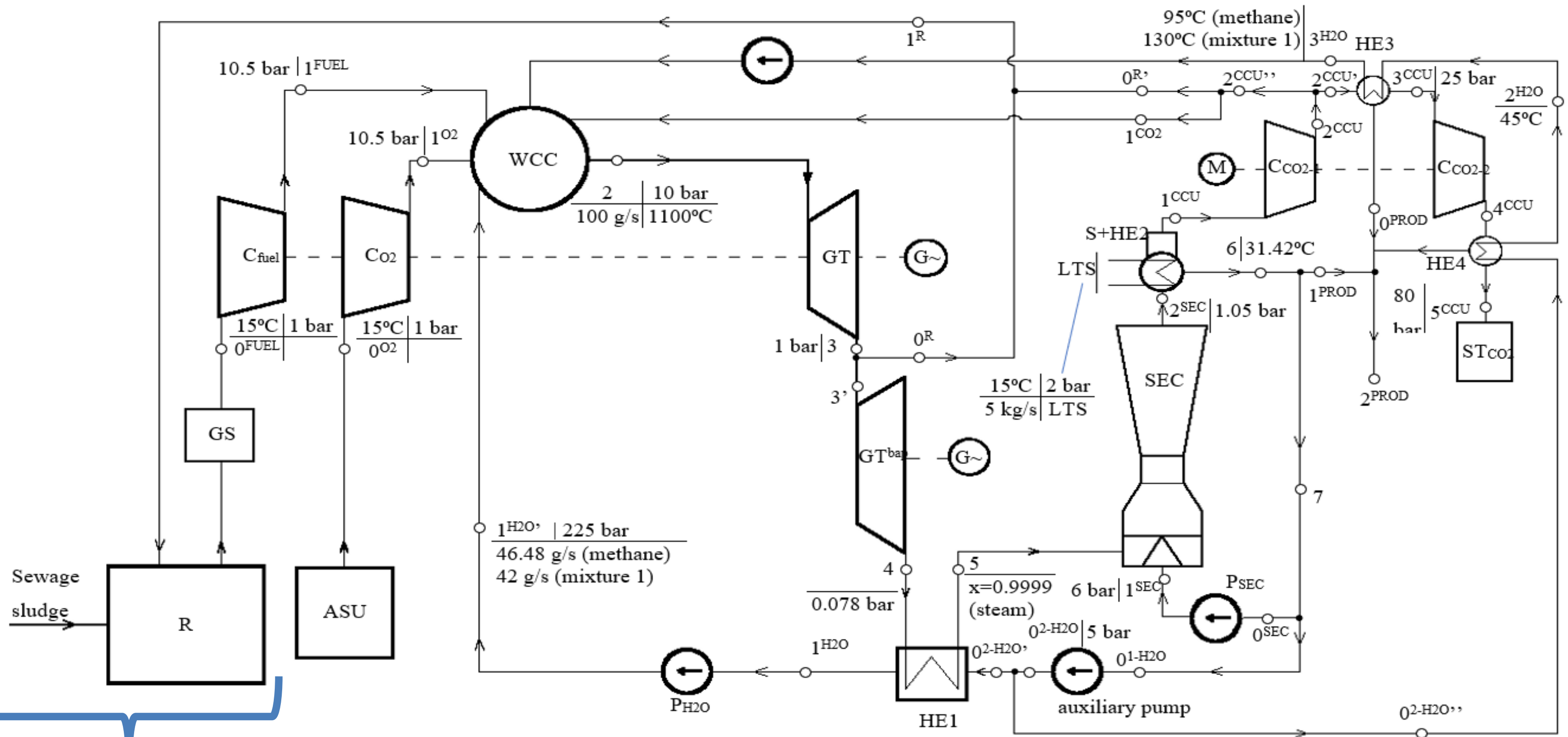
POLNOR CCS: Negative CO_2 emission gas power plant nCO2PP – General concept of nCO2PP cycle



fuel preparation

energy generation

carbon capture

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WP1: Technical feasibility study of a novel concept of negative CO2 emission power plant

Ecological analysis results of negative CO_2 emission power plant using gasified sewage sludge vs methane for zero-emission

Parameter	Symbol	Unit	Methane conventional power plant	Methane zero-emission power plant	Syngas negative CO_2 power plant
Net efficiency	η_{net}	%	47.1	41.5	39.4
Emission of carbon dioxide	e_{CO_2}	kg/MWh	418.78	0.0	-727.12
Relative emissivity of carbon dioxide	$\eta_{net} \cdot e_{CO_2}$	%kg/MWh	197.42	0.0	-286.70
Avoided emission of carbon dioxide	Avoid e_{CO_2}	kg/MWh	0.00	475.33	1454.23
Avoided relative emissivity of carbon dioxide	Avoid $\eta_{net} \cdot e_{CO_2}$	%kg/MWh	0.00	197.45	573.40

Ziółkowski, P et al. Thermodynamic Analysis of Negative CO2 Emission Power Plant Using Aspen Plus, Aspen Hysys, and Ebsilon Software. Energies 2021, 14, 6304. https:// doi.org/10.3390/en14196304

WP1: Technical feasibility study of a novel concept of negative CO2 emission power plant

Main technical data for economic analysis

No.	Description	Unit	Value
1.	The annual stream of sewage sludge in working condition	Mg/year	10 000
2.	Amount of CO_2 captured in the installation	Mg/year	10 469.5
3.	Amount of electricity generated in the installation	MWh/year	19 997.6
4.	Amount of electricity for own needs	MWh/year	5 592.9
5.	Net electrical energy	MWh/year	14 404.7

