U.S. Department of Energy, National Energy Technology Laboratory's
(NETL) **2022 *Virtual* Workshop on Multiphase Flow Science**.
August 2-4 (online)

Development of an innovative Gas Turbine Chemical Looping Combustor for Carbon Negative Power Generation

DR. PIETRO BARTOCCI,
SPANISH NATIONAL RESEARCH COUNCIL

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Presentation index

Introduction to current energy scenarios

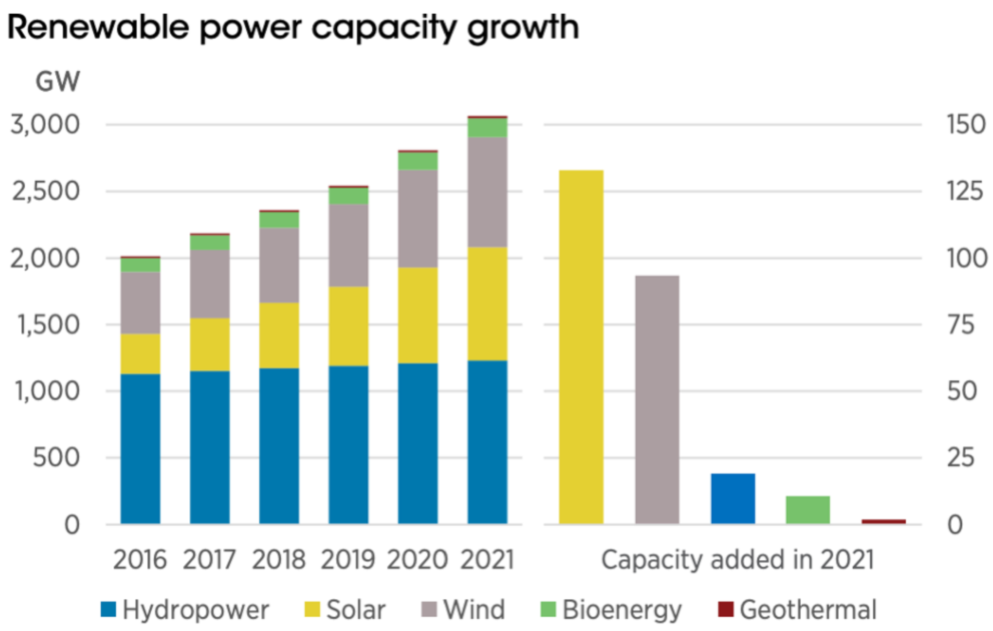
Integrating CL combustors into gas turbines cycles

GTCLC-NEG Project presentation

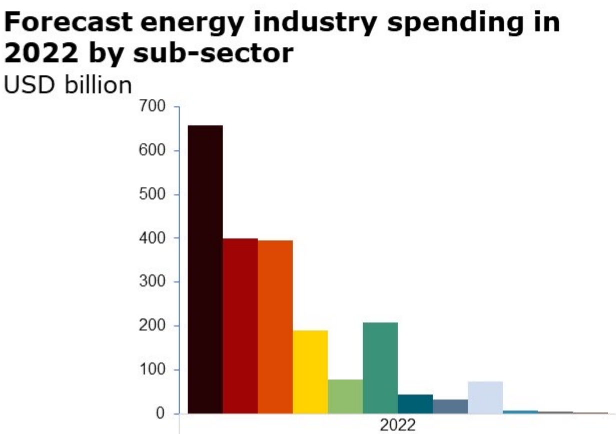
Modeling a Fuel Reactor in Batch Conditions

Further developments

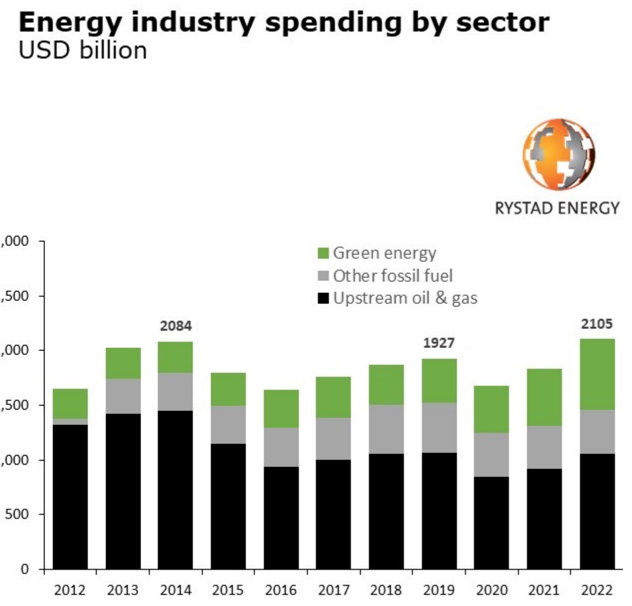
ENERGY SCENARIOS



Source: IRENA 2022 Energy statistics
https://taiyangnews.info/business/irena-releases-renewable-capacity-statistics-2022/



	2022
Oil (16%)	658.00
Gas & LNG (15%)	401.00
Other fossil fuel (0%)	396.00
Solar (64%)	191.47
Nuclear (-2%)	78.01
Onshore wind (24%)	209.06
Offshore wind (-15%)	43.79
Hydropower (-7%)	33.80
Batteries (29%)	75.00
Hydrogen (37%)	7.88
CCS (54%)	5.73
Geothermal (38%)	4.75

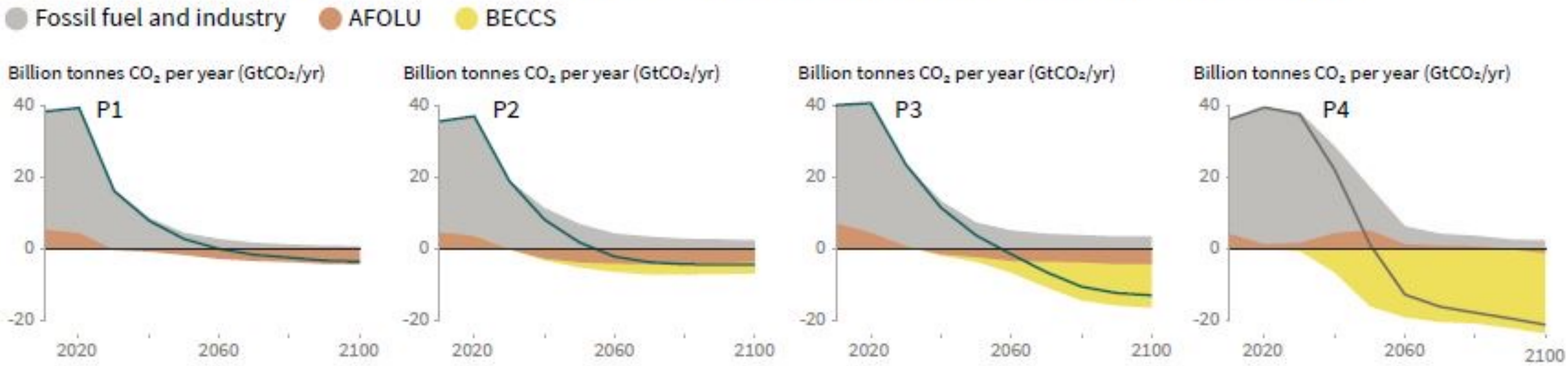


Source: Rystad Energy ServiceCube

RENEWABLE

FOSSIL

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



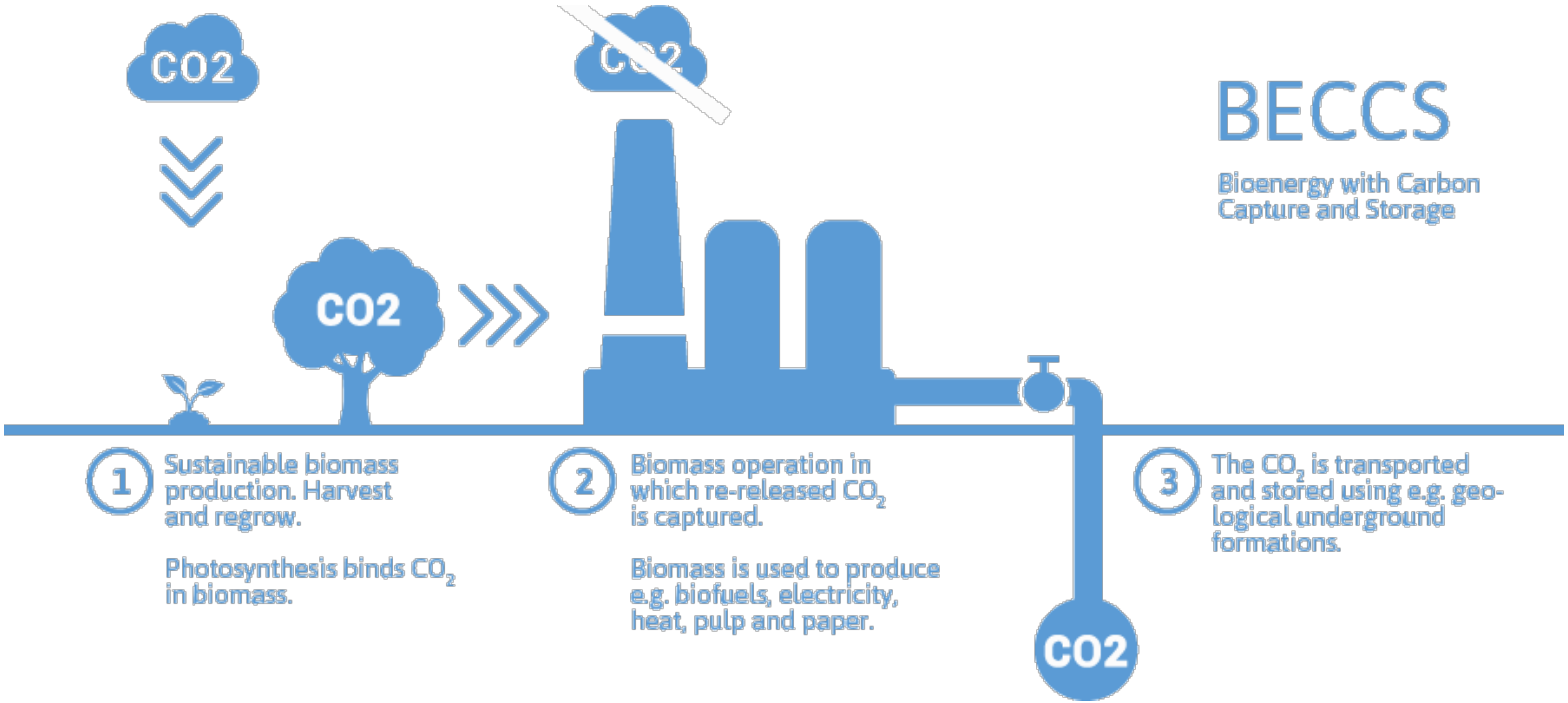
P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

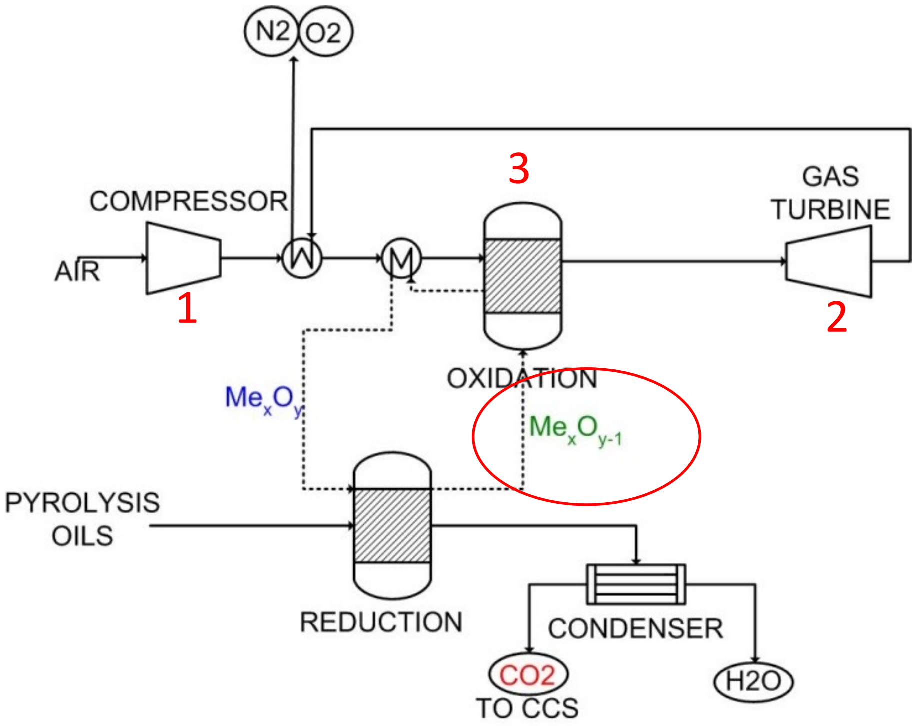
Carbon Negative Technologies



“Integrating CL combustors into gas turbines cycles”

