Ansys Simulation Solutions for Carbon Capture, Utilization and Storage (CCUS)

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Agenda

- Introduction – Carbon Capture, Utilization and Storage (CCUS)
  - Various Technologies – CCUS
  - Application of the Various CCUS Technologies
  - CO_2 Capture Technology – Patent Activity
  - Issues due to CO_2 Leakage

- Application of CFD to Simulate Carbon Capture
  - Case 1 – Absorption of CO_2 with MEA
  - Case 2 – Adsorption of CO_2 with K_2CO_3
  - Case 3 – Cryogenic Distillation of CO_2

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Why has Carbon Capture become so important?

- CO_2 emissions is the primary driver of global climate change.
- The amount of CO_2 emitted by the **power and the energy sector** running on fossil fuels constitutes approximately **65% of the total emission of GHG***
- Substantial CO_2 emission reduction was agreed upon in the **Paris agreement**, 2015
  - **Maintain the global average temperature rise below 2 ^{o}C**
- Fossil fuels will still play a major role in future power production due to renewable energy limitations and hard to decarbonize industries.
- It is therefore necessary to remove CO_2 emissions at the source or through direct air capture.
  - Carbon Capture technology is the solution.
- NA leading with 13 active projects and 13 more in the pipeline. Century Plant in Texas being the largest, absorbing 8 Mt/yr of CO_2.

Department of Energy

Biden-Harris Administration Announces $3.7 Billion to Kick-Start America's Carbon Dioxide Removal Industry

DECEMBER 13, 2022

*US EPA, Global Greenhouse Gas Emissions Data:
https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

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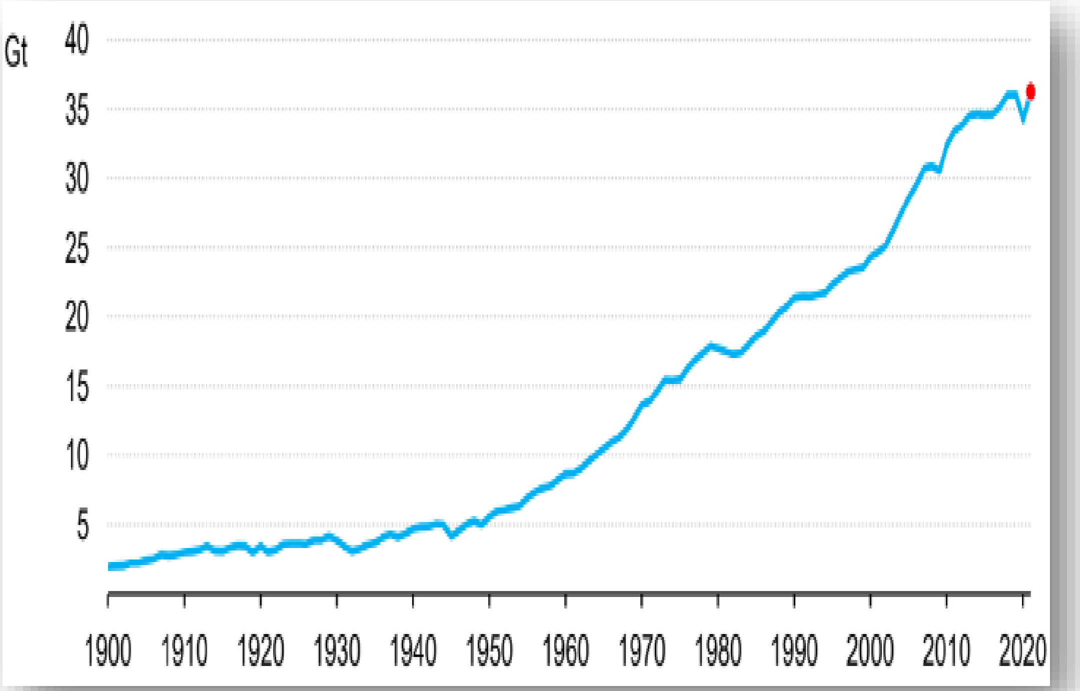
Carbon Capture and Sequestration – A Big Challenge

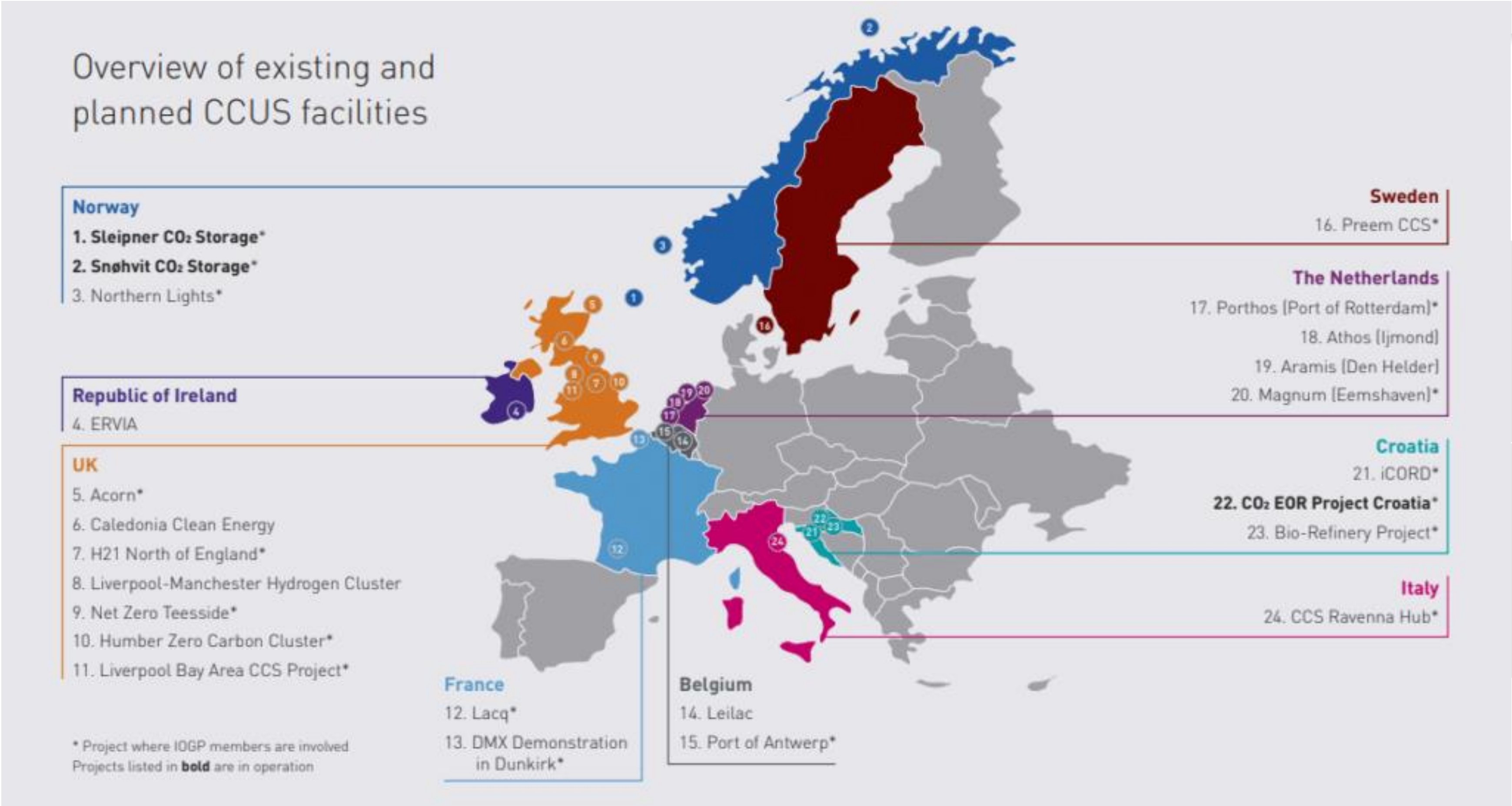
- Carbon **Capture**
  - Absorption/Adsorption/Membrane Separation/Cryogenic Distillation
- CO_2 **Transport**
  - Pipeline, Ships
- CO_2 **Utilization**
  - Food industry, EOR, Concrete, Synthetic methane/HC
- CO_2 **Storage**
  - Geological formations (seabed)
  - Depleted Oil Wells