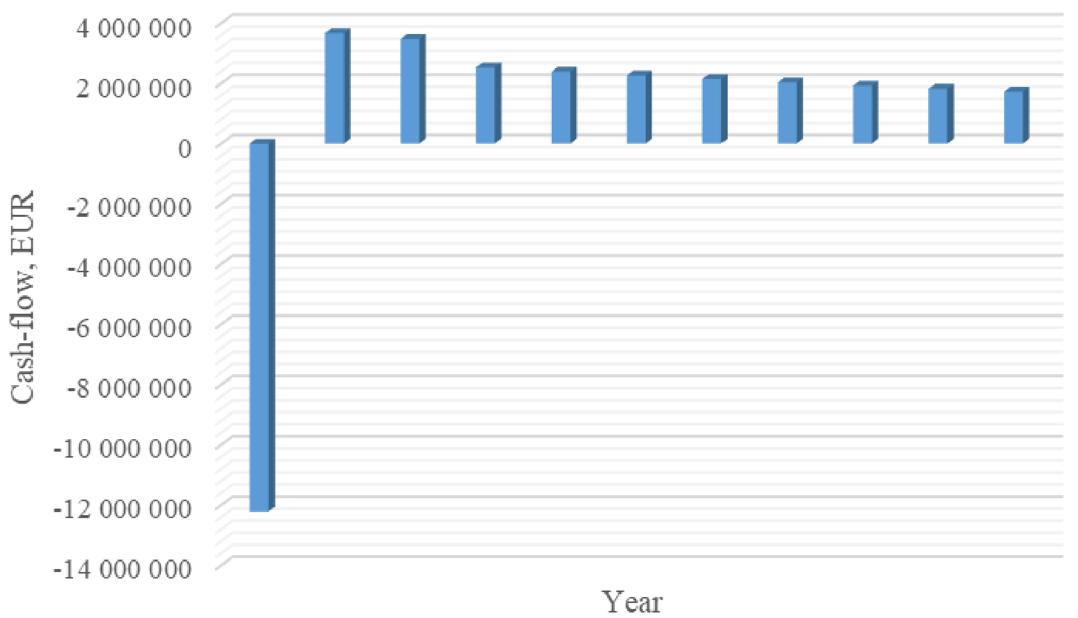
Investment costs

No.	Description	Cost, EUR
1.	Gas turbine with a special combustion chamber	9 000 000
2.	Heat exchanger	12 300
3.	Spray-ejector condenser	330 000
4.	CO_2 compression system	40 000
5.	O_2 generating station	900 000
6.	Pumps	41 910
7.	Plasma gasifier	310 000
8.	Pre-treatment	980 000
9.	Syngas cleaning system	600 000
	TOTAL	12 214 210

WP1: Technical feasibility study of a novel concept of negative CO2 emission power plant

Yearly incomes/avoided costs for the installation

Description	EUR/year
Avoided cost of sewage sludge disposal	851 100
Avoided cost of CO_2 emissions	924 562
Electricity produced (netto)	2 095 884
TOTAL	3 871 545

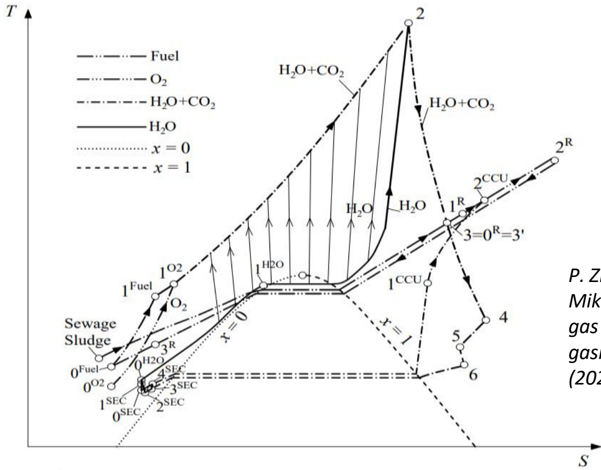


Discounted cash-flows of the analysed installation

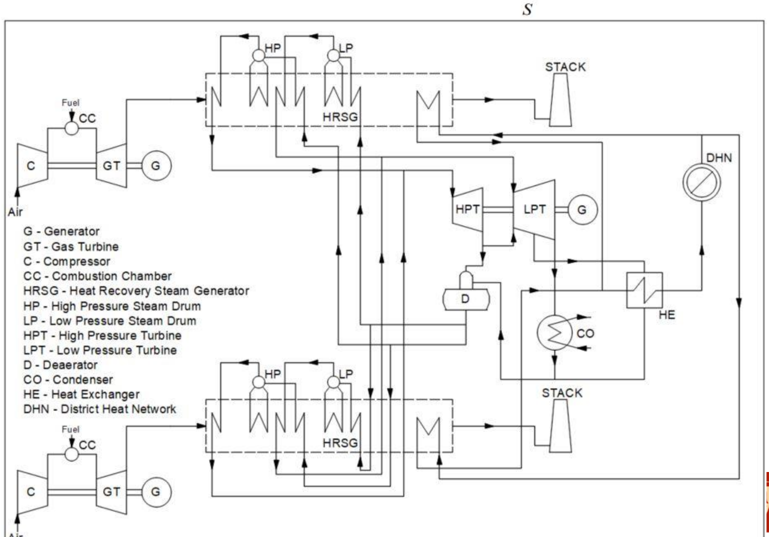
WP1: Technical feasibility study of a novel concept of negative CO2 emission power plant

'WP1: Technical feasibility study of a novel concept of negative CO_2 emission power plant' **has been positively evaluated** and on this basis further implementation is fully justified.

WP2: Integrated assessment of negative emission power plant using sludge as fuel - industrial research

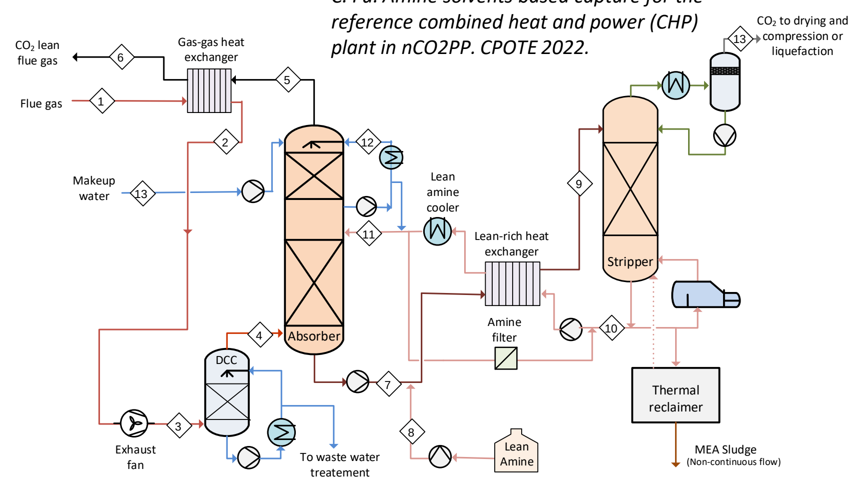


P. Ziółkowski, K. Stasiak, M. Amiri, D. Mikielewicz: Negative carbon dioxide gas power plant integrated with gasification of sewage sludge. Energy (2022) accepted.