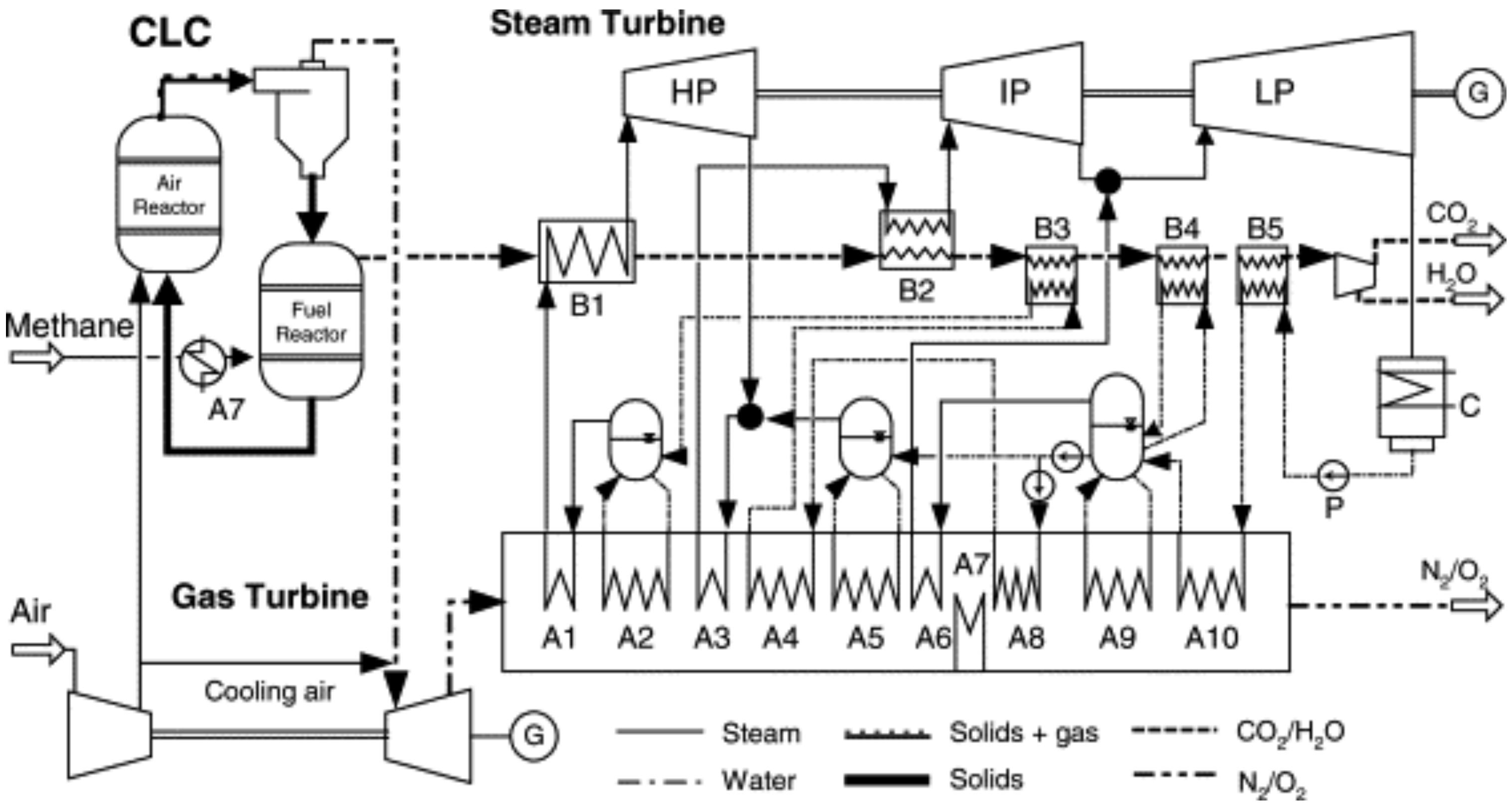
To transform a GT into a carbon neutral/carbon negative machine

Legend
1: Compressor
2: Turbine
3: Combustion chamber



1. F Zerobin, S Penthor, O Bertsch, T Pröll, Fluidized bed reactor design study for pressurized chemical looping combustion of natural gas, Powder Technology 316 (2017) 569–577
2. Jens Wolf, Marie Anheden, Jinyue Yan, Comparison of nickel- and iron-based oxygen carriers in chemical looping combustion for CO2 capture in power generation, Fuel, 84, 2005, 993-1006
3. S. Consonni, G. Lozza, G. Pelliccia, S. Rossini, F. Saviano, Chemical-Looping Combustion for Combined Cycles With CO2 Capture, Journal of Engineering for Gas Turbines and Power, JULY 2006, Vol. 128-525

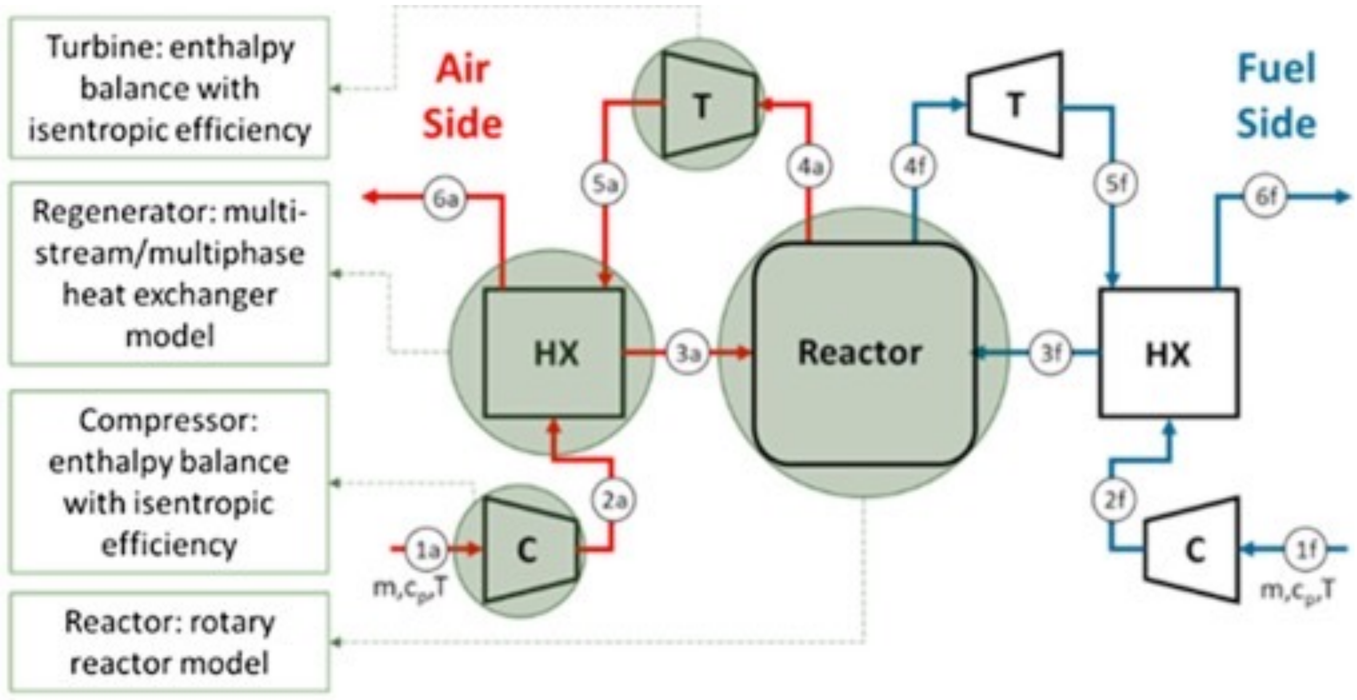
Some Premises



Jens Wolf, Marie Anheden, Jinyue Yan, Comparison of nickel- and iron-based oxygen carriers in chemical looping combustion for CO2 capture in power generation, Fuel, Volume 84, Issues 7–8, 2005, Pages 993-1006, ISSN 0016-2361,

MARIE CURIE ACTIONS

Some Premises



Chukwunwike O. Iloeje, Zhenlong Zhao, Ahmed F. Ghoniem, Design and techno-economic optimization of a rotary chemical looping combustion power plant with CO2 capture, Applied Energy, Volume 231, 2018, Pages 1179-1190,

MARIE CURIE ACTIONS

Barriers

(1) high efficiency bimetallic oxygen carriers are needed

(2) low attrition rate oxygen carriers are needed which can work in extreme conditions;

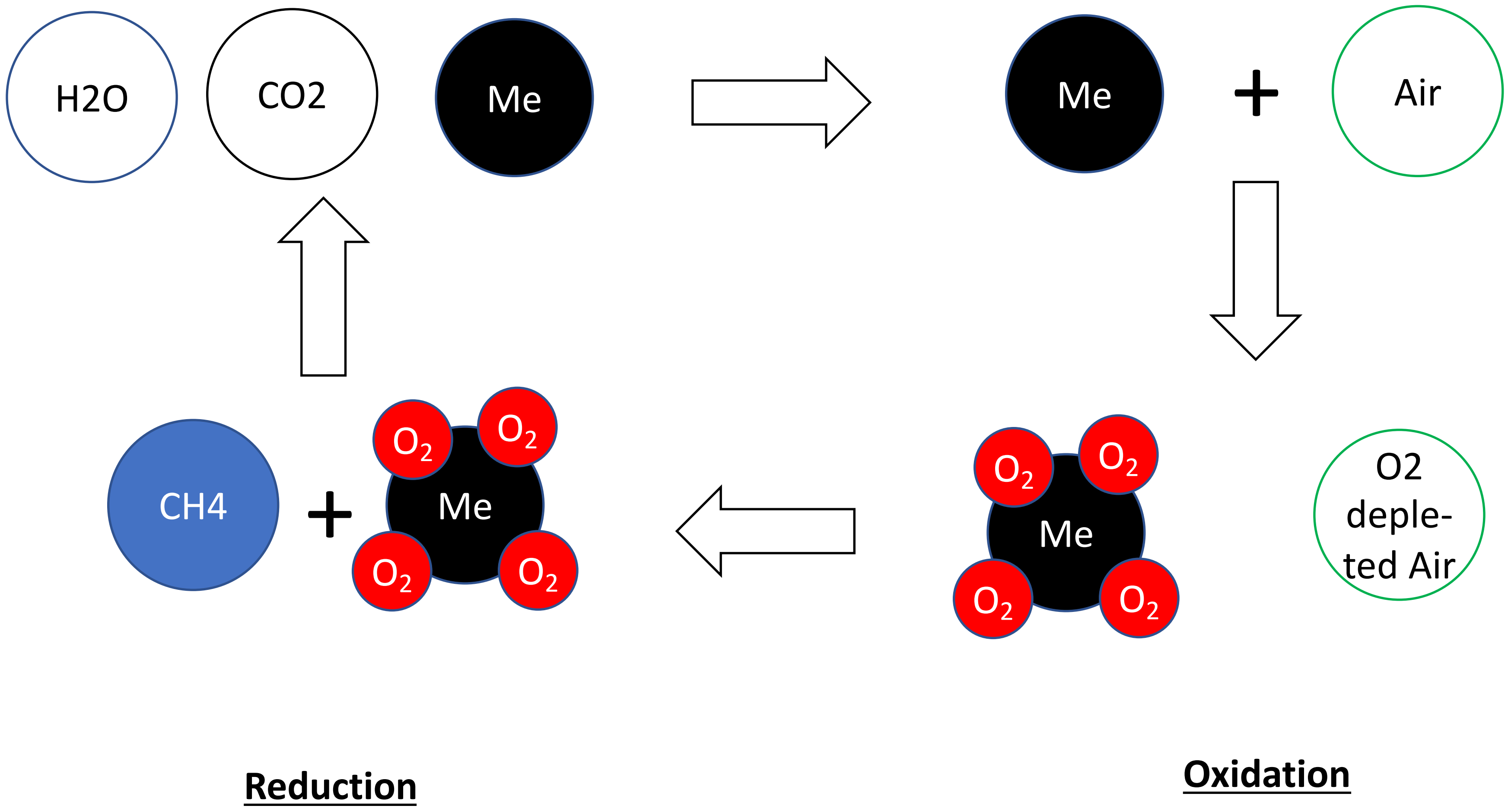
(3) kinetics aspects under high pressure and temperature conditions are not known;

(4) reactor injection system has to be adapted to biofuels; the use of the hot air produced from the air reactor in a gas turbine has to be optimized; exhausts should be filtered to retain the dust released by oxygen carrier attrition;

(5) high electrical efficiency of the power system has to be granted together with high fuel conversion in the combustor
.