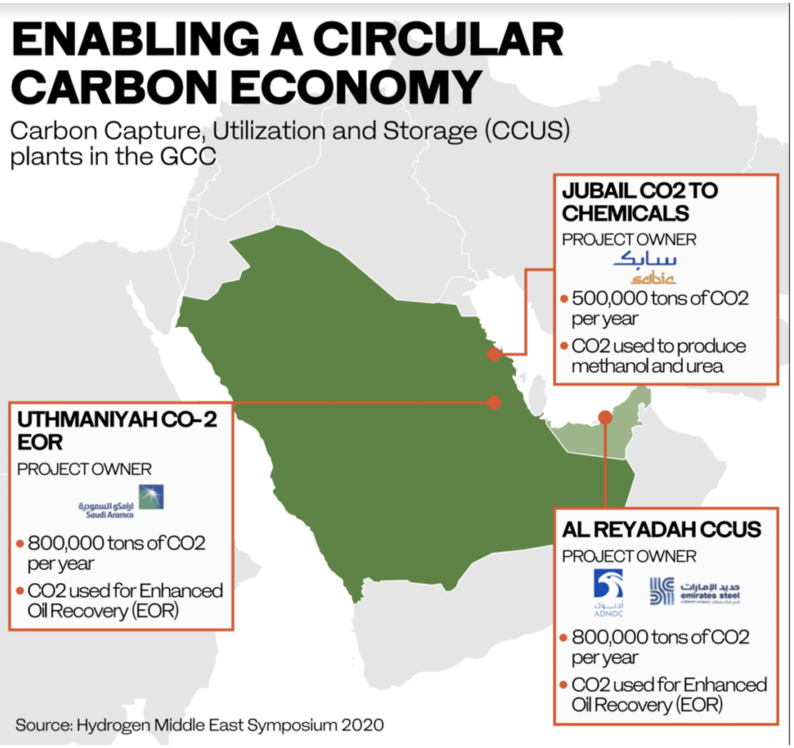


Global anthropogenic CO_2 emissions from 1900-2021

To stay below 2°C of warming, engineering solutions must grow at least 1,300 times by 2050. – American Energy Society (Feb. 2023)

Active/Future Projects in EMEA

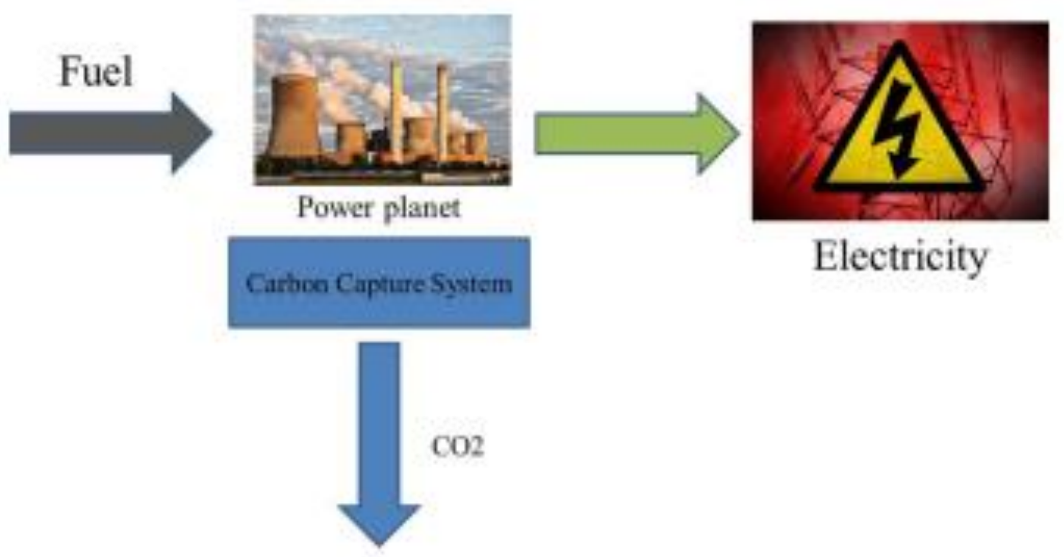




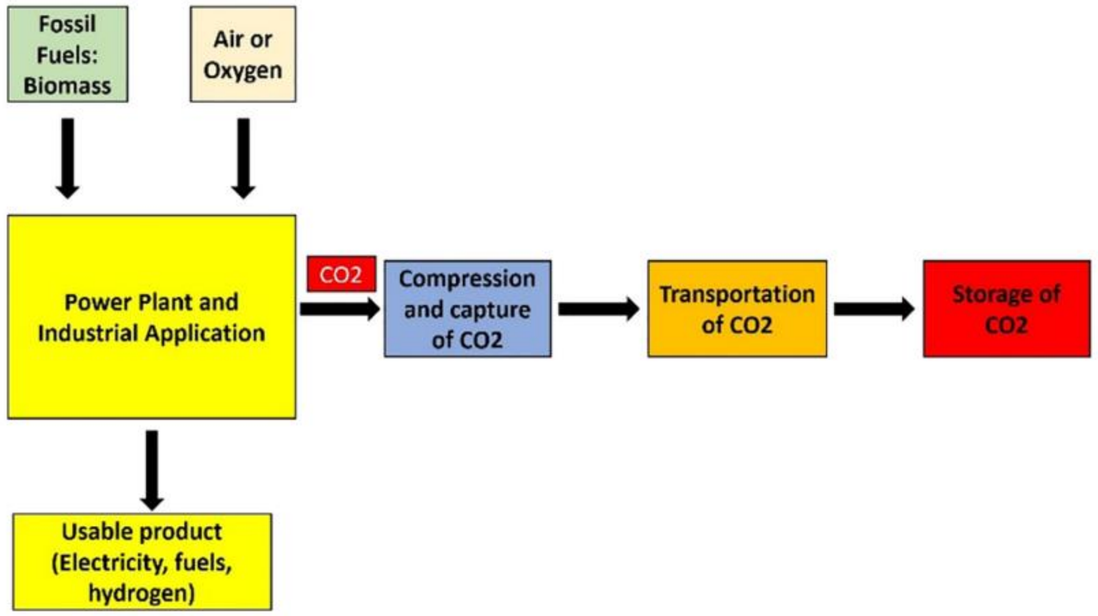
https://www.europeanfiles.eu/climate/large-scale-decarbonisation-solutions-for-a-climate-neutral-industry-and-jobs-in-europe

Introduction – Carbon Capture, Utilization and Storage (CCUS)

- The main objective of carbon capture and storage technologies is to transform the carbon present in flue gases/emissions to carbon-di-oxide that in turn can be injected into underground geological formations.
- The carbon-dioxide must be liquified for easy transportation and storage.