D2.1, Framework for process design and assessment

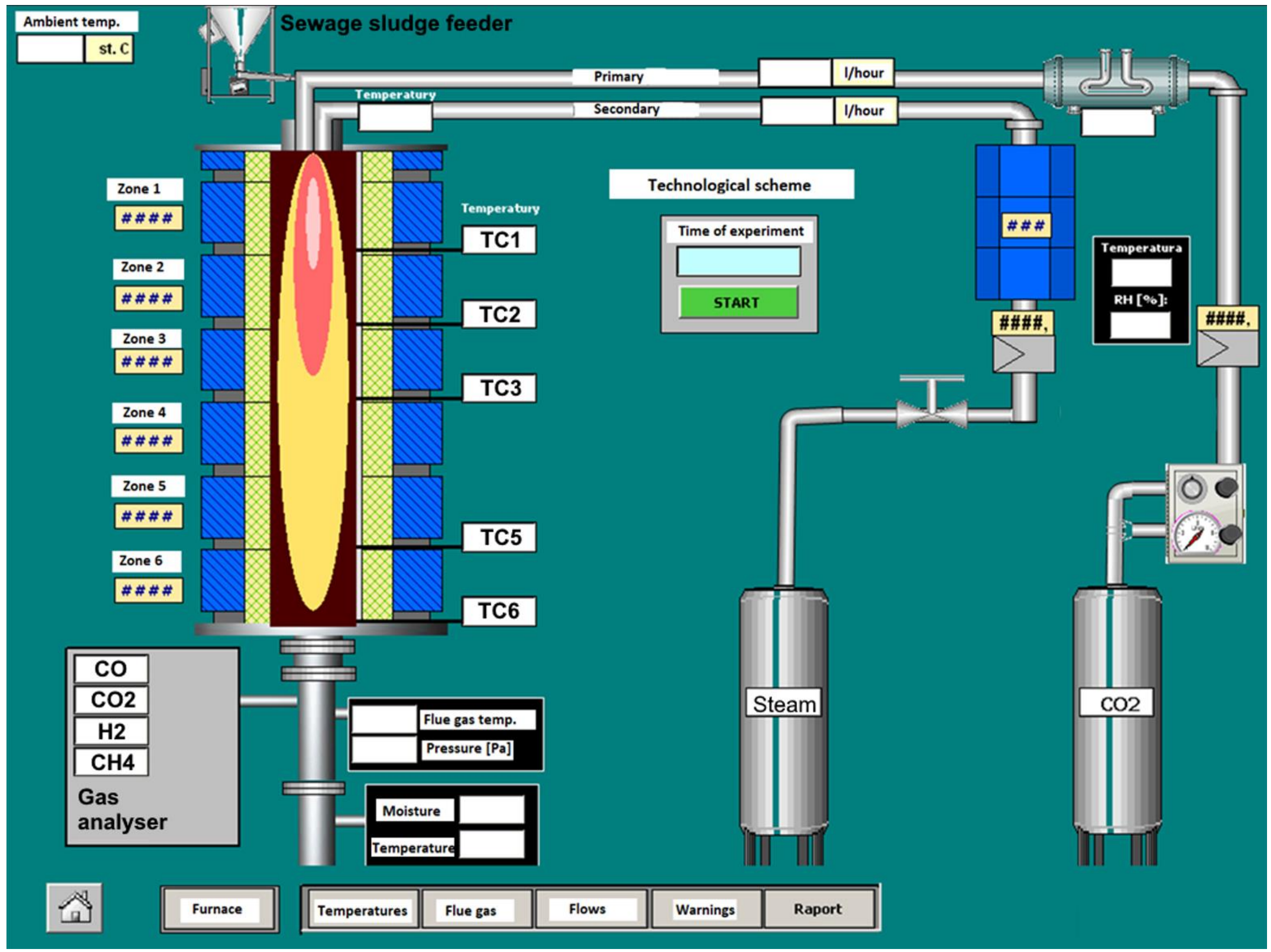
C. Fu. Amine solvents based capture for the reference combined heat and power (CHP) plant in nCO2PP. CPOTE 2022.



Parameter	Unit	MEA	AMP-PZ
CO_2 flowrate in flue gas	kg/h	27504.47	27504.47
CO_2 flowrate in CO_2 captured	kg/h	24797.59	24710.29
Lean loading		0.23	0.31
Capture rate		0.902	0.898
Specific reboiler duty	kJ/kgCO_2	3773	3332
Specific power consumption	kJ/kgCO_2	675	670
Specific water makeup	kg/tonneCO_2	489.7	459.8
Specific amine makeup	kg/tonneCO_2	1.44	7.22
Specific cooling duty	kJ/kgCO_2	5296.8	3774.1

WP3: Enabling technology 1: Thermal valorisation of sewage sludge (HTC) and conversion to syngas

Isothermal flow reactor



Reactor working panel

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WP3: Enabling technology 1: Thermal valorisation of sewage sludge (HTC) and conversion to syngas