MARIE CURIE ACTIONS

Carbon capture with Chemical Looping Combustion



GTCLC-NEG PROJECT PRESENTATION

Combustion and Gasification group

COMBUSTION AND GASIFICATION GROUP

Consejo Superior de Investigaciones Científicas (CSIC)
- Spanish National Research Council (CSIC) -
Instituto de Carboquímica (ICB) Zaragoza

INSTITUTO DE CARBOQUIMICA

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

http://www.icb.csic.es/

2015 2016 2017 2018

Combustion and Gasification group

COMBUSTION AND GASIFICATION GROUP

icb INSTITUTO DE CARBOQUIMICA

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Research lines

- **Combustion /gasification** in bubbling and circulating fluidized bed reactors using fossil and renewable fuels (coal, biomass, wastes, etc.)
- **Hot gas cleaning. Sulphur compounds** (SO_2, H_2S, etc.) with calcium based sorbents
- **Modelling, simulation and optimisation of fluidized bed reactors**
- **CO_2 capture**
  - *Chemical Looping Combustion*
  - Oxyfuel combustion (fluidized bed)
- **Syngas/H_2 production with CO_2 capture**
  - *"Chemical Looping Reforming"*
  - *"Chemical Looping Gasification"*

Research on **Chemical Looping** since 2000

Combustion and Gasification group

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Chemical looping research

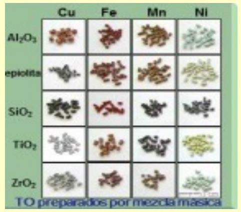
OXYGEN CARRIERS

Preparation | Reactivity TGA | Fluidization FB

Impregnation
Pelletization
Granulation

mg

g



~ 300

TESTING IN PLANT

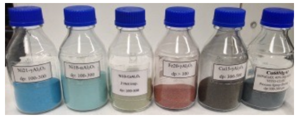
0.5 – 50 kW

Gaseous, liquids and solid fuels

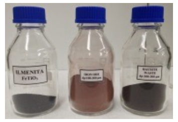
kg

12

SINTHETICS

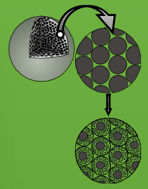


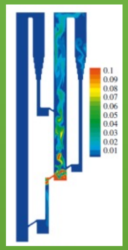
NATURAL



SCALING AND OPTIMIZATION

Kinetics *Modelling*





Combustion and Gasification group

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Chemical looping research

- More than 1500 h of experiment work in Chemical Looping units (about 20% of the global experience in CL)

CLC/CLR - 500 W_{th}
Natural gas / syngas

CLC/CLR - 500 W
Líquid fuels

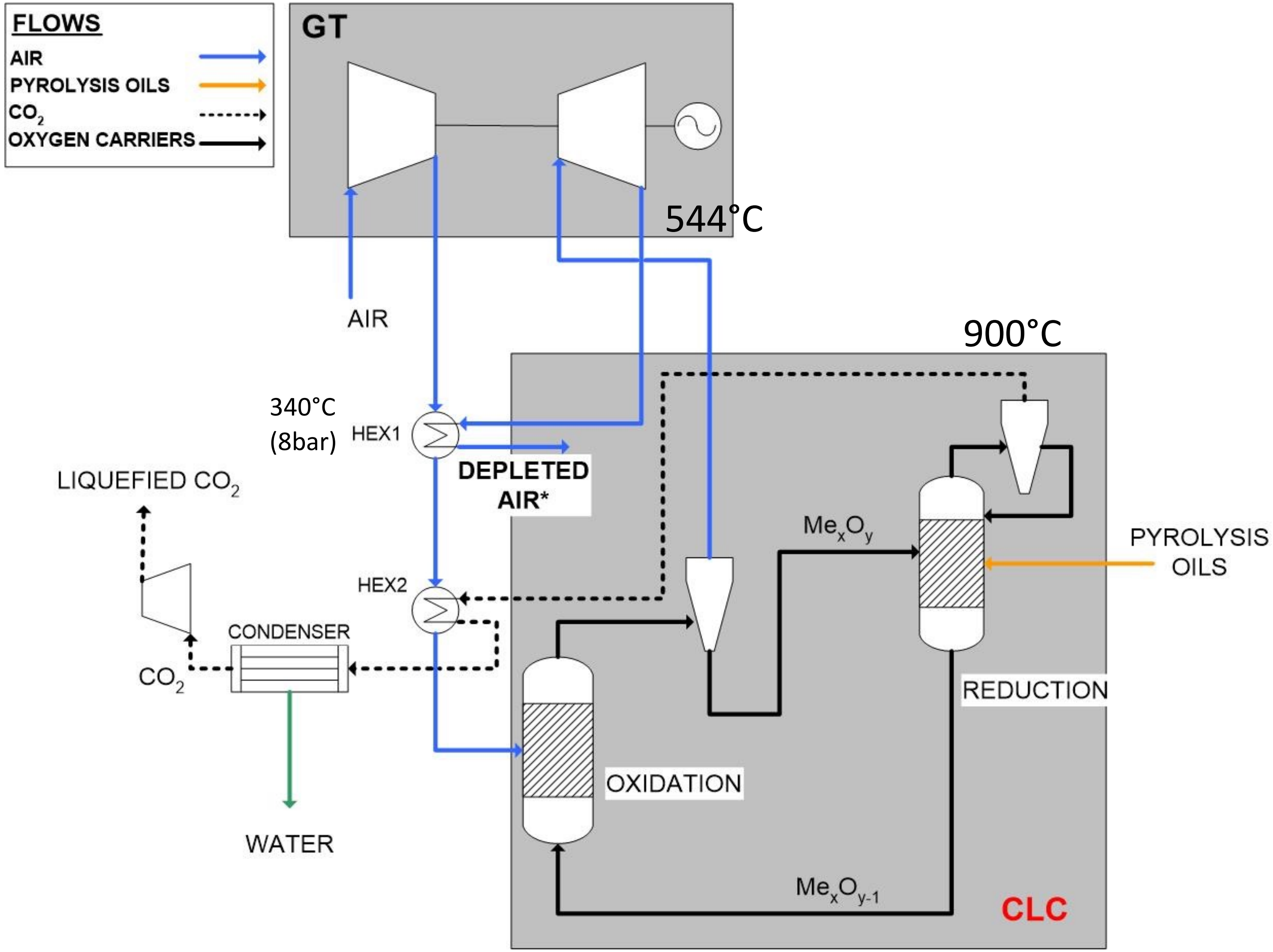
CLC/CLR - 10 kW_{th}
Natural gas / syngas

Press CLR - 1 kW_{th}
Natural gas

CLC - 1 kW_{th}
Solid fuels

CLC - 50 kW_{th}
Solid fuels

The GTCLC-NEG project



PROJECT LOGO (GT-CLC)

The Project WPs

WP1: OC PREPARATION AND CHARACTERIZATION

WP2: BATCH TESTS

WP3: MODELING (P,R,P)

WP4: CONTINUOS PILOT TESTS

WP5: REACTOR DESIGN

MODELING A FUEL REACTOR IN BATCH CONDITIONS

The Oxygen Carrier

Oxygen carrier [1]:

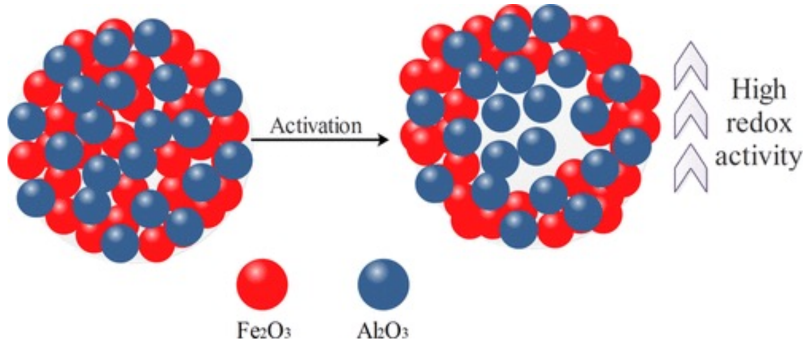
$Fe_2O_3 + Al_2O_3$

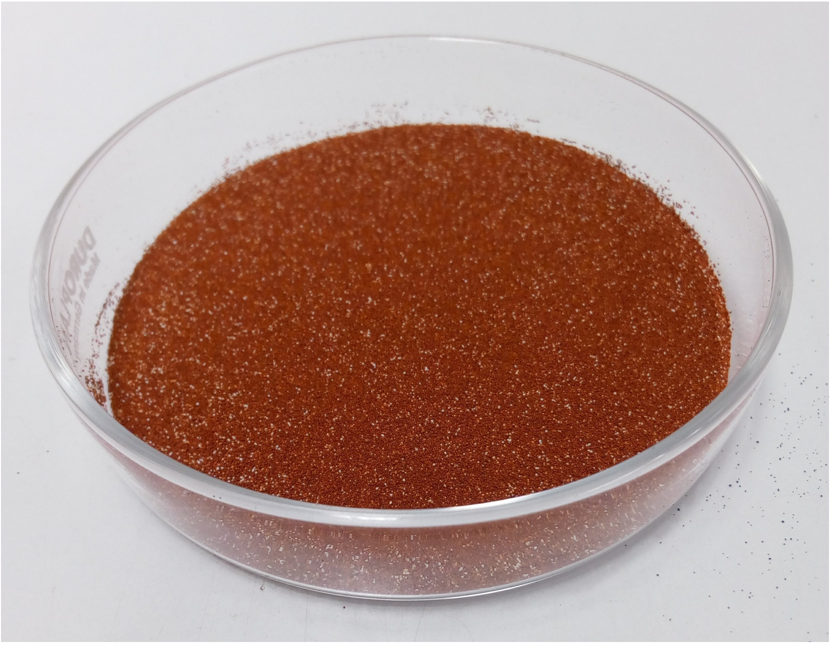
Dimensions: 90–212 µm

Density: 2150 kg/m^3

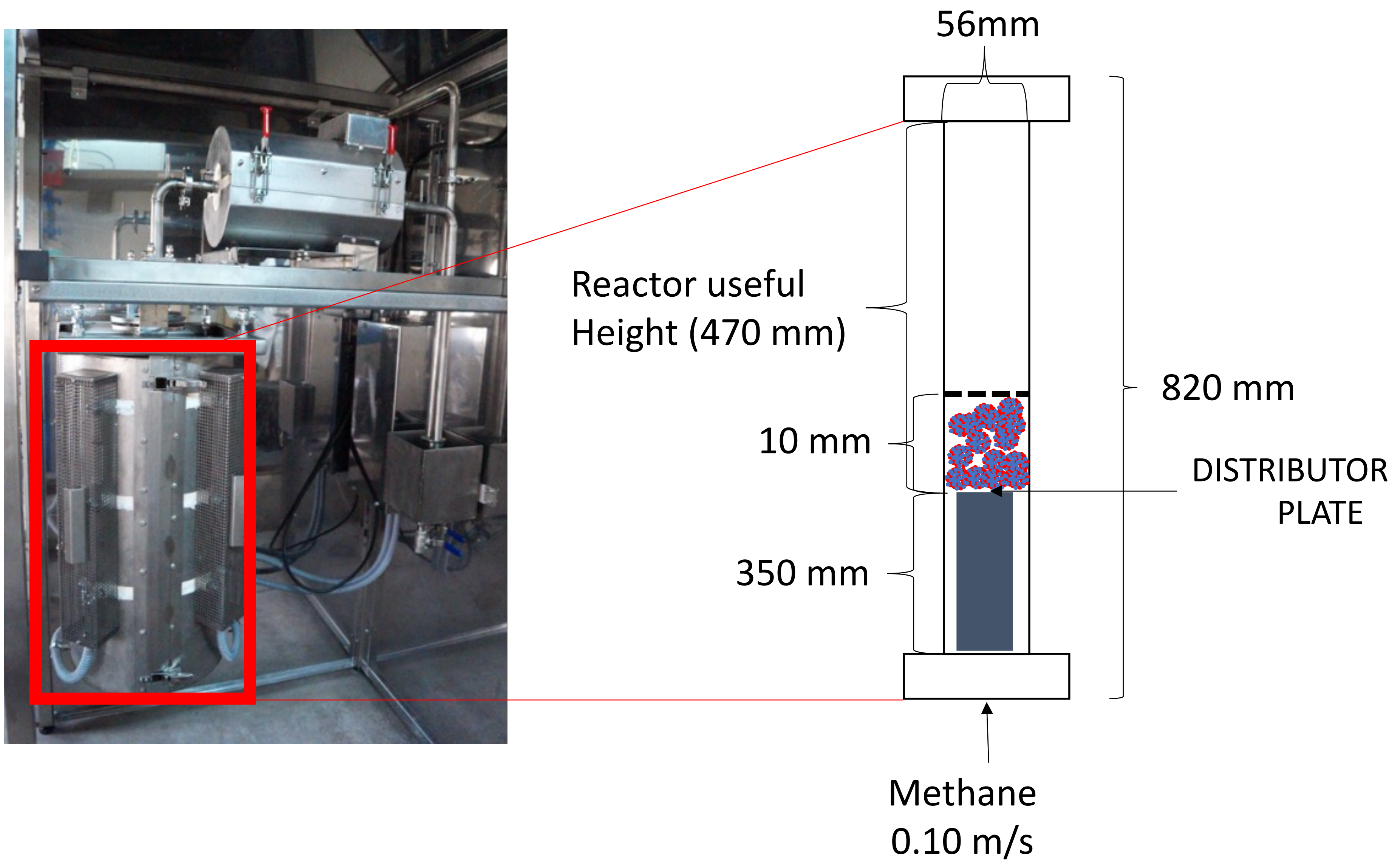
Porosity: 0.56

[1] A. Abad, T. Mattisson, A. Lyngfelt, M. Johansson, The use of iron oxide as oxygen carrier in a chemical-looping reactor, Fuel, Volume 86, Issues 7–8, 2007, Pages 1021-1035,





The Reactor


56mm
Reactor useful
Height (470 mm)
820 mm
10 mm
DISTRIBUTOR
PLATE
350 mm
Methane
0.10 m/s

The Model

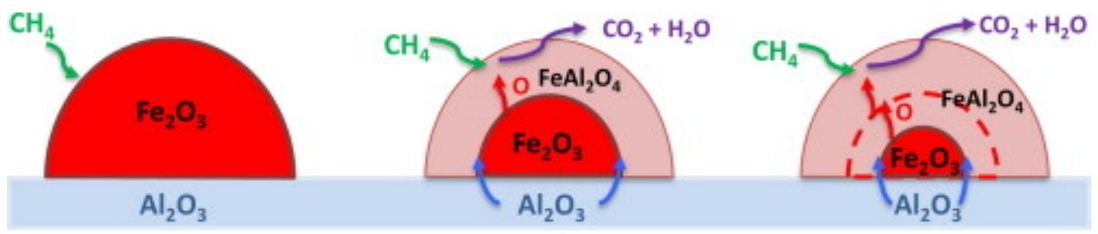
MULTIPHASE MODELING (OS)

MFiX Multiphase Flow with Interphase eXchanges

⇧

UDF

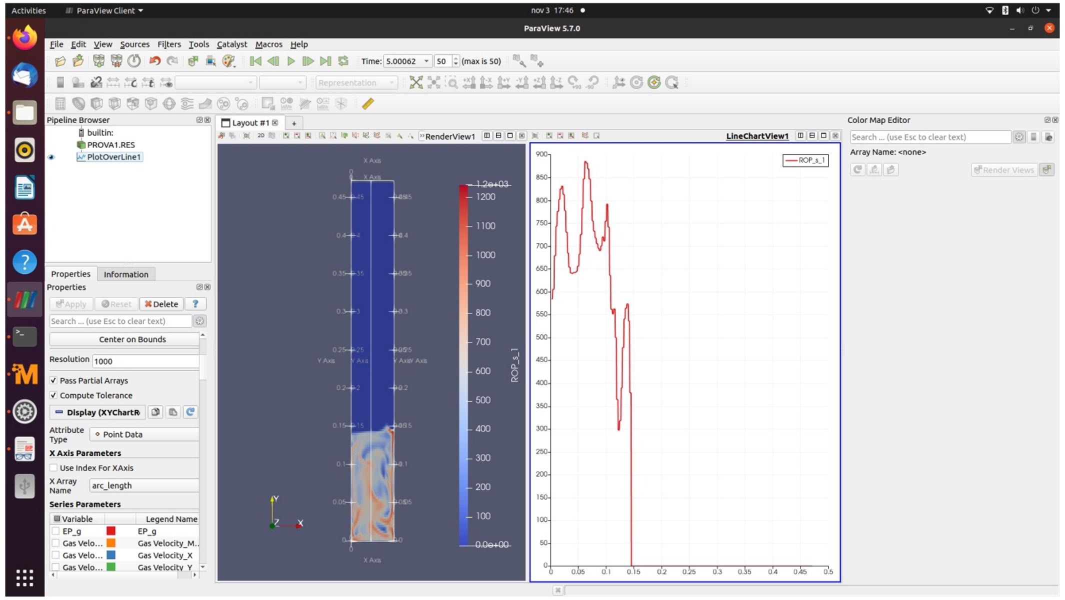
⇧



1. Fresh particle 2. Kinetic control 3. Diffusion control [1]

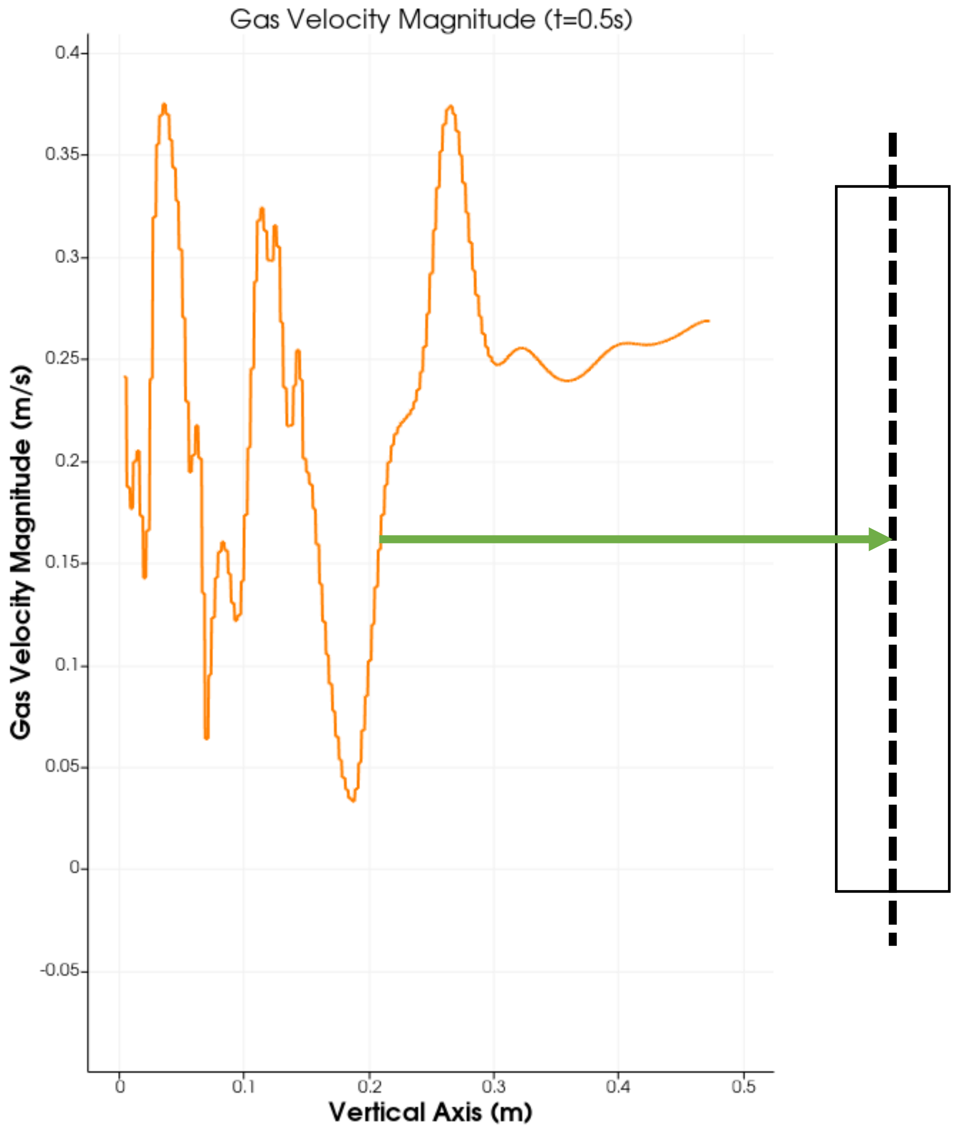
POST-PROCESSING (OS)