Graphical Abstract: Wilberforce et al. 2019



Steps in carbon capture and storage

Introduction – Carbon Capture, Utilization and Storage (CCUS)

- Carbon Capture (CC) Technologies
- CO_2 Transport
- CO_2 Sequestration

Introduction – Carbon Capture, Utilization and Storage (CCUS)

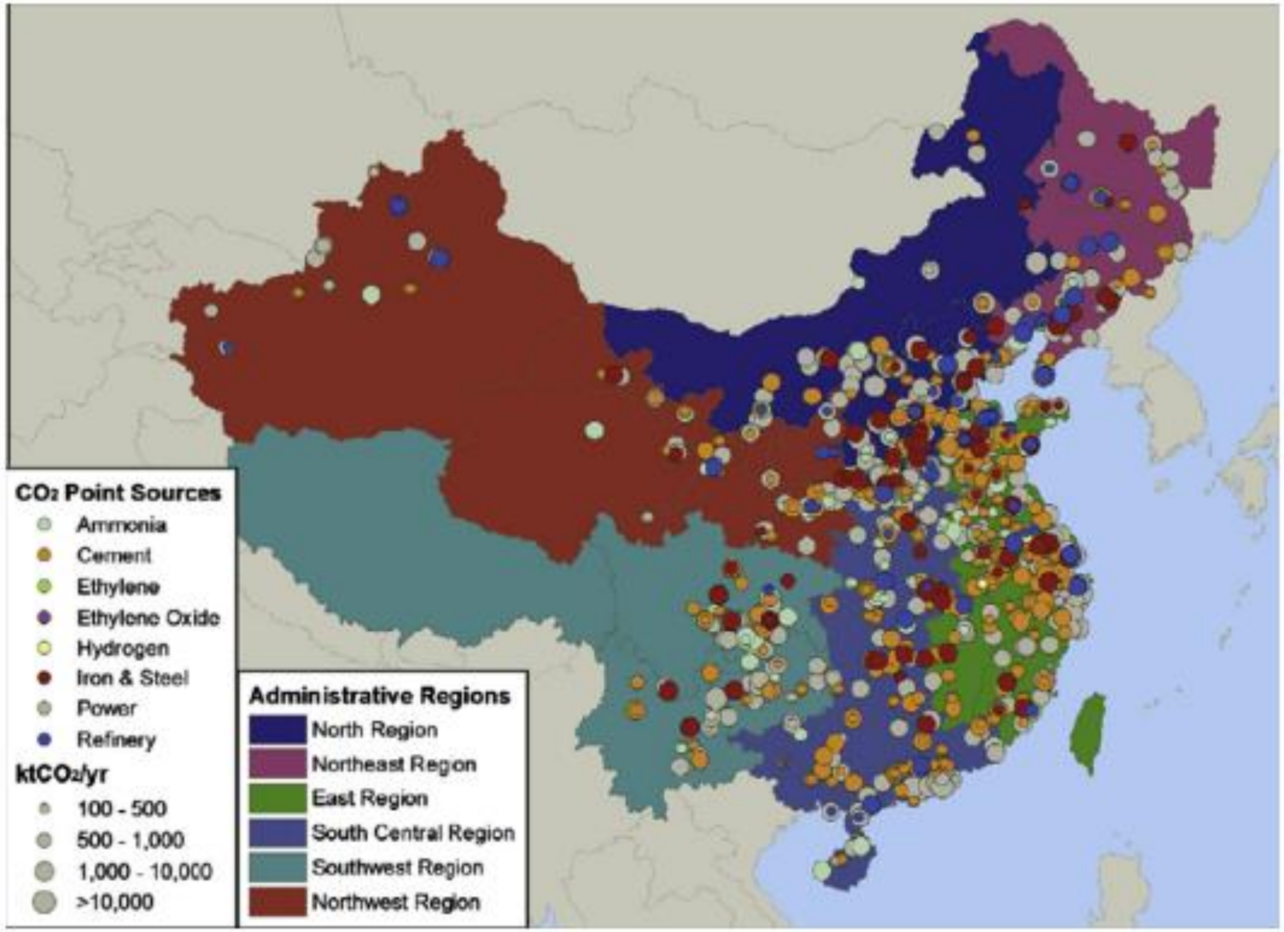


Fig. 1. Map of large CO_2 point sources by type, size, and administrative region in China [12].

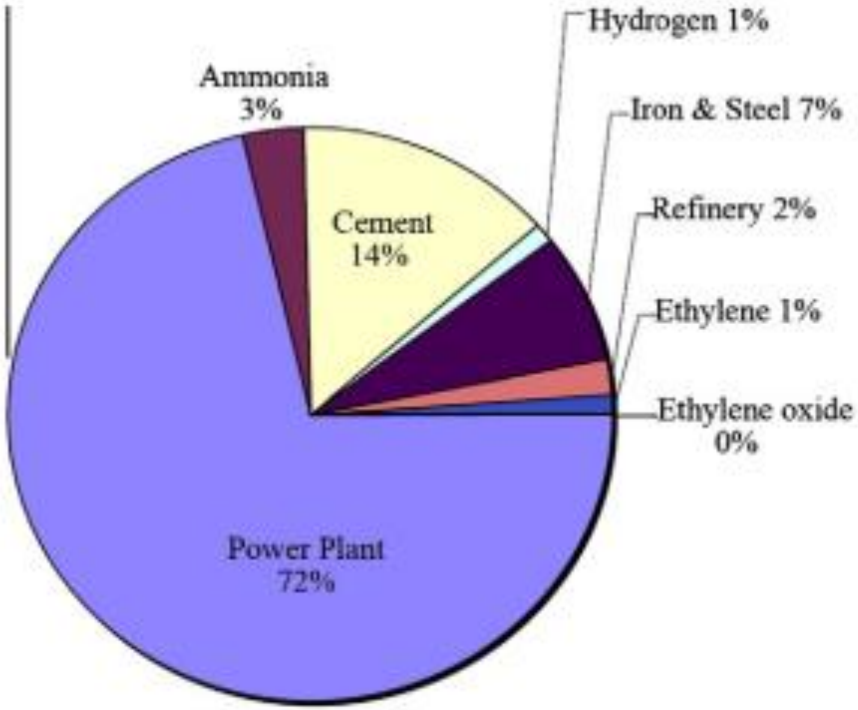
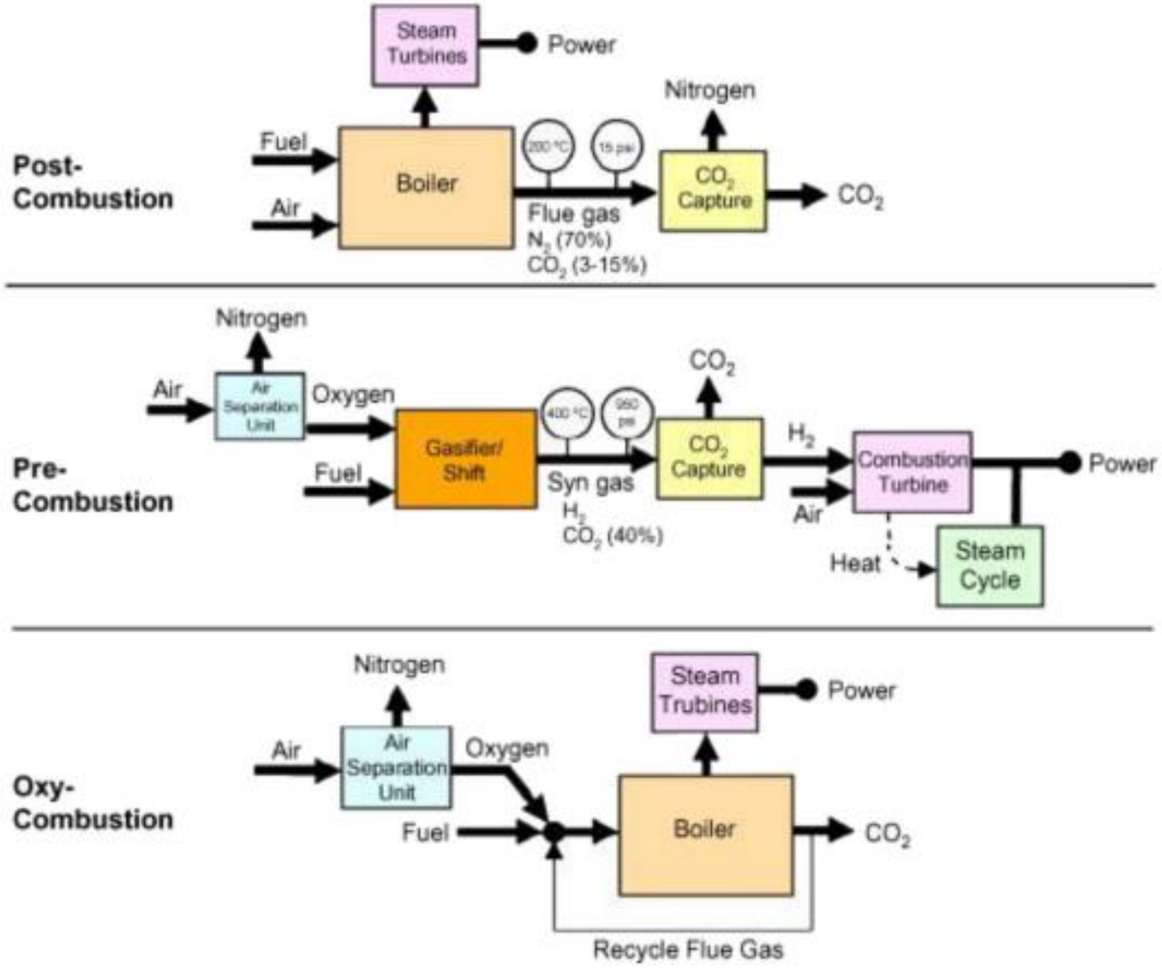