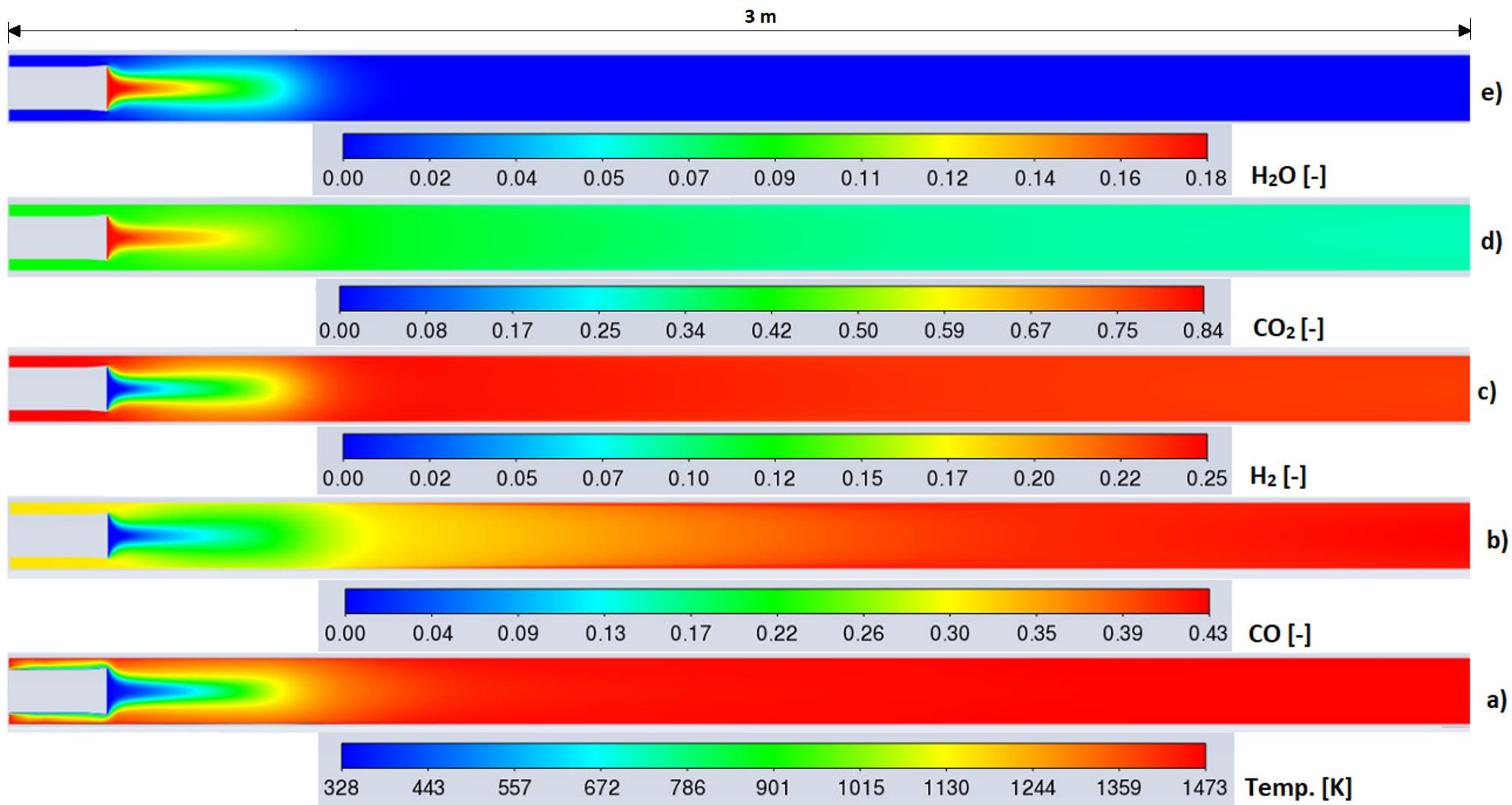
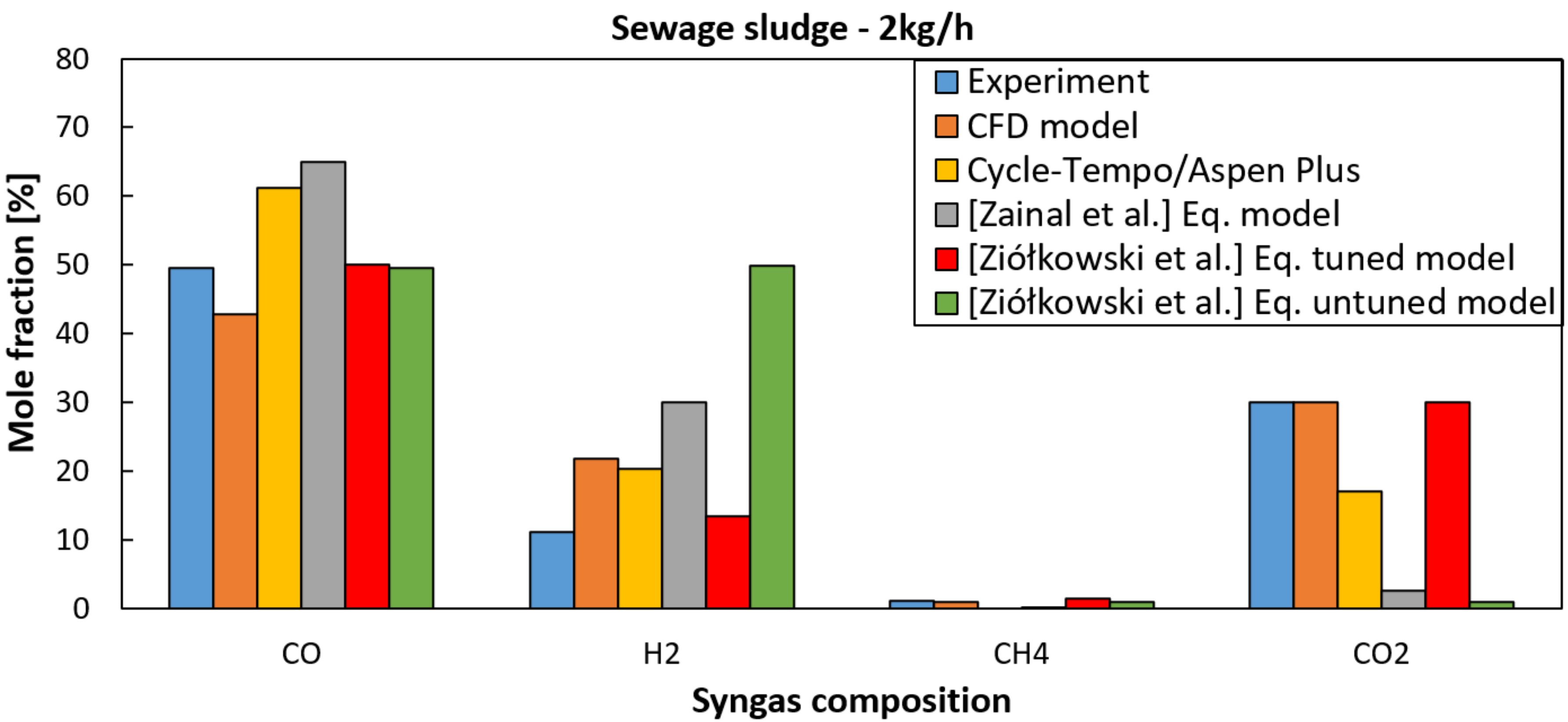


Fig. a) Temperature distribution, b) CO mole fraction, c) H_2 mole fraction, d) CO_2 mole fraction, e) H_2O mole fraction distribution inside a 3-meter drop tube furnace from CFD model.