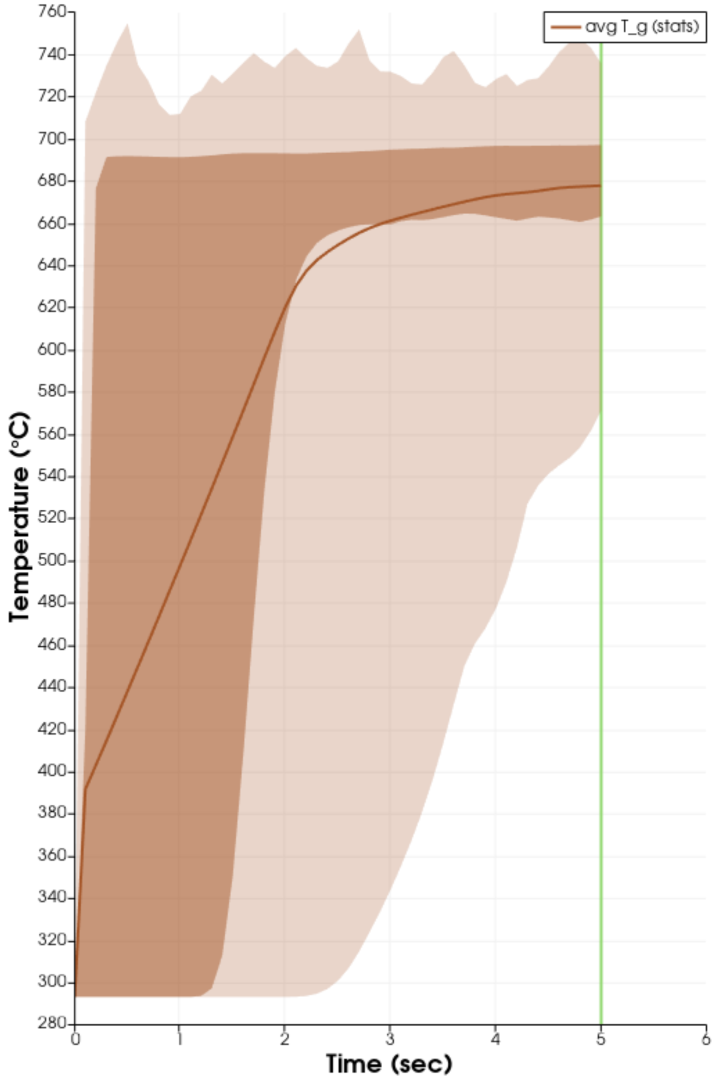
ParaView



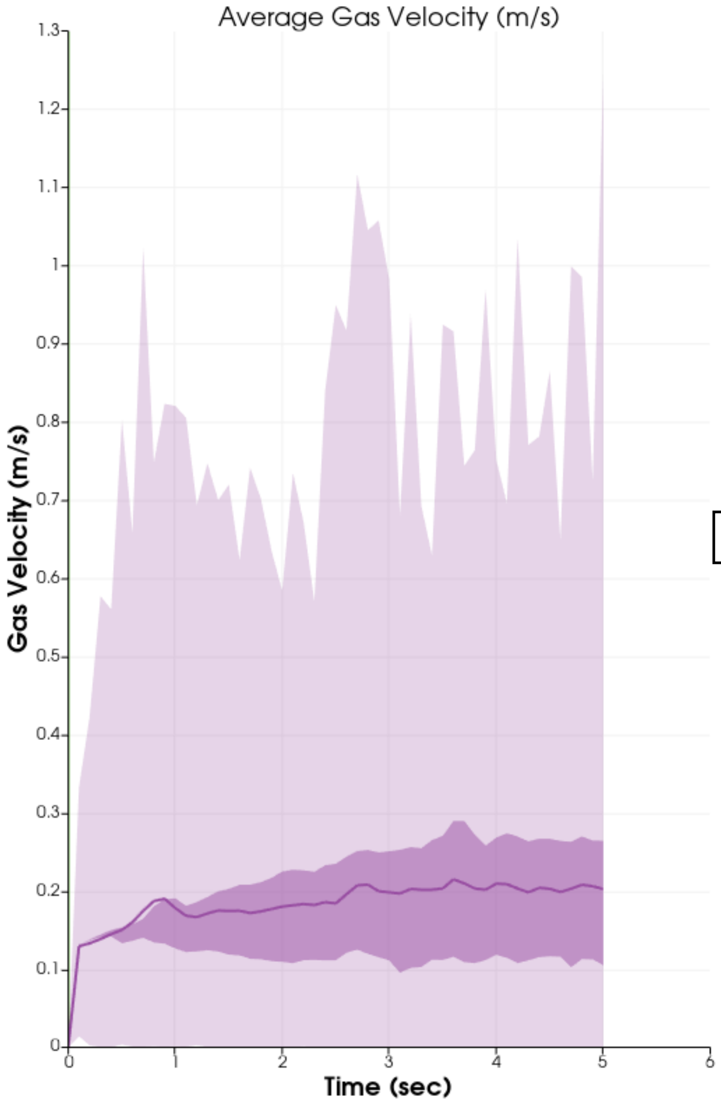
[1] A. Cabello, A. Abad, F. García-Labiano, P. Gayán, L.F. de Diego, J. Adánez, Kinetic determination of a highly reactive impregnated Fe2O3/Al2O3 oxygen carrier for use in gas-fueled Chemical Looping Combustion, Chemical Engineering Journal, Volume 258, 2014, Pages 265-280,

RESULTS 1

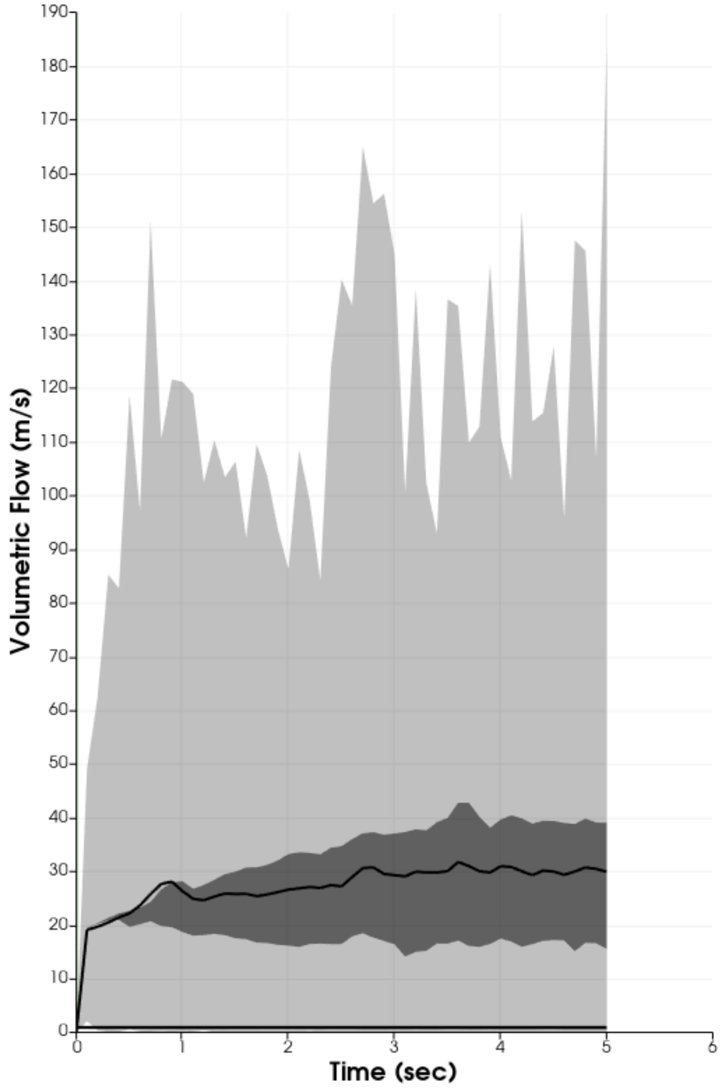

Gas Velocity Magnitude (t=0.5s)
Gas Velocity Magnitude (m/s)
Vertical Axis (m)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
0.1
0.2
0.3
0.4
0.5


avg T_g (stats)
Temperature (°C)
Time (sec)
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
0
1
2
3
4
5
6

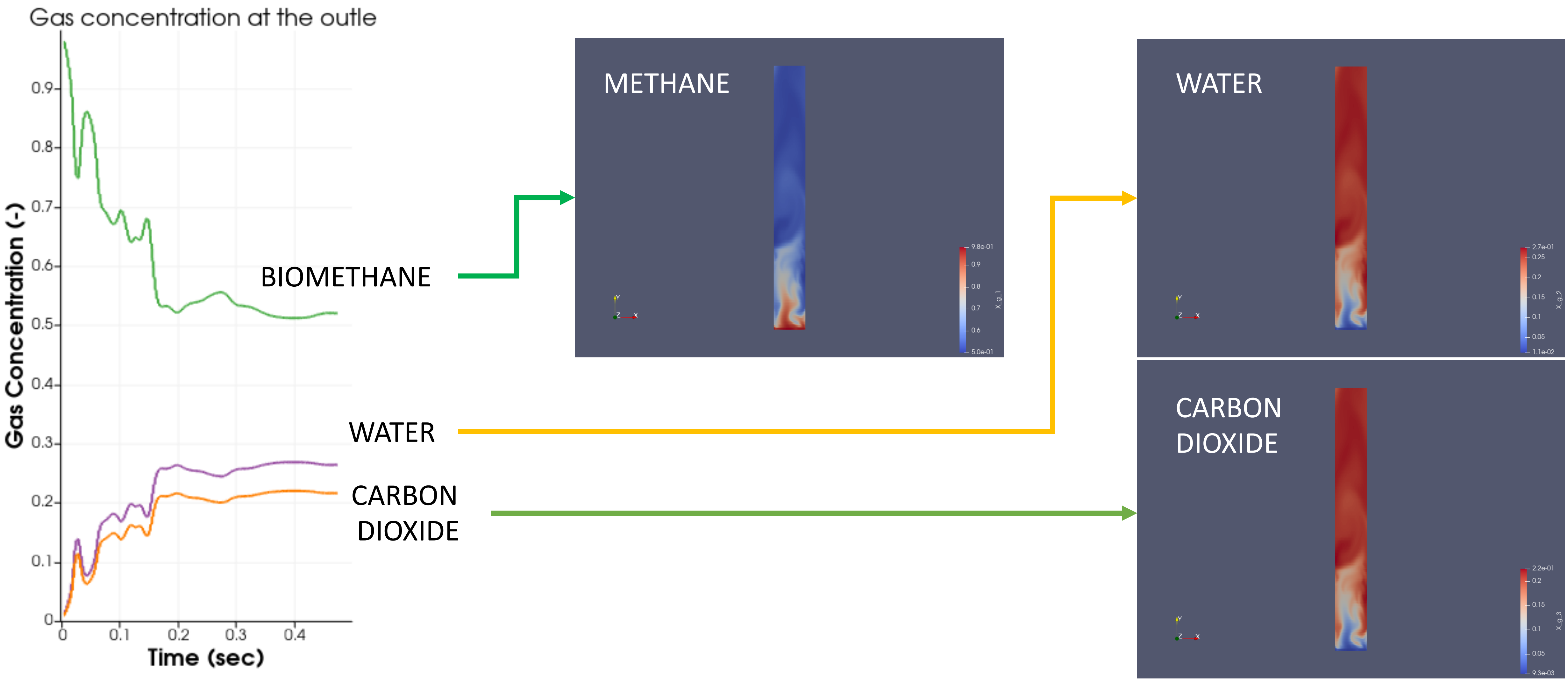
RESULTS 2



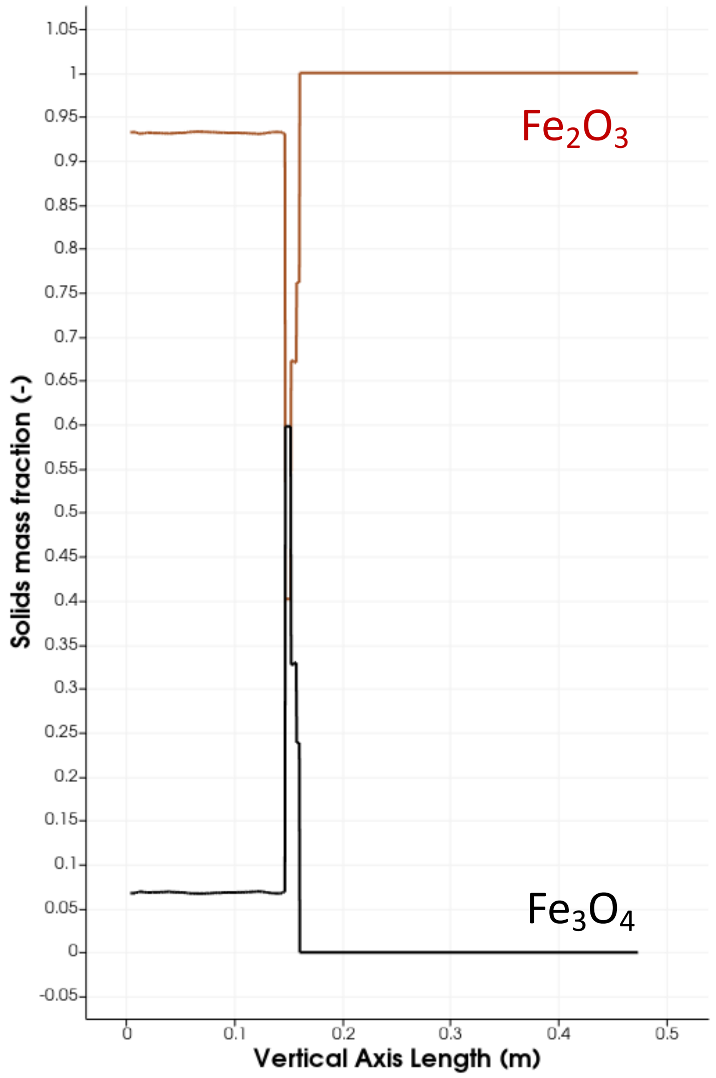
mag(Gas Velocity)*0.056*0.056*3.14/4*1000*60