Fig. 2. The contributions of large point sources in each sector to overall total CO_2 emissions in China [12].

Post-combustion CO_2 capture is more suitable for the traditional pulverized coal power plants. Li et al. 2013

Various Technologies – CCUS

- The technologies used for CCS are categorized based on when the carbon is eliminated as:
  - Pre-combustion systems (***commercially proven concept***) – approx. 5%
  - Post-combustion systems (***commercially proven concept***) – approx. 90%
  - Oxy-combustion systems (an option to post-combustion approach; ***recent development***) – approx. 5%
  - Industrial Separation
  - Chemical Looping Combustion (CLC) – pre-combustion carbon capture. CLC uses metal oxides as O_2 carriers to avoid dilution with N2 and emission of Nox. (Alalwan and Alminshid. 2021)
  - *CO_2 concentration in gas stream and fuel type are important factors in capture system selection*



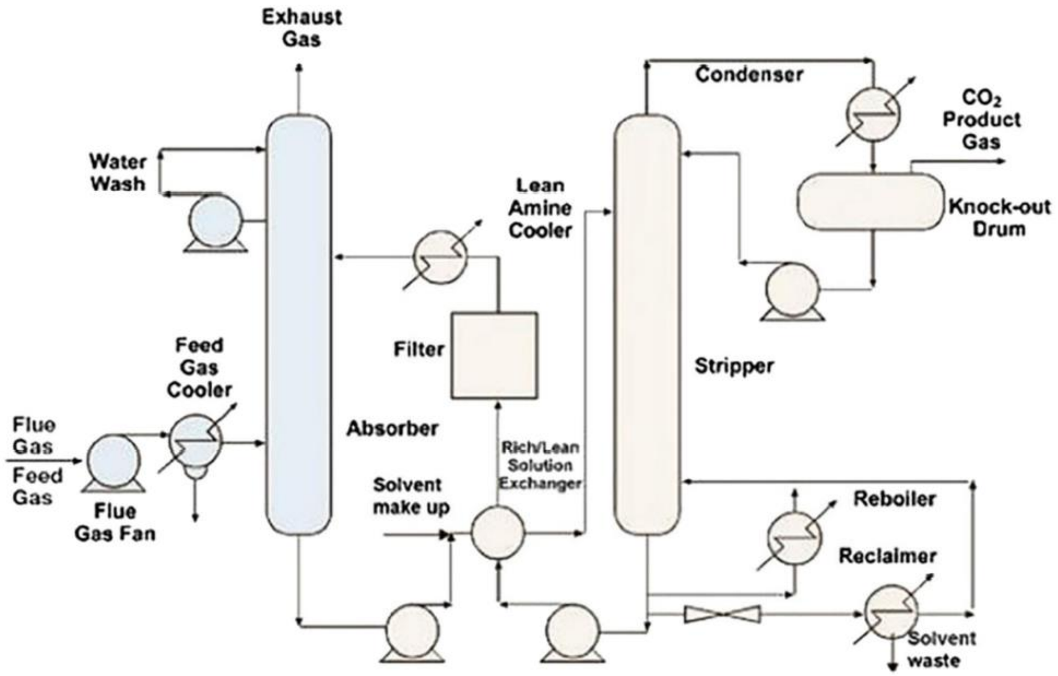
Source: Figueroa et al. 2008

Various Technologies – CCUS (contd..)

According to several authors, the only commercial technique in CO_2 capture and desorption is based on amine absorbents (Gomes, et al 2015; Greer et al 2010)

Mono-ethanolamine (MEA) scrubbing is recognized as a well-established technology with 80–90 mol% CO_2 recoveries in power plants applications using 20–30 wt.% MEA aqueous solutions (Weiland et al., 1982; Escobillana et al., 1991)

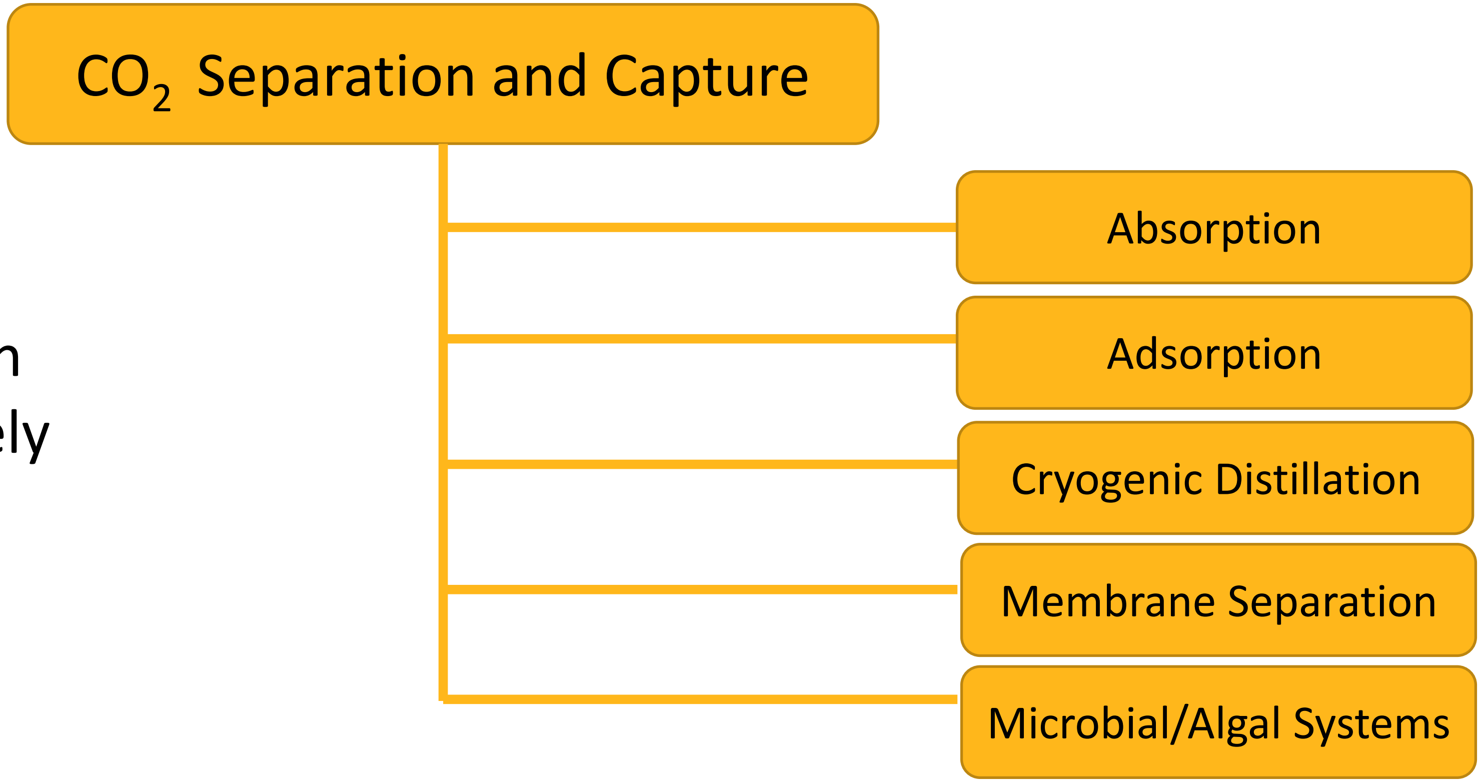
Absorption-regeneration technology has been recognized as the **most matured process**, with amine-based or ammonia-based absorption processes receiving the greatest attention (Bai and Yeh, 1997; 1999; Rao and Rubin, 2002)