WP3: Enabling technology 1: Thermal valorisation of sewage sludge (HTC) and conversion to syngas



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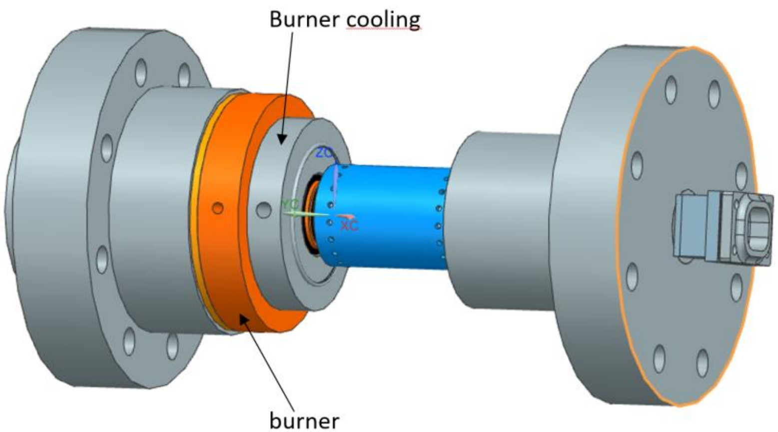
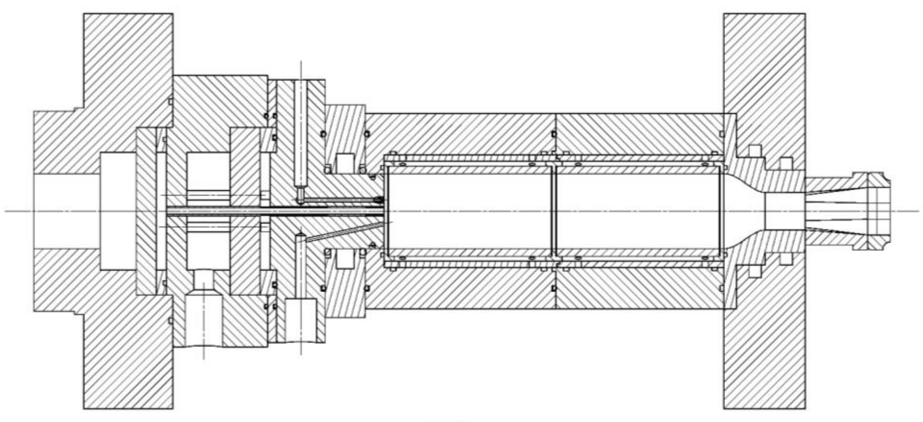
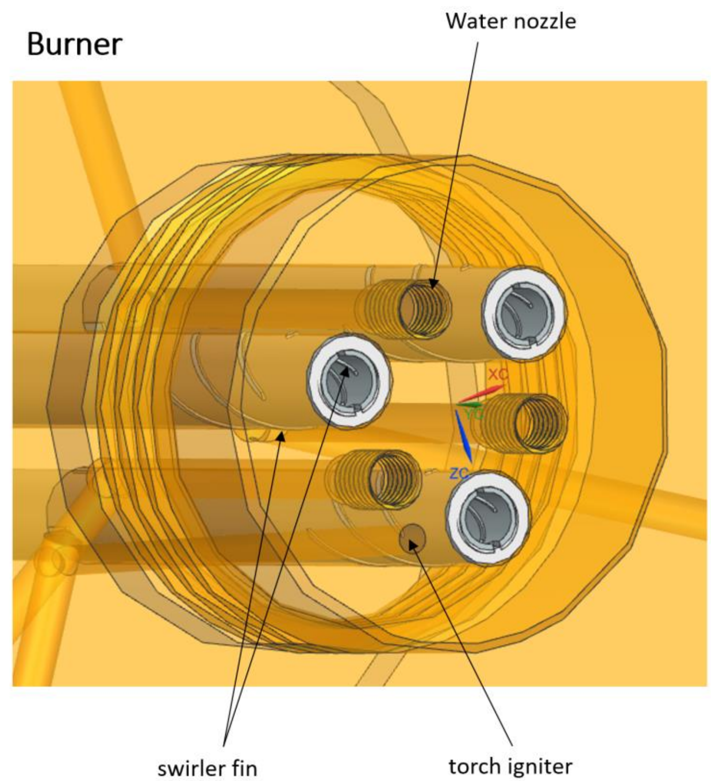
WP4: Enabling technology 2: Efficient wet combustion of syngas







WP4: Enabling technology 2: Efficient wet combustion of syngas

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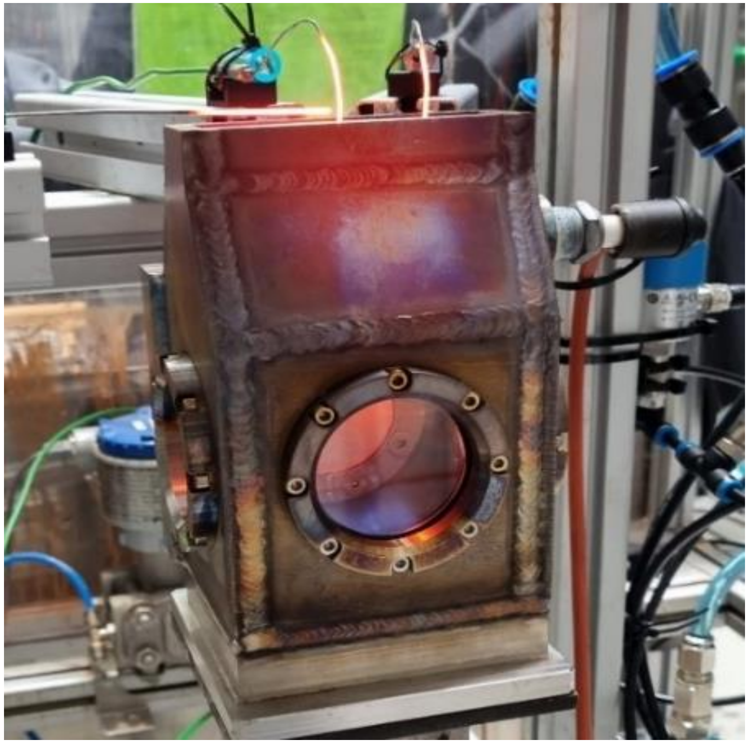
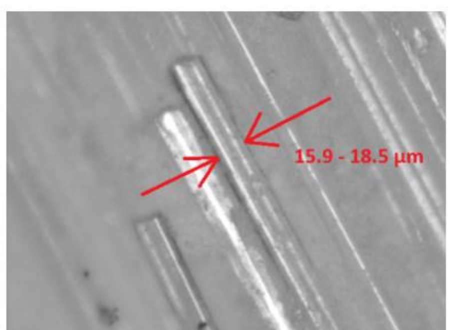
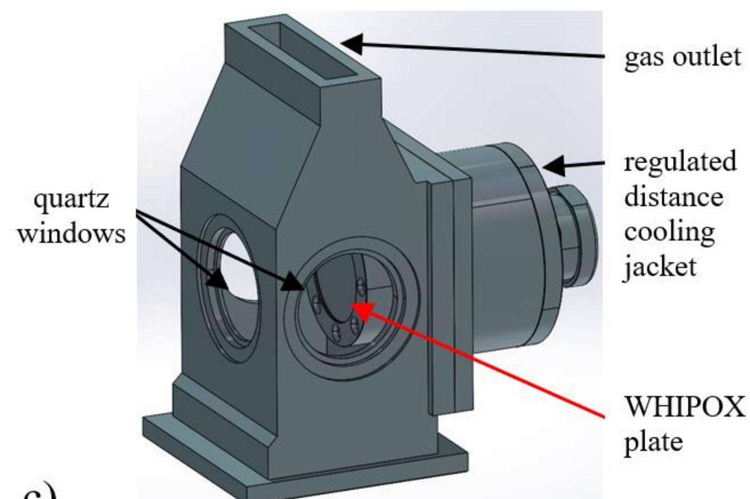