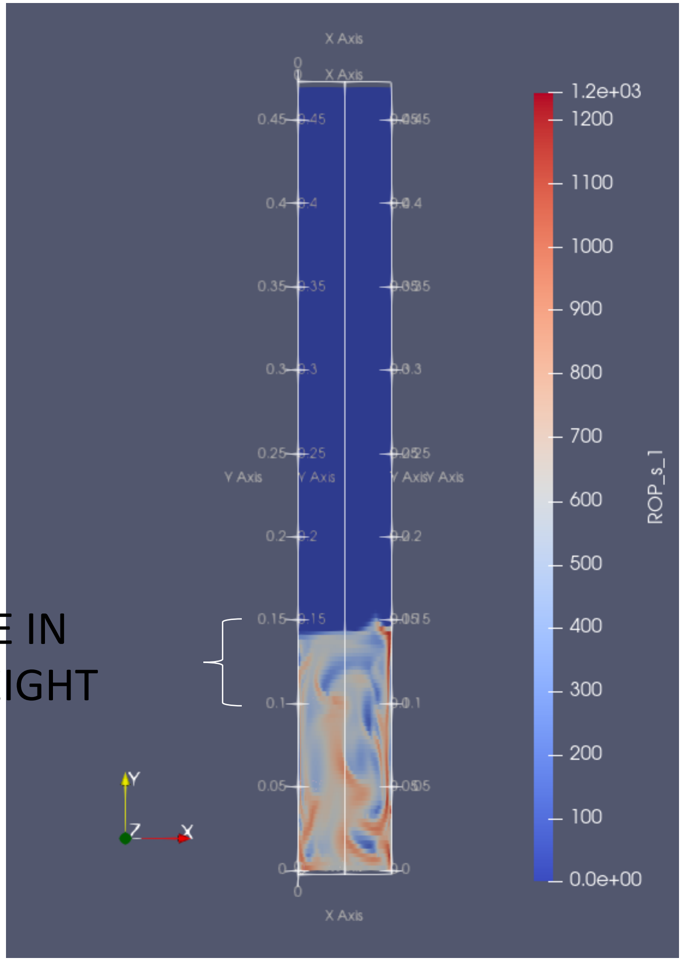


RESULTS 3: GAS YIELDS



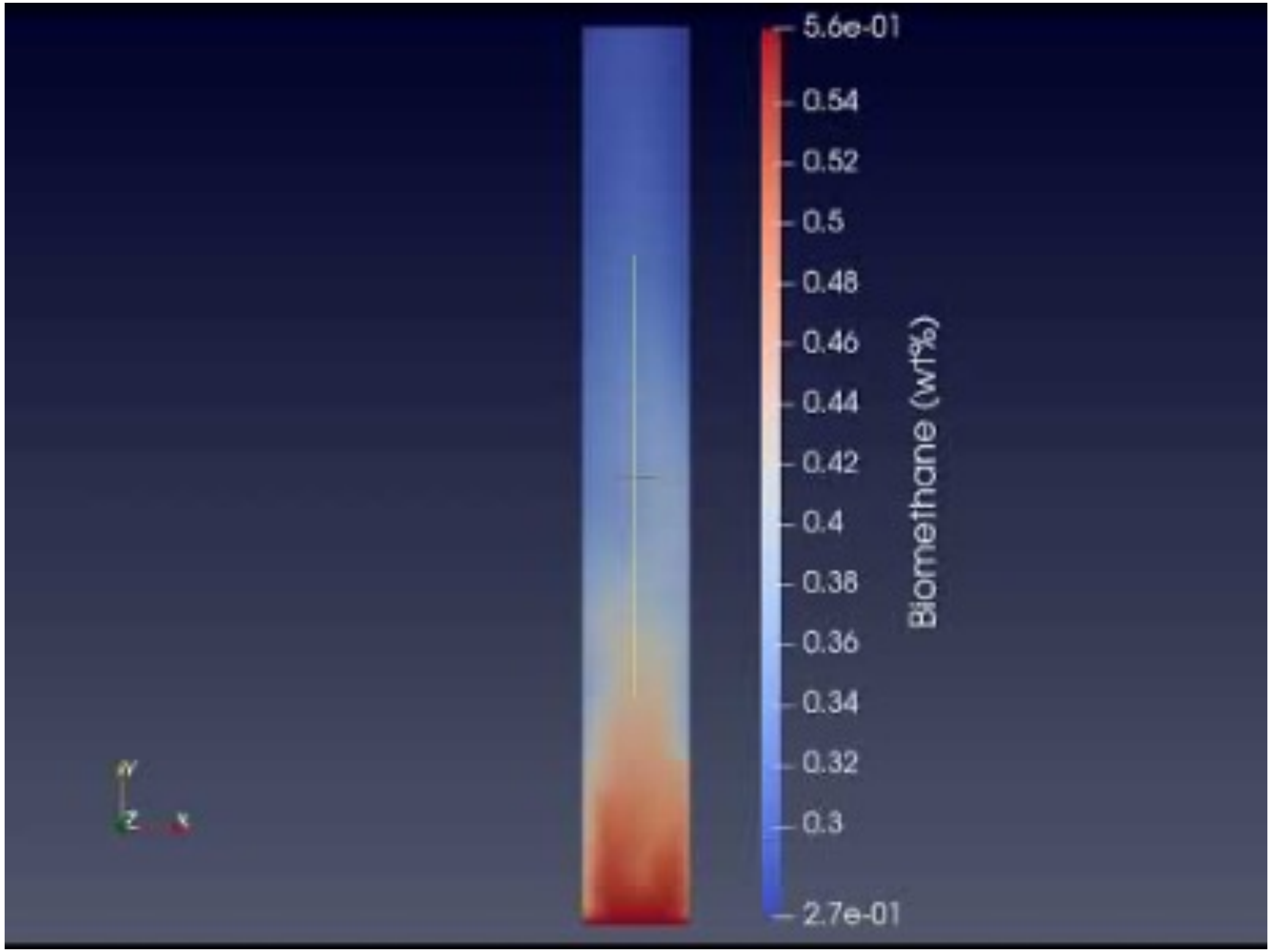
RESULTS 4: SOLID BEHAVIOR



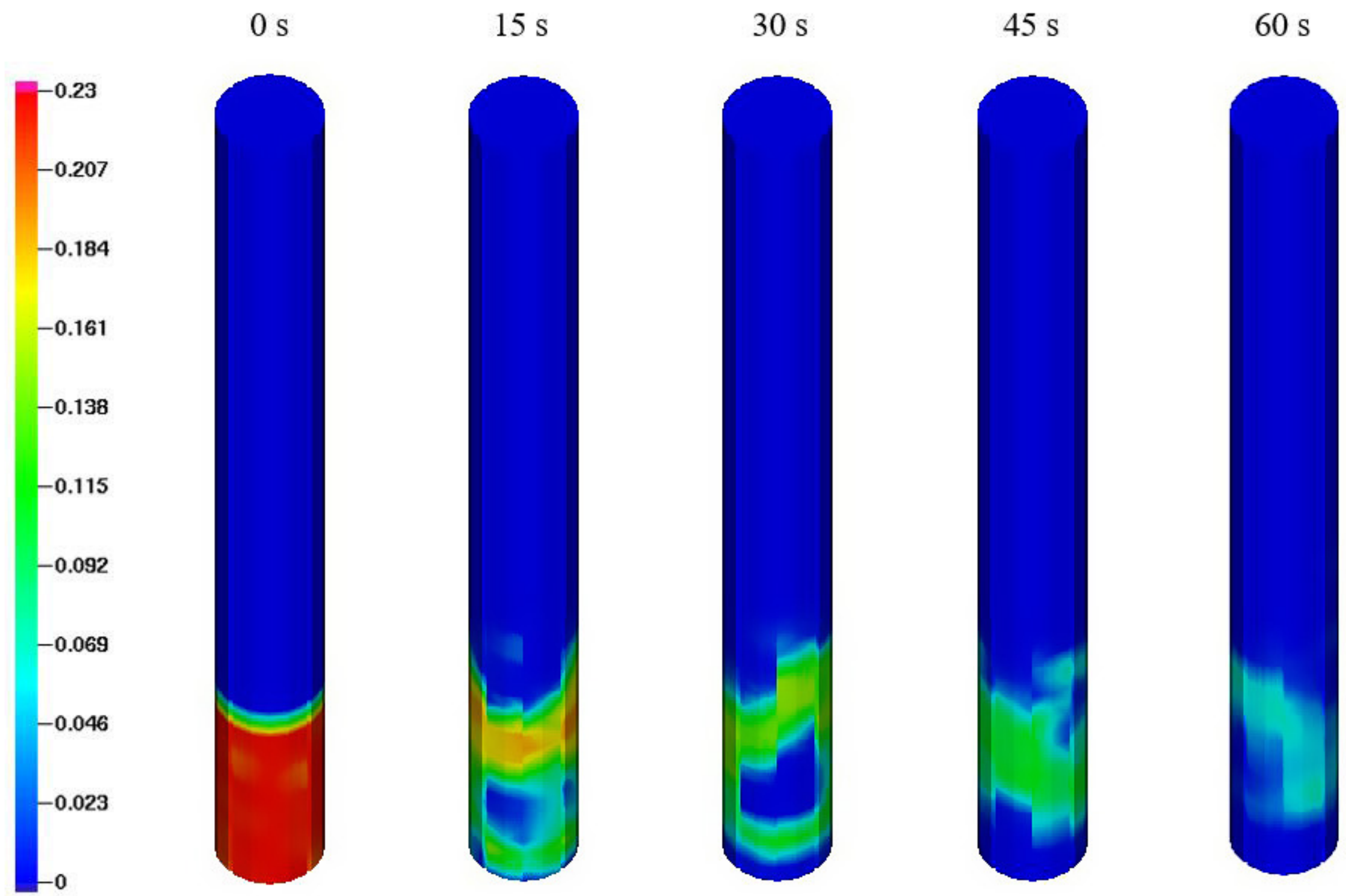


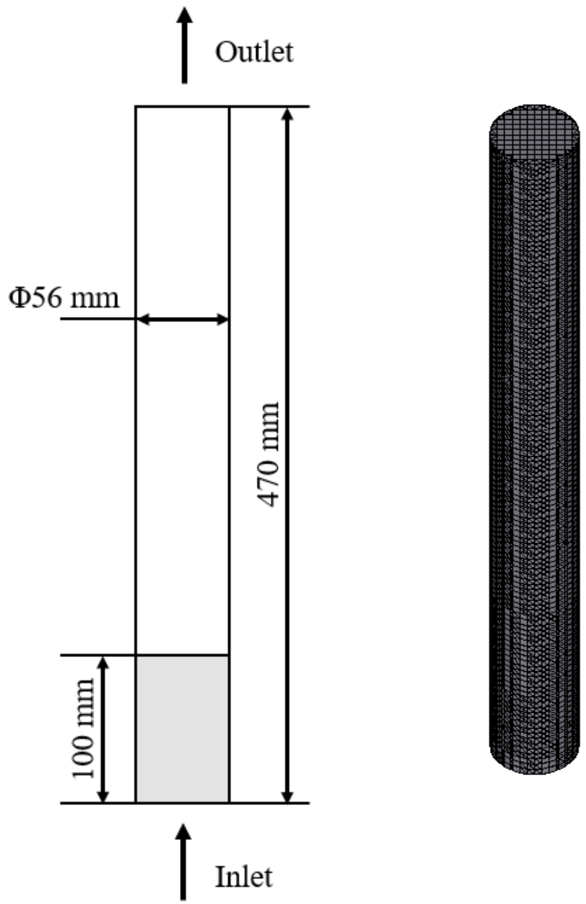
INCREASE IN
LEVEL HEIGHT

THE FINAL MODEL



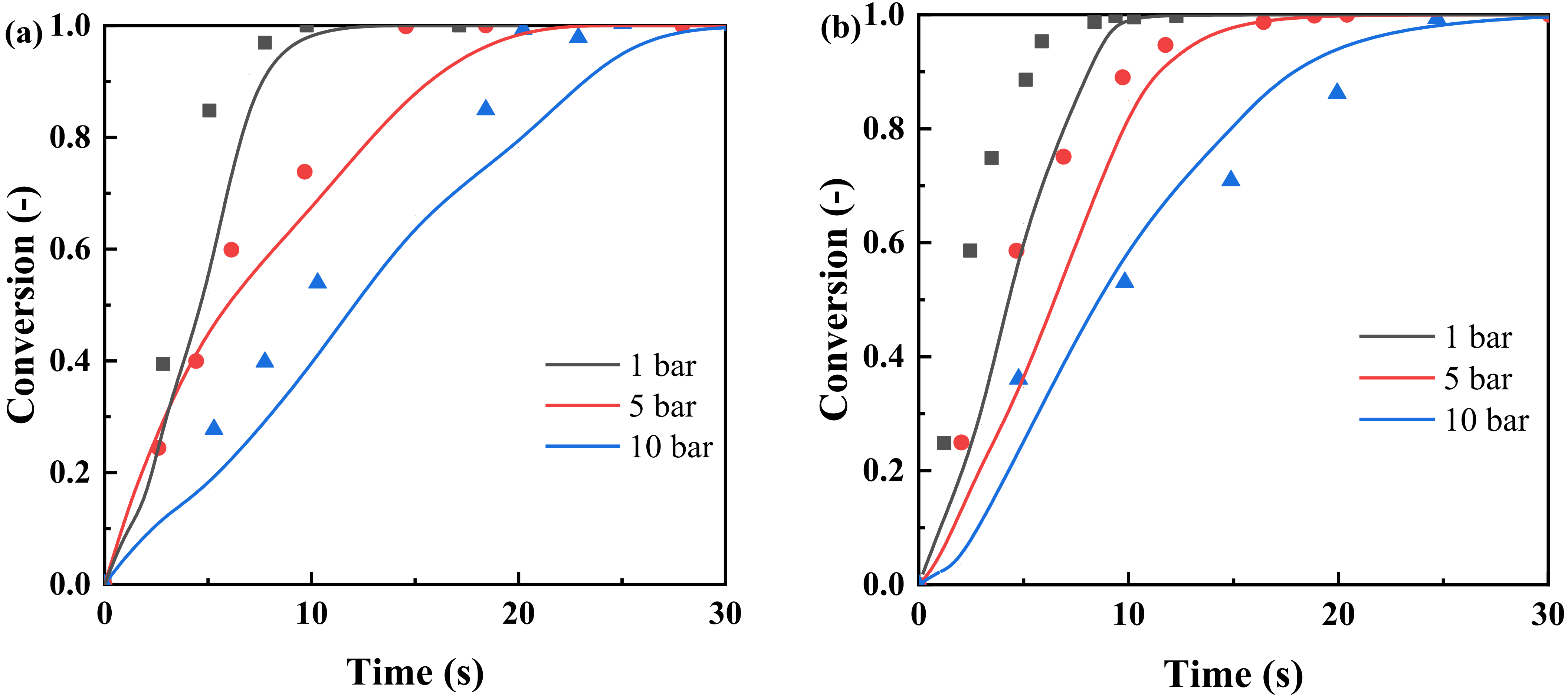
MODELING THE PRESSURISED FUEL REACTOR