Carbon dioxide capturing method using an amine type post combustion

Various Technologies – CCUS (contd..)

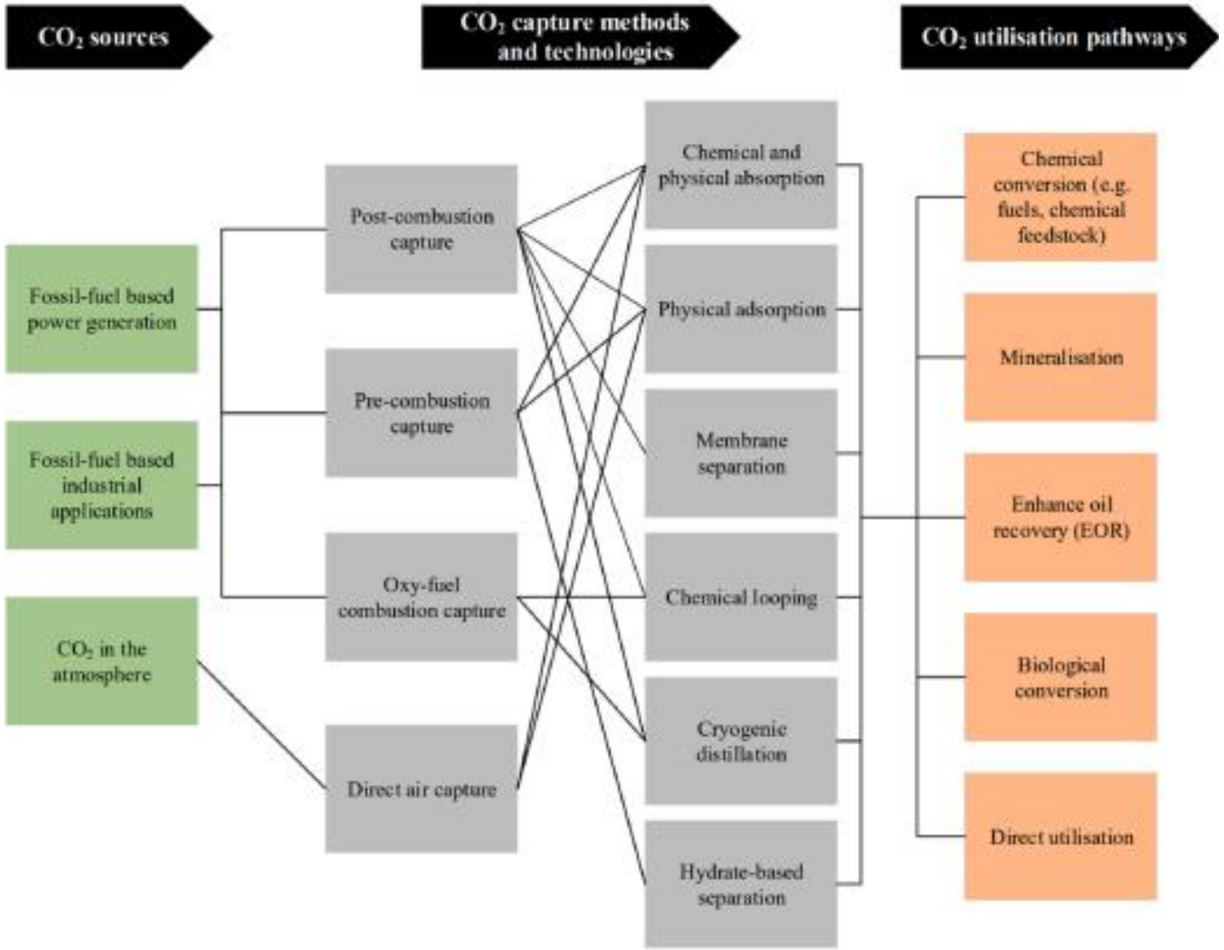
- Carbon capture technologies can also be categorized based on how the carbon is eliminated.
- Membrane Separation, Absorption and Adsorption are the most widely adopted techniques of carbon capture (Li et al. 2013).
- Absorption and Adsorption are much more cost effective than membrane separation.

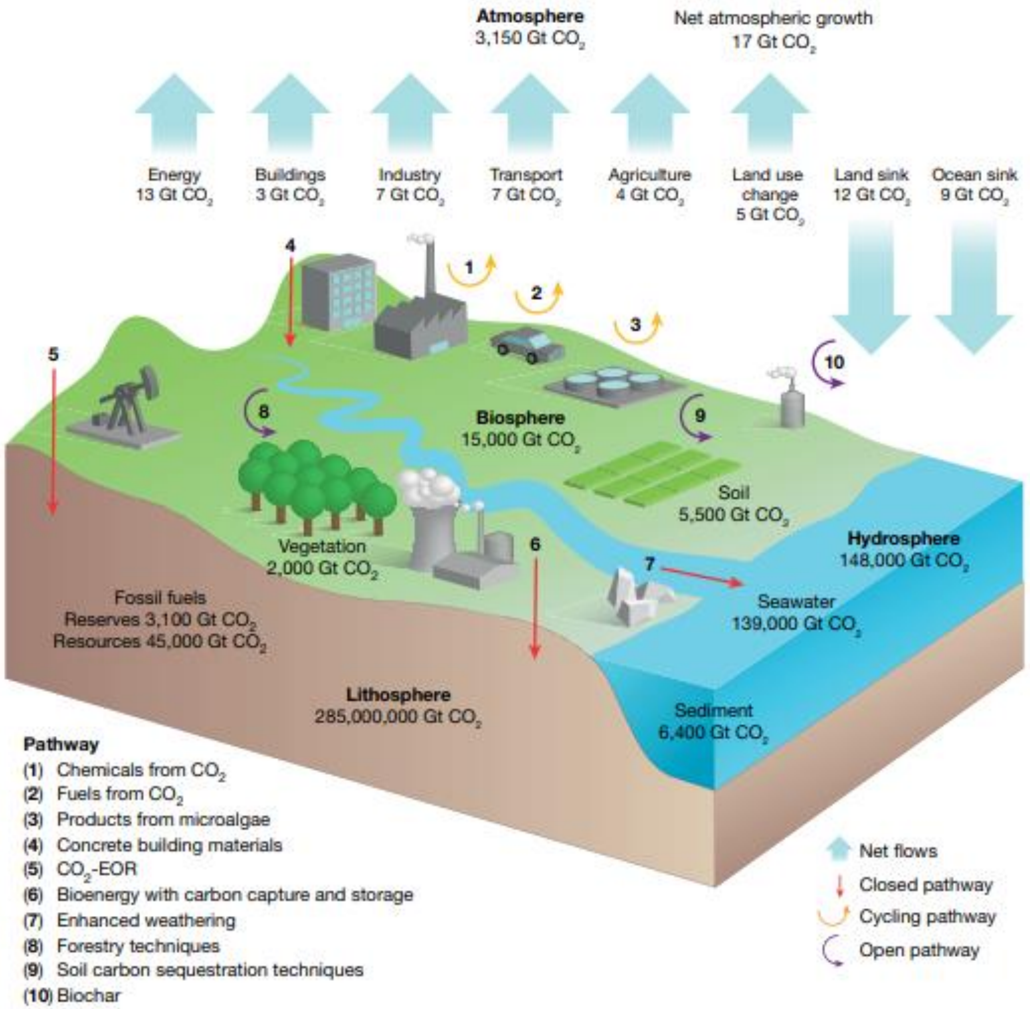


Sreenivasulu et al 2015. "The post-combustion capture of CO_2 from industrial flue gases through gas–liquid absorption need high level R&D with focus on evolving cost effective desorption option. At present, it is the only industrial carbon emission management technology that has very high potential for wide scale deployment"

Various Technologies – CCUS (contd..)