WP4: Enabling technology 2: Efficient wet combustion of syngas

a) 

b) 

c) 

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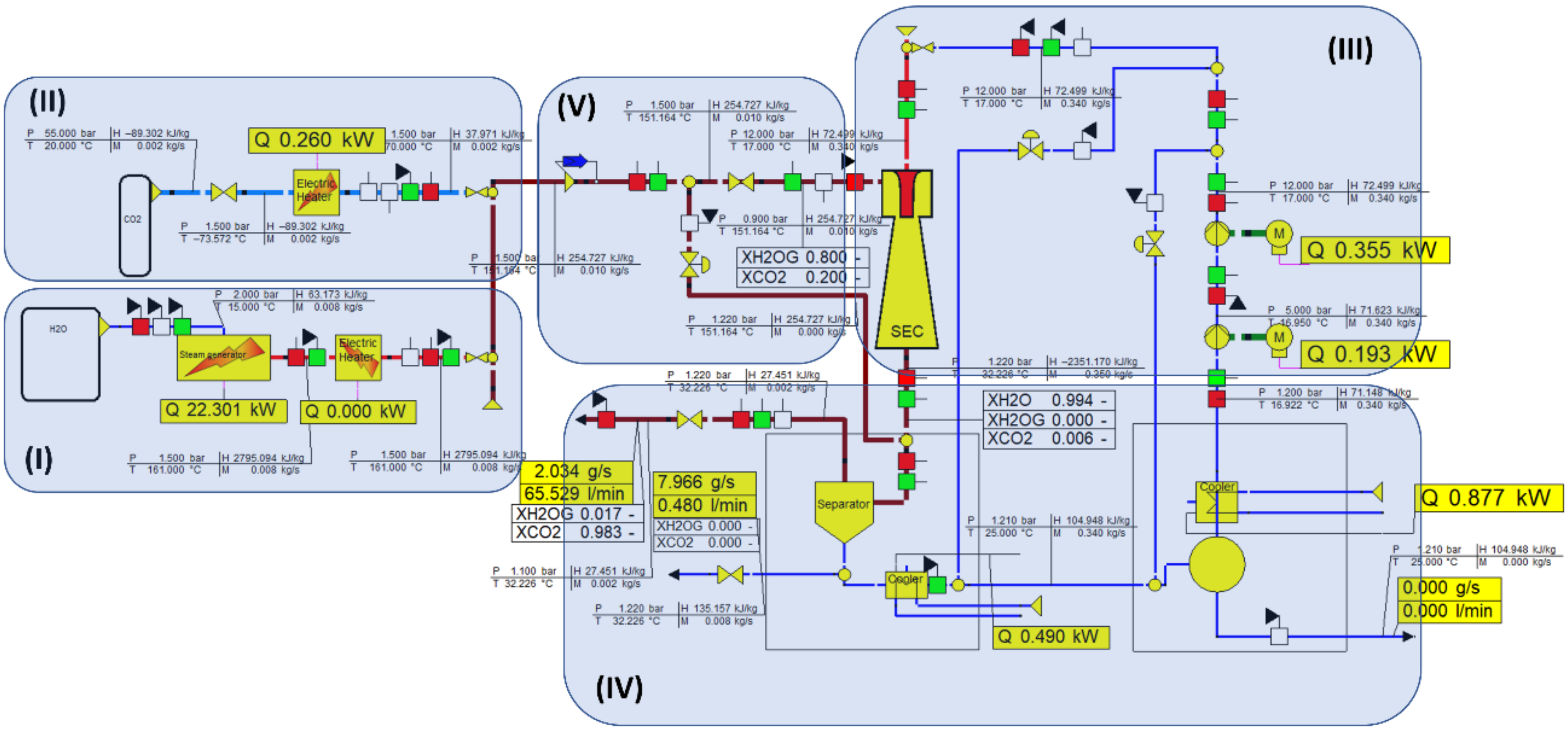
WP5: Enabling technology 3: Critical process components



The concept of the designed test -rig at AGH with the Spray-Ejector Condenser performances investigations/*Monitoring of Thermal and Flow Processes in the Two-Phase Spray-Ejector Condenser for Thermal Power Plant Applications, Paweł Madejski, Piotr Michalak, Michał Karch, Tomasz Kuś and Krzysztof Banasiak, Energies 2022, 15, 7151.*

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WP5: Enabling technology 3: Critical process components

Fig. Spray-Ejector Condenser

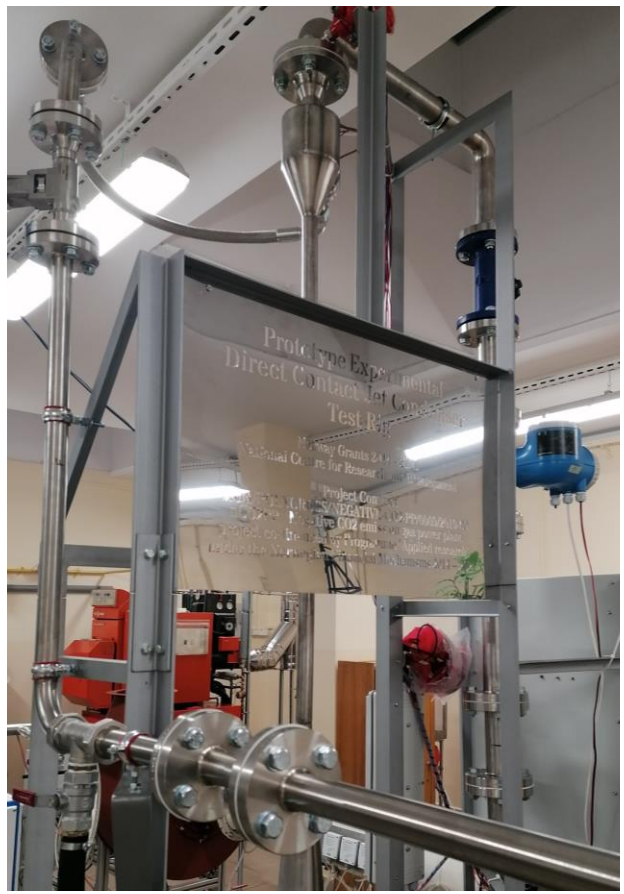

Fig. Prototype Experimental Direct Contact Jet Condenser Test Rig at AGH

Fig. Flow character visualization, registered during direct contact condensation in Spray-Ejector Condenser