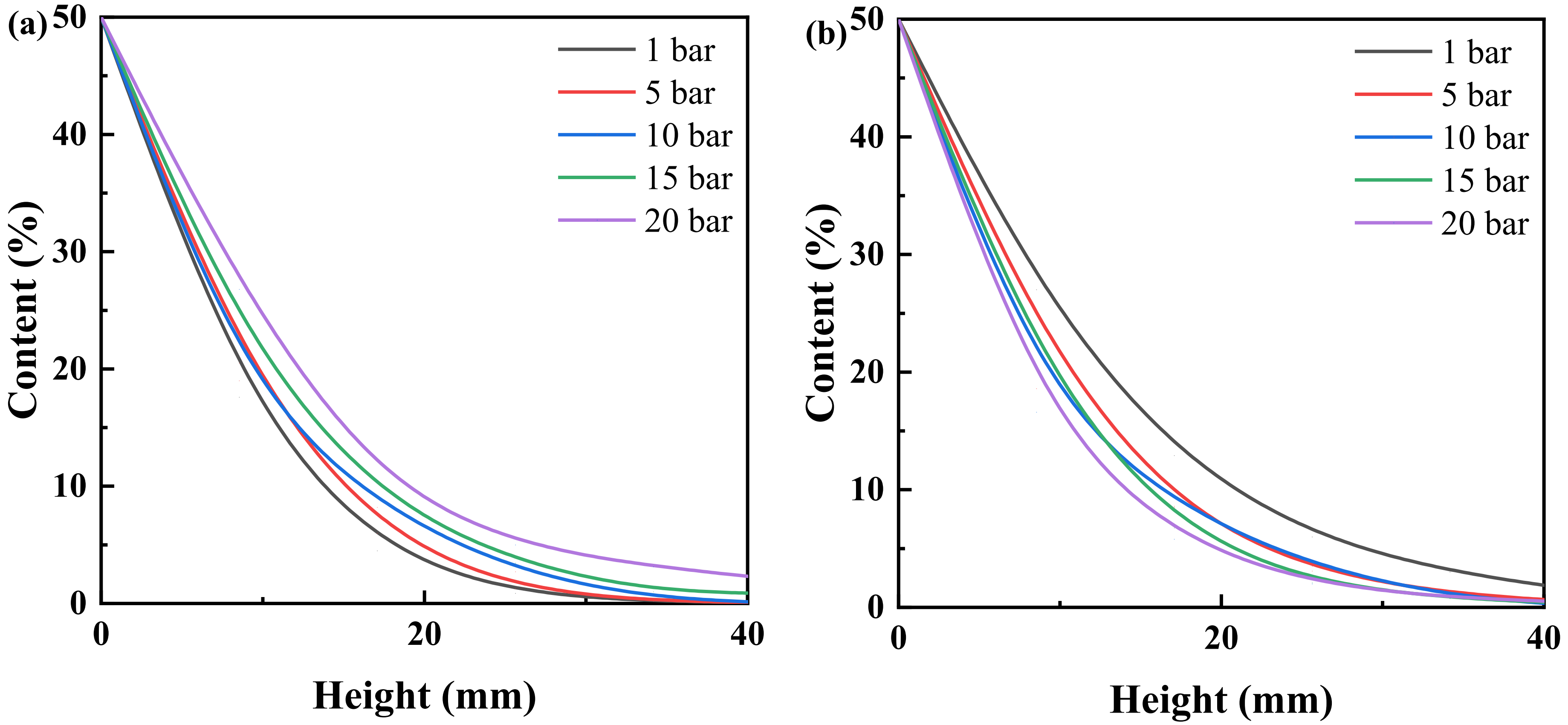
Fe_2O_3 particle volume fraction during time. (Syngas, 1073 K, 10 bar)

VALIDATION

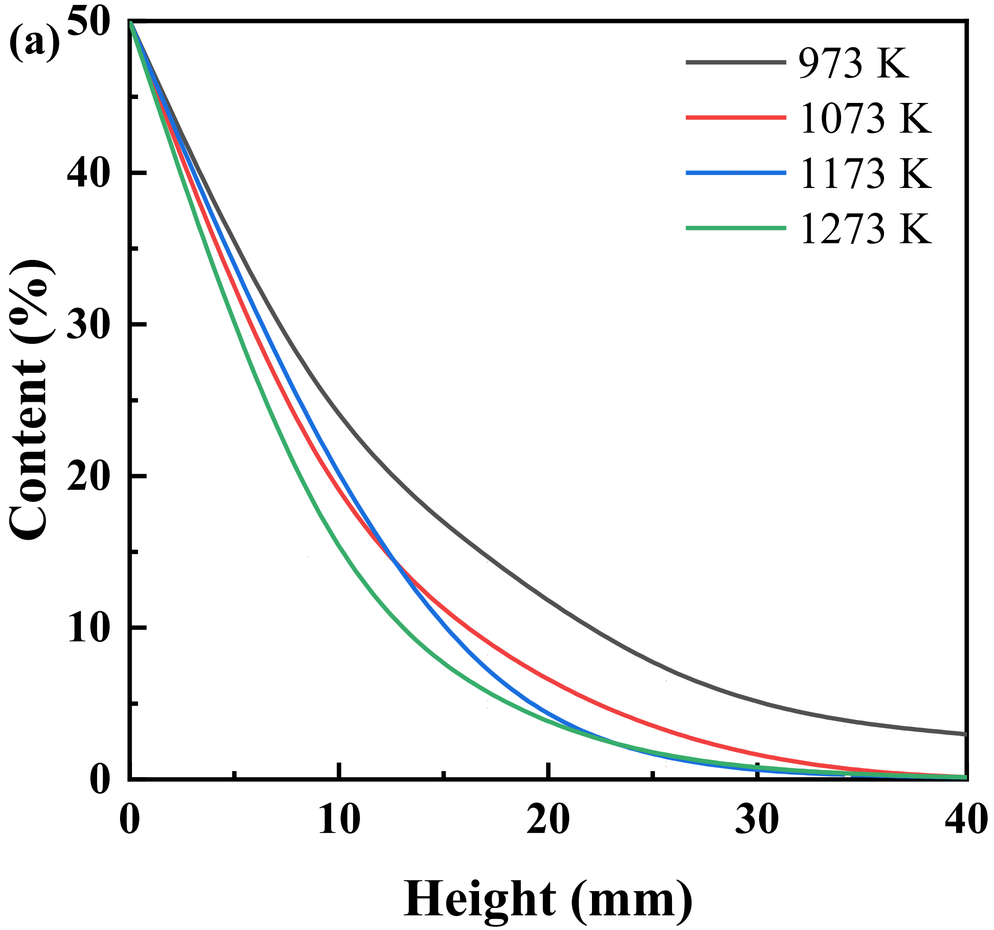


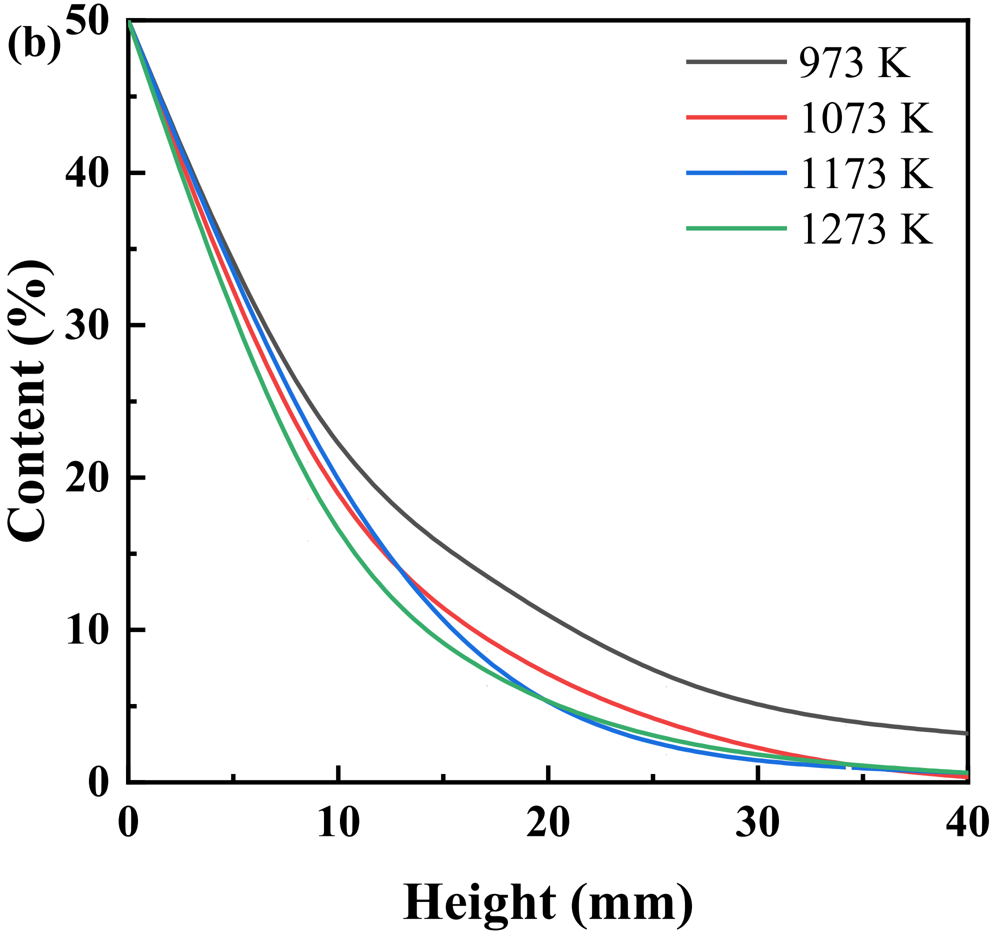
(a)
1.0
0.8
0.6
0.4
0.2
0.0
Conversion (-)
0
10
20
30
Time (s)
1 bar
5 bar
10 bar
(b)
1.0
0.8
0.6
0.4
0.2
0.0
Conversion (-)
0
10
20
30
Time (s)
1 bar
5 bar
10 bar