- CO_2 Utilization Pathway





Hepburn et al. 2019

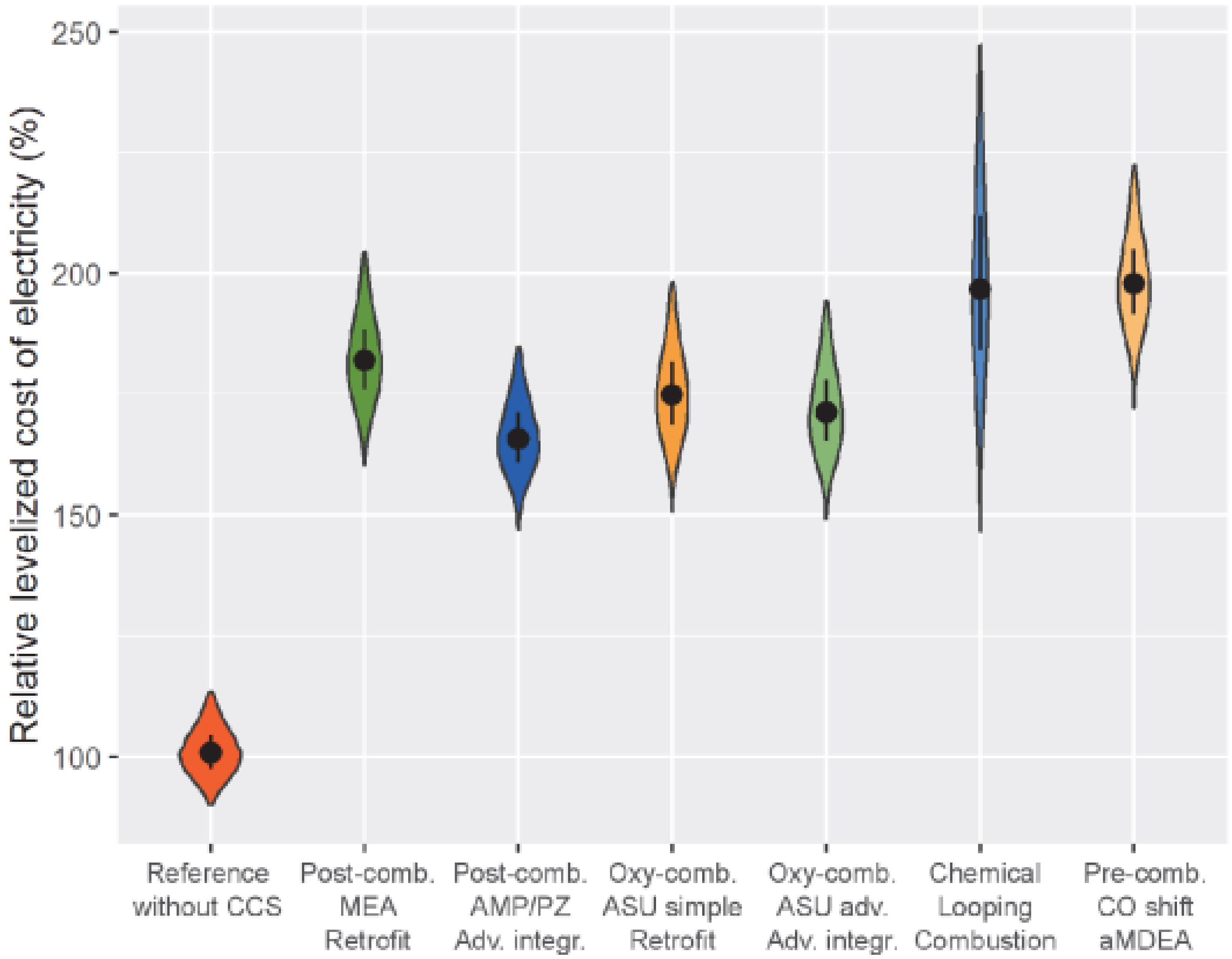
Application of the Various CCUS Technologies

- A combination of enhanced oil recovery with a storage system will reduce the overall cost.
- For commercial and industrial power plants, post-combustion CO_2 capture is considered the matured type of technology compared to the others.
- Using solvent for the CO_2 capture is very important in post-combustion capture of CO_2.
- Researchers are also exploring the various type of solvent, design and an integrated solvent design for the capture of CO_2.

Application of the Various CCUS Technologies

- Chemical absorption is suitable for low CO_2 feed i.e., < 20% because higher solvent recirculation rate and heavy duty.
- Membrane permeation is best suited for medium to higher CO_2 partial pressure compared to chemical absorption.
- 2010 – Brazil pre-salt oil and gas field used membrane separation for CO_2 capture.
- Other high CO_2 content project could be found in pre-salt field in Brazil's offshore preoil field (Libra 48%; Jupiter 78%) and La Barge gas field in Wyoming. These projects use cryogenic distillation