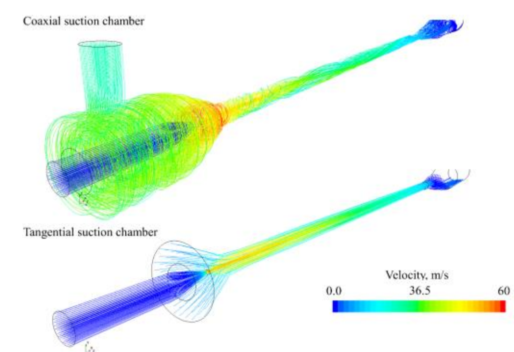

Fig. Velocity streamlines for different suction chamber

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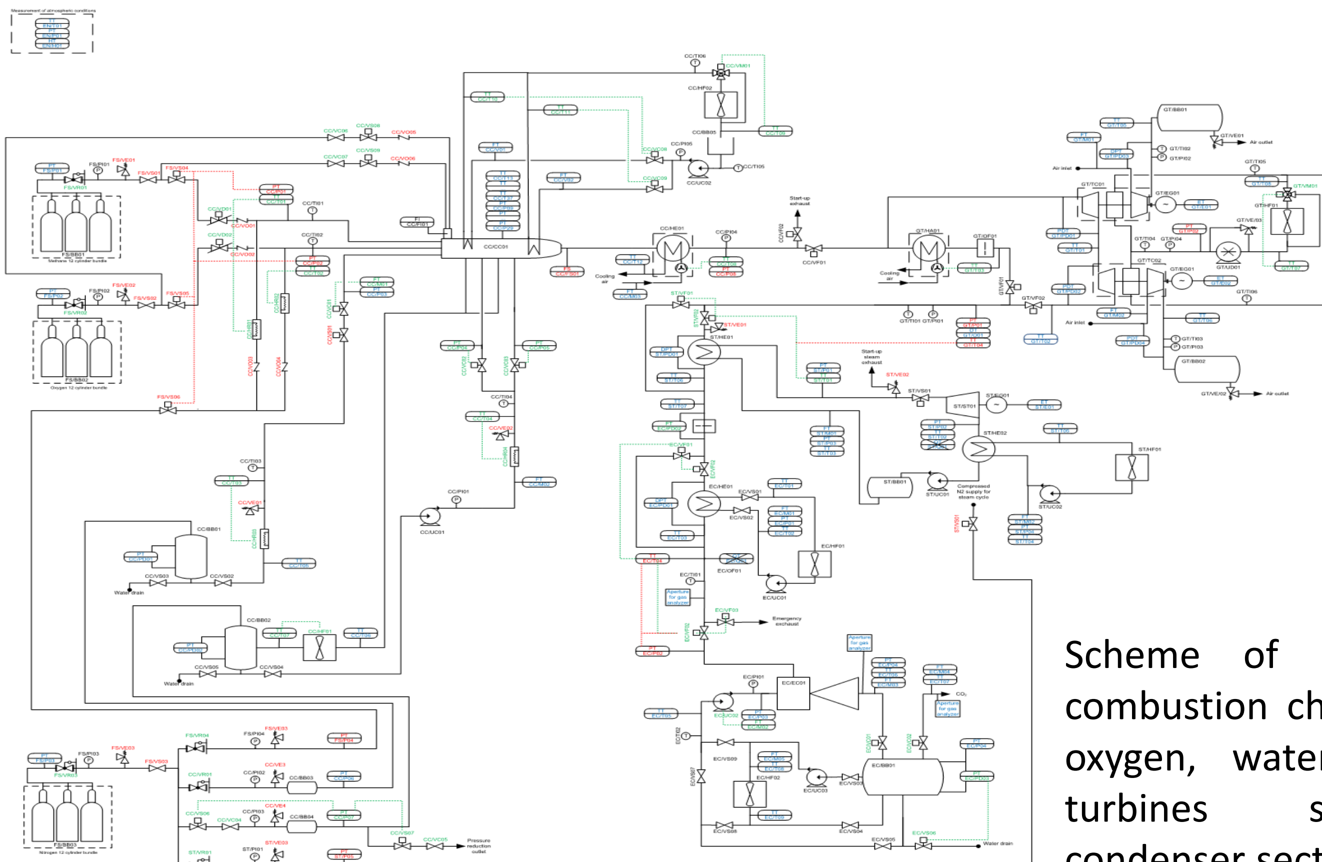
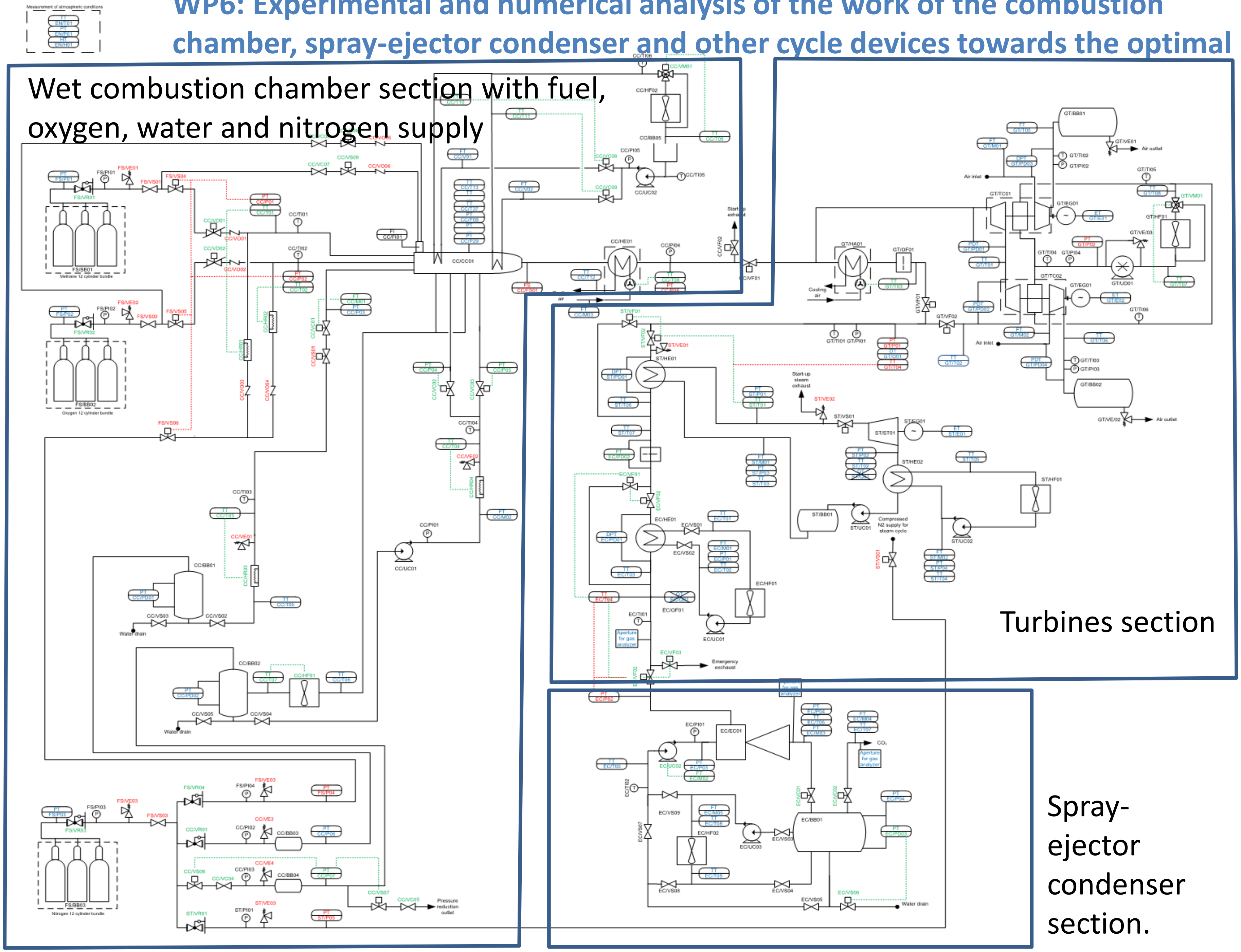
WP6: Experimental and numerical analysis of the work of the combustion chamber, spray-ejector condenser and other cycle devices towards the optimal