CONTENT OF H2 AND CO AT DIFFERENT REACTOR HEIGHT WITH DIFFERENT PRESSURES

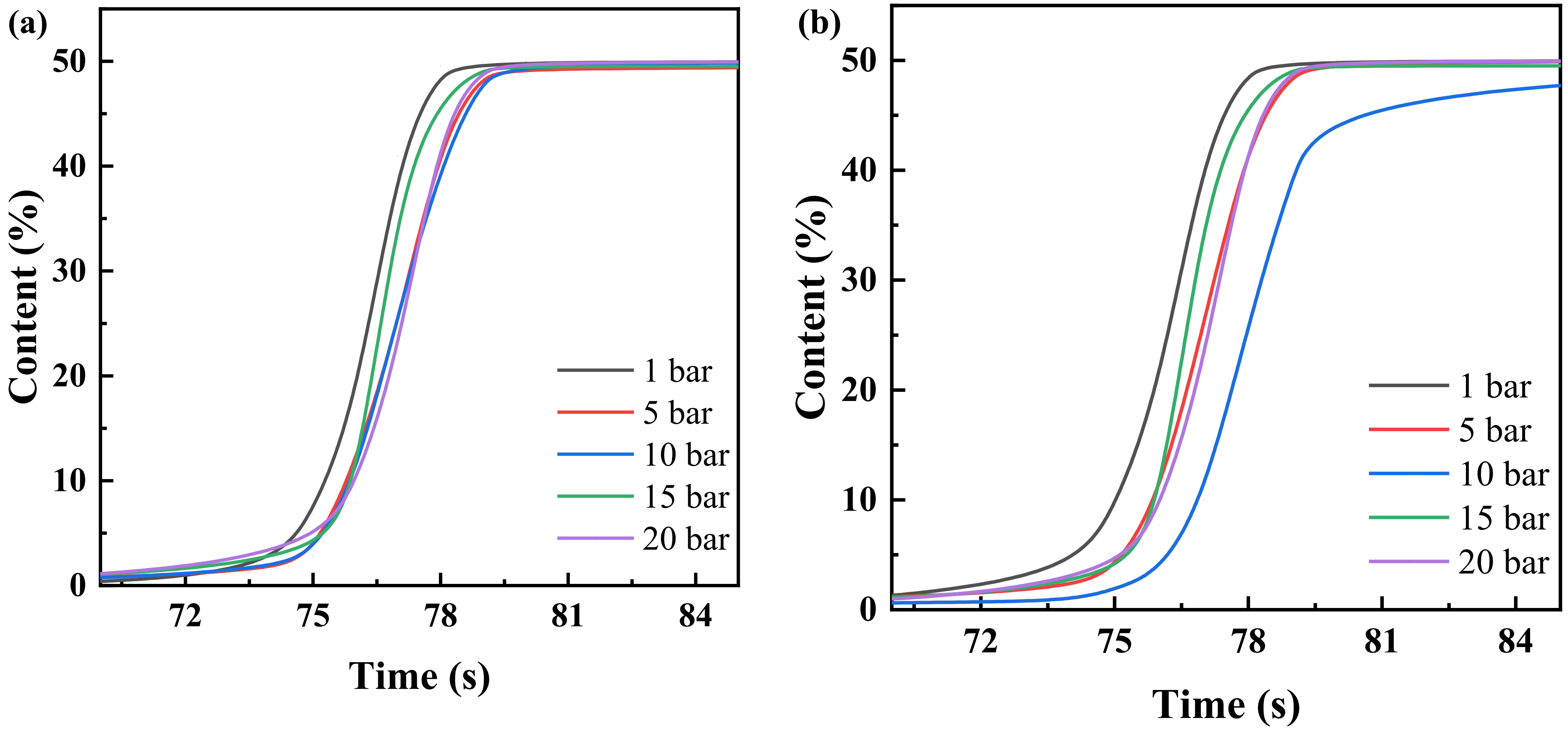


CONTENT OF H2 AND CO AT DIFFERENT REACTOR HEIGHT WITH DIFFERENT TEMPERATURES

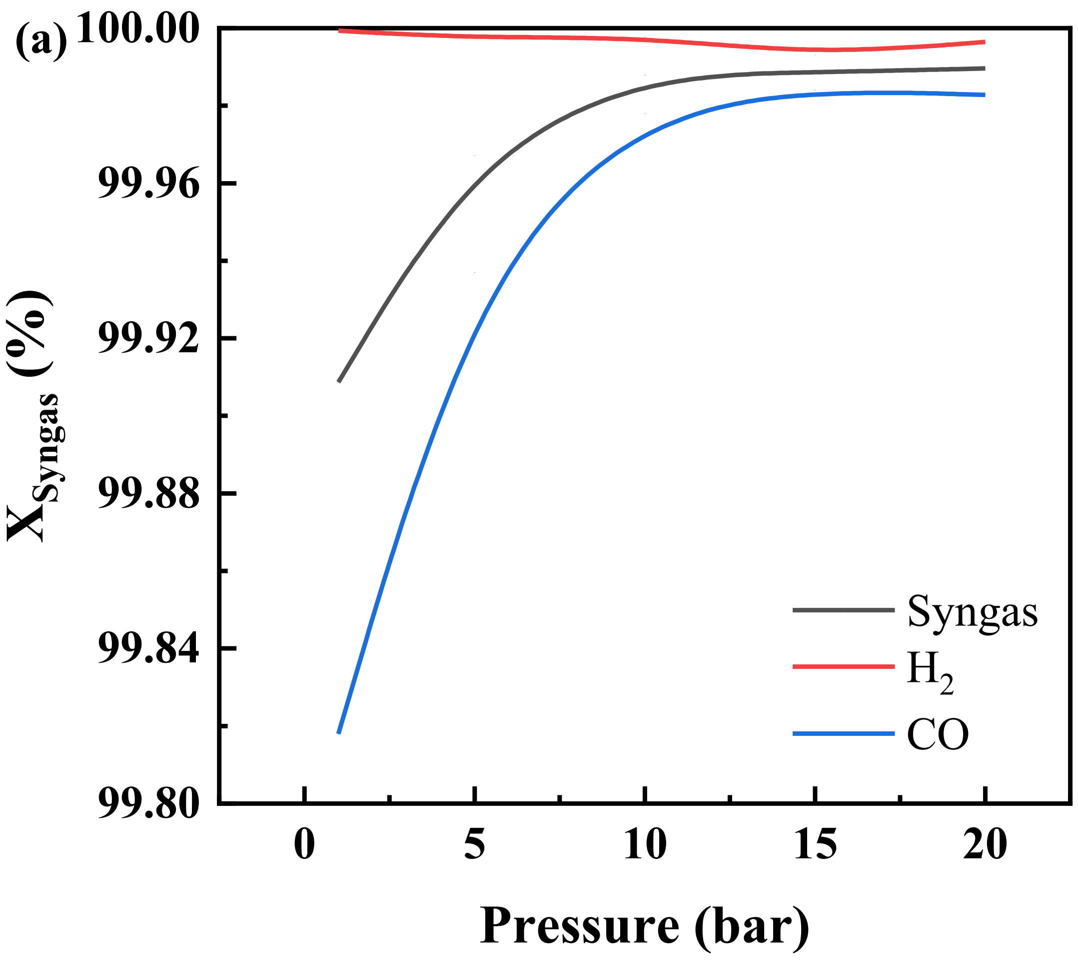




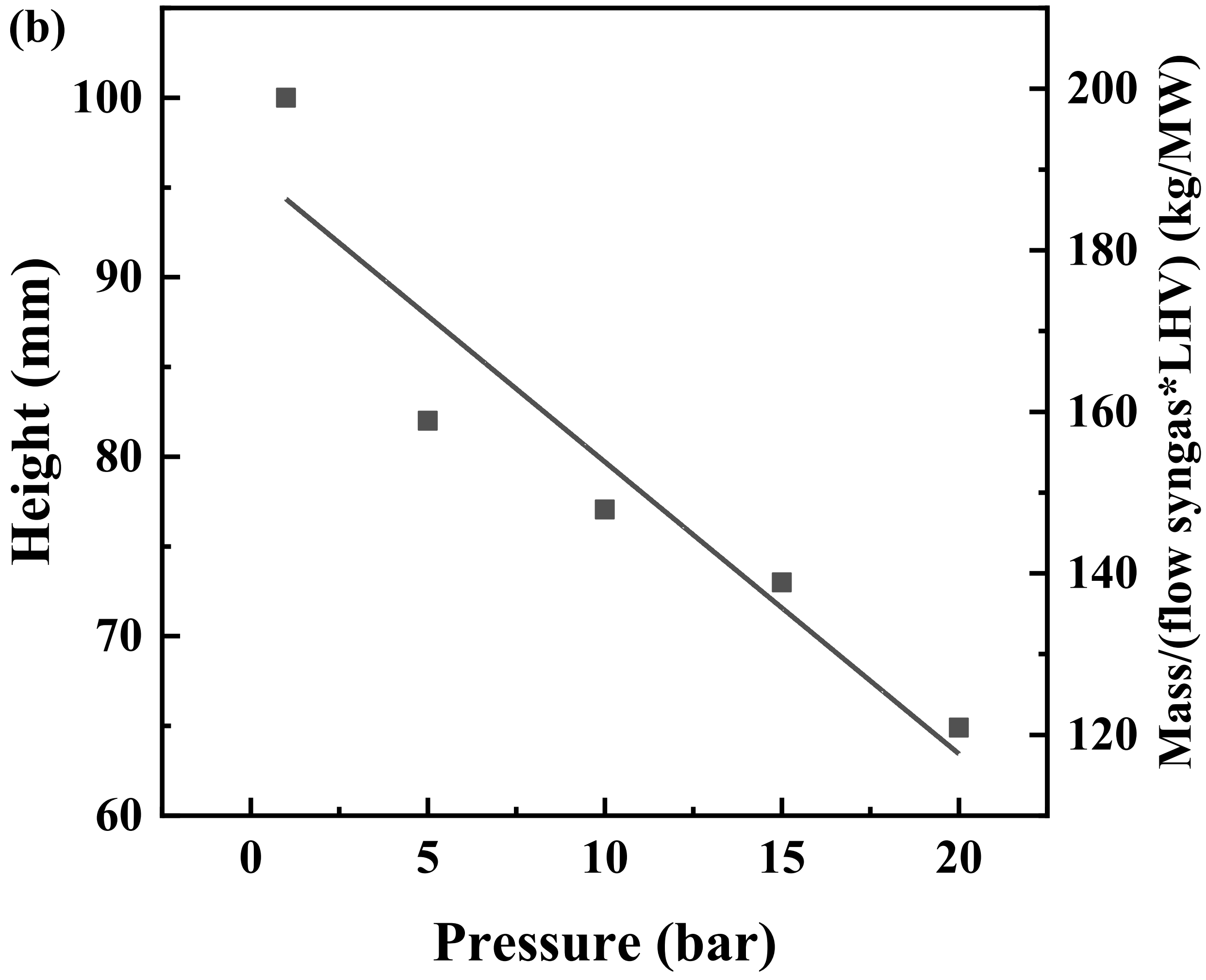
Concentration of H_2 and CO at the outlet of the reactor under different pressures.



Influence of pressure on the conversion efficiency of syngas in the Fuel Reactor



Adaptations required to bed height to counteract the effect of pressure increase on oxygen carrier conversion rate



CONCLUSIONS

1. A FEASIBILITY ANALYSIS OF INTRODUCING CLC COMBUSTORS IN THE NGCC PLANTS IN ITALY IS PRESENTED
2. A CFD MODEL OF A FUEL REACTOR FED WITH NATURAL GAS HAS BEEN REALIZED IN MFIX SOFTWARE
3. A CFD MODEL OF PRESSURISED REACTOR FED WITH SYNGAS HAS BEEN PERFORMED
4. A METHOD FOR THE OPTIMIZATION OF PLANT EFFICIENCY HAS BEEN DEVELOPED BASED ON AN ENERGY BALANCE BETWEEN THE AIR REACTOR AND THE FUEL REACTOR

FUTURE DEVELOPMENTS

1. A CFD MODEL OF THE ENTIRE RECTOR WILL BE REALISED
2. MOLECULAR DYNAMICS MODELING WILL BE PERFORMED OT FURTHER UDERSTAND THE EFFECT OF PRESSURE
3. DIGITAL TWINS ANALYSIS WILL BE PERFORMED TO OTPIMIZE TURIBNE BEHAVIOR
4. DIFFERENT OXYGEN CARRIERS WILL BE TAKEND INTO ACCOUNT
5. OXYGEN CARRIER DUST ABATEMENT METHODS WILL BE DEVELOPED TO ASSURE THE TURBINE IS NOT DAMEGED BY ENTRAINED PARTICLES

Acknowledgements

- This work has been partially funded by the GTCLC-NEG project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 101018756.

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CONTACTS

bartocci@crbnet.it

PROJECT WEBSITE

https://pietrobartocci.wixsite.com/gtclc-neg

PROJECT REPOSITORY

https://zenodo.org/deposit?page=1&size=20