Application of the Various CCUS Technologies

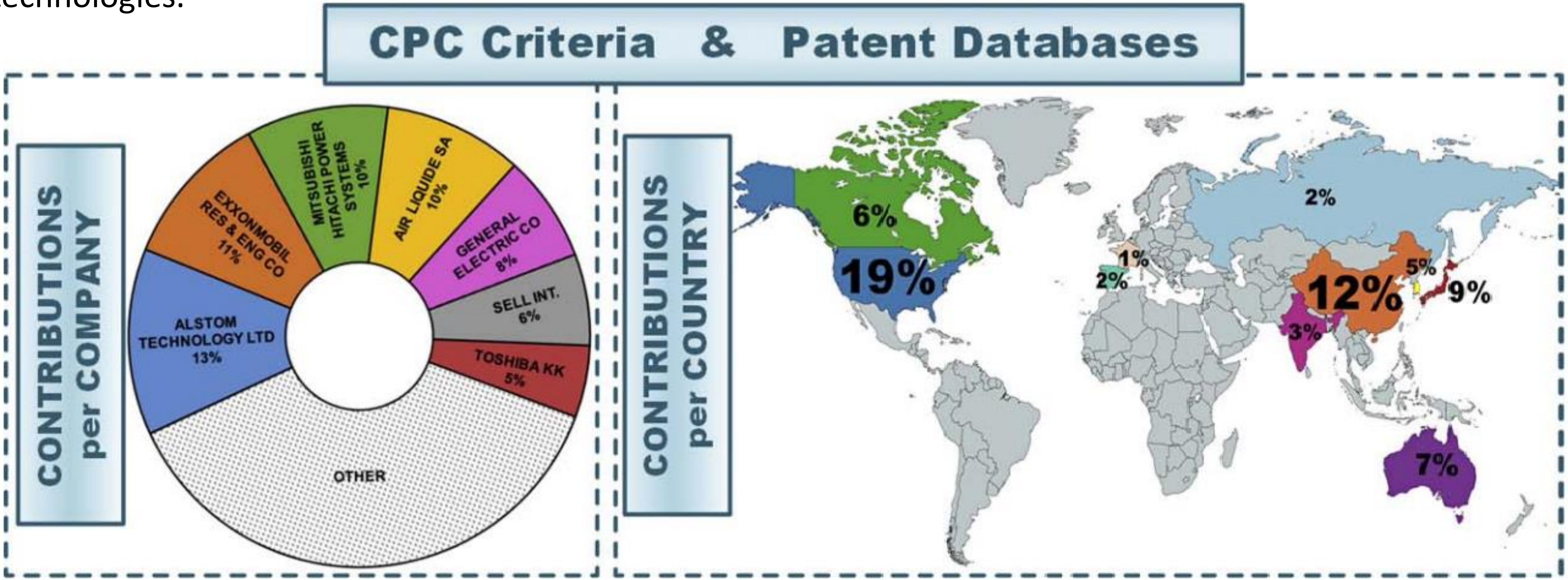


Application of the Various CCUS Technologies

Pathway	Post-comb.	Post-comb.	Post-comb.	Post-comb.	Oxy-comb.	Oxy-comb.	Pre-comb.
Technology	**Amine absorption**	**Ammonia absorption**	**Activated carbon adsorption**	**Inertial extraction**	**Cryogenic**	**Chemical Looping Combustion**	**Chemical absorption**
Maturity (TRL)	6-7	6-7	3-4	3-4	6-7	4-5	7
Net efficiency loss	7-8 %-pths	7-8 %-pths	6-7 %-pths	3-4 %-pths	7-8 %-pths	4-5 %-pths	6-7 %-pths
Energy performance	😐	😐	😐	🙂	😐	🙂	😐
Economic performance	😐	😐	?	?	😐	😐	🙁
Operability	😐	🙁	😐	🙂	😐	🙁	🙁
Flexibility	🙂	😐	😐	😐	😐	🙁	🙁
Risk	😐	🙁	🙂	🙂	🙂	😐	😐
Market	Retrofit New built	Retrofit New built	Retrofit New built	Retrofit New built	(Retrofit) New built	New built	New built
Interest	Maturity	Stable and cheap solvent	No emission	No emission Performance Easy to build	Maturity No chemicals	Performance	Maturity Polygeneration possible
Technological gap	Pollutant emission Solvent degradation	Seasonal variation Precipitation	Complex regeneration Solid ageing	CO_2 quality	Start-up duration	Complexity O_2 carrier solid	Operability Flexibility

CO_2 Capture Technology – Patent Activity

Most of the patents are in capture technologies that use absorption and adsorption chemical processes. Companies such as Mitsubishi Hitachi Power Systems Europe GmbH, Alstom Technology Ltd., ExxonMobil Research and Engineering Company and Air Liquide SA dominate the development of these main capture technologies.



CO_2 Capture Technology – Patent Activity

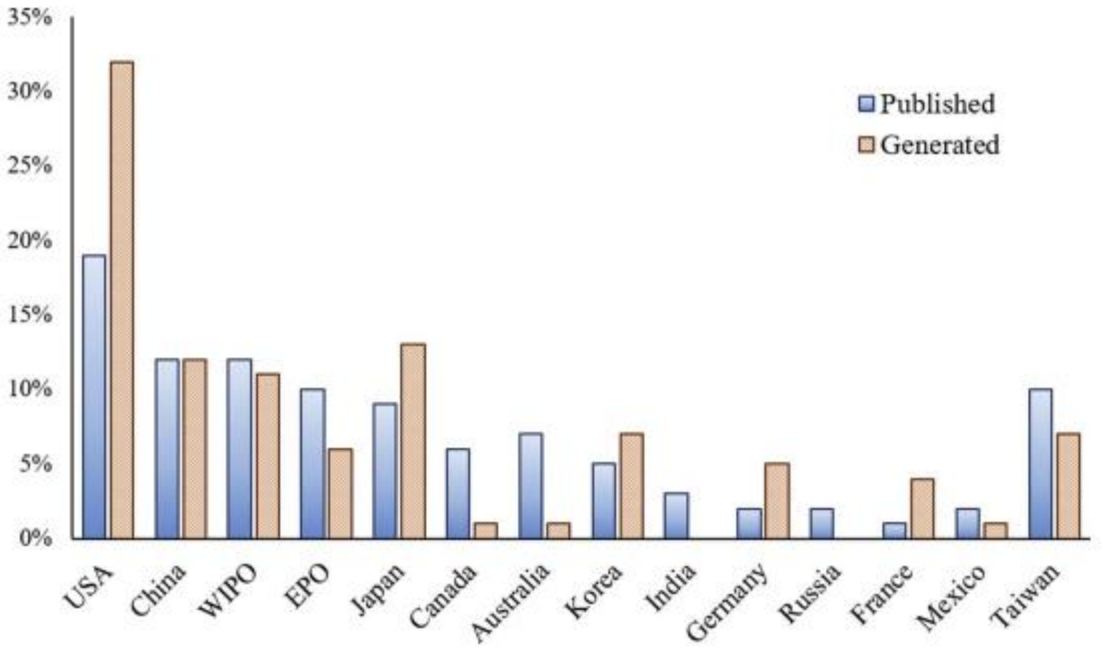
Routes to CO_2 capture in power generation (by fuel)and industrial applications (by sector) [10].

		Syngas-hydrogen capture	*Post-process capture*	*Oxy-fuel combustion*	*Inherent separation*
First-phase industrial applications	Gas processing	-	-	-	Sweetening
	Iron and steel	Direct reduced iron (DRI)*, smelting (*e.g.* Corex)		Oxy-fuel combustion	DRI*
	Refining	-	-	-	Coal-to-liquids; synthetic natural gas from coal Hydrogen production
	Chemicals	-	-	-	Ammonia/methanol
	Biofuels	-	-	-	Ethanol fermentation
Power generation	Gas	Gas reforming and combined cycle	Natural gas combined cycle	Oxy-fuel combustion	Chemical looping combustion
	Coal	Integrated gasification combined cycle (IGCC)	Pulverised coal-fired boiler	Oxy-fuel combustion	Chemical looping combustion
	Biomass	IGCC	Biomass-fired boiler	Oxy-fuel combustion	Chemical looping combustion
Second-phase industrial applications	Iron and steel	Hydrogen reduction	Blast furnace capture	Oxy-fuel blast furnace	-
	Refining	Hydrogen fuel steam generation	Process heater and combined heat and power (CHP) capture	Process heater and CHP oxy-fuel	-
	Chemicals	-	Process heater, CHP, steam cracker capture	Process heater and CHP oxy-fuel	-
	Biofuels	Biomass-to-liquids	-	-	Advanced biofuels
	Cement	-	Rotary kiln	Oxy-fuel kiln	Calcium looping
	Pulp and paper	Black liquor gasification	Process heater and CHP capture	Process heater and CHP oxy-fuel	-

Legend: technical maturity of operational CO_2 capture plants to date

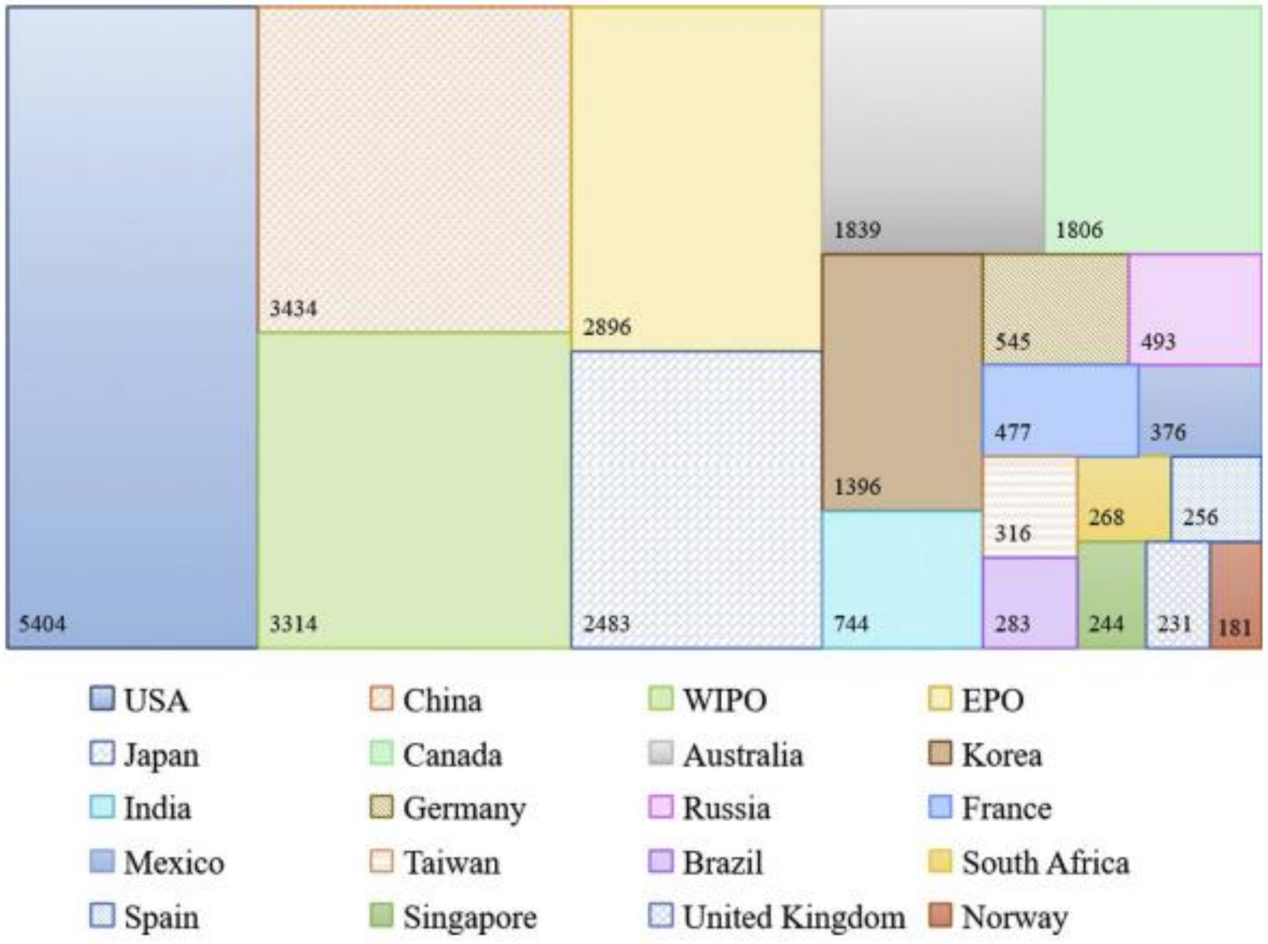
Commercial · Demonstration · Pilot · Lab or concept

Invention field	Patent families	Patent documents
Capture by biological separation	207	687
Capture by chemical separation	2850	11,463
Absorption	2643	10,550
Adsorption	2164	7743
Membranes	787	2749
Rectification-condensation	460	2242



CO_2 Capture Technology – Patent Activity

- Distribution of the total amount of patents per country



CO_2 Capture Technology – Patent Activity

Classification of companies per CPC technology.

Capture technology (CPC code)	Applicant	
	Generation	Publication
Biological separation (Y02C 10/02)	CO_2 Solutions Inc. (10%) Sfn Biosystems Inc. (3%) Alstom Technology Ltd. (3%) Rogmans Maria (3%) Cybel Holding Sa (2%)	Alstom Technology Ltd. (9%) CO_2 Solutions Inc. (8%) Novozymes A/S (5%) Akermin Inc. (4%) Morphic Technologies Ab (3%)
Chemical separation (Y02C 10/04)	Mitsubishi Hitachi Power Systems Europe GmbH (8%) Alstom Technology Ltd. (6%) General Electric Co. (2%) Kansai Electric Power Co. Inc. (2%) ExxonMobil Research and Engineering Company (2%) Korea Inst Energy Res (2%)	Mitsubishi Hitachi Power Systems Europe GmbH (10%) Alstom Technology Ltd. (9%) General Electric Co. (4%) ExxonMobil Research and Engineering Company (3%) Kansai Electric Power Co. Inc. (3%)
Absortion (Y02C 10/06)	Mitsubishi Hitachi Power Systems Europe GmbH (10%) Alstom Technology Ltd. (6%) Toshiba KK (4%) Kansai Electric Power Co. Inc. (3%) Siemens AG (3%)	Mitsubishi Hitachi Power Systems Europe GmbH (12%) Alstom Technology Ltd. (9%) Toshiba KK (5%) Kansai Electric Power Co. Inc. (4%) General Electric Co. (4%)
Adsorption (Y02C 10/08)	Air Liquide SA (4%) ExxonMobil Research and Engineering Company (4%) Mitsubishi Hitachi Power Systems Europe GmbH (3%) Air Products and Chemicals Inc. (3%) Nippon Steel and Sumitomo Metal Co. (2%)	ExxonMobil Research and Engineering Company (7%) Air Liquide Sa (5%) Air Products and Chemicals Inc. (4%) Mitsubishi Hitachi Power Systems Europe GmbH (4%) Praxair Technology Inc. (3%)
Membrane (Y02C 10/10)	UOP LLC (7%) FujiFilm Corporation (5%) General Electric Co. (4%) Membrane Technology and Research Inc. (4%) Air Liquide SA (3%) Tianjin University (3%)	UOP LLC (7%) General Electric Co. (5%) Kilimanjaro Energy Inc. (5%) FujiFilm Co. (4%) Shell Internationale BV (4%)
Rectification & condensation (Y02C 10/12)	Air Liquide SA (23%) ExxonMobil Research and Engineering Company (8%) Shell Internationale Research Maatschappij BV (6%) Alstom Technology Ltd. (5%) BP Alternative Energy International Ltd. (4%)	Air Liquide SA (25%) ExxonMobil Research and Engineering Company (9%) Alstom Technology Ltd. (9%) Shell Internationale Research Maatschappij BV (6%)

Issues due to CO_2 Leakage

- The leakage of CO_2 as a result of transportation can destroy groundwater, plant life and soil quality.
- Exposure to high amount of CO_2 can ultimately lead to death.

Ansys Solution Overview

Post-Combustion Carbon Capture – Absorption

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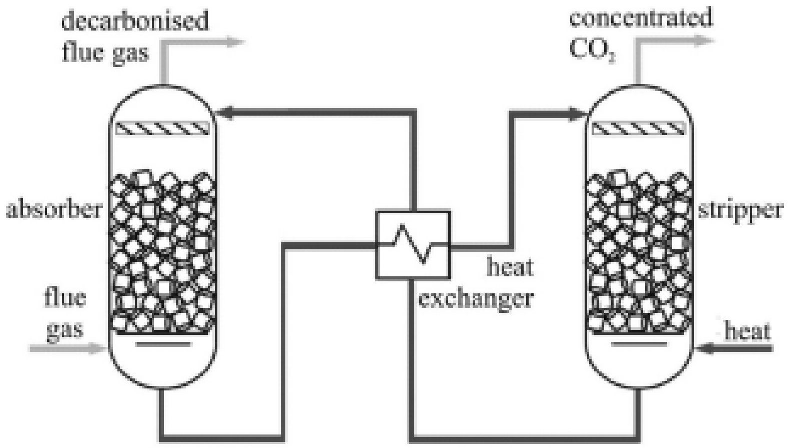