Scheme of demo installation: wet combustion chamber section with fuel, oxygen, water and nitrogen supply; turbines section, spray-ejector condenser section.

WP6: Experimental and numerical analysis of the work of the combustion chamber, spray-ejector condenser and other cycle devices towards the optimal



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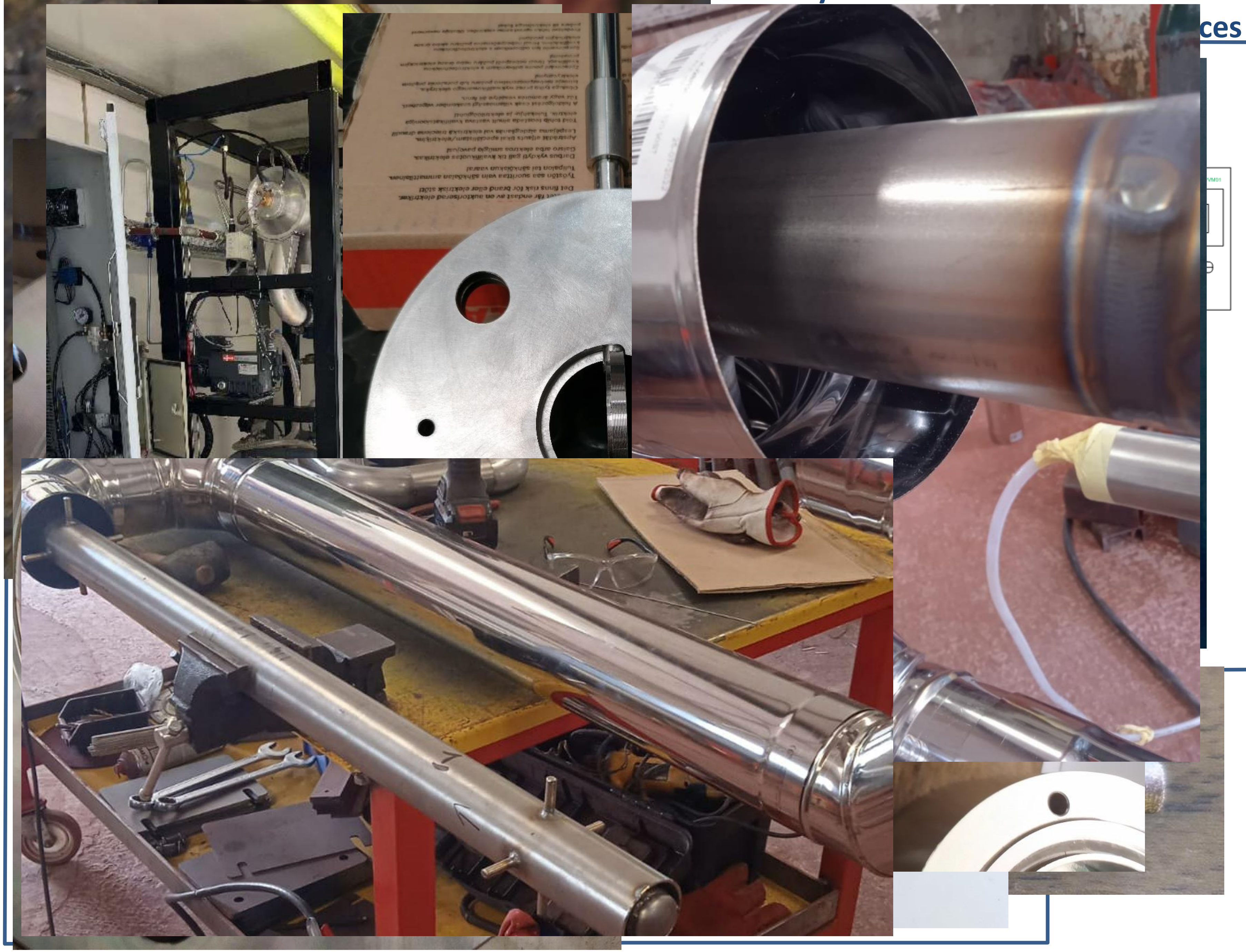

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Acknowledgments

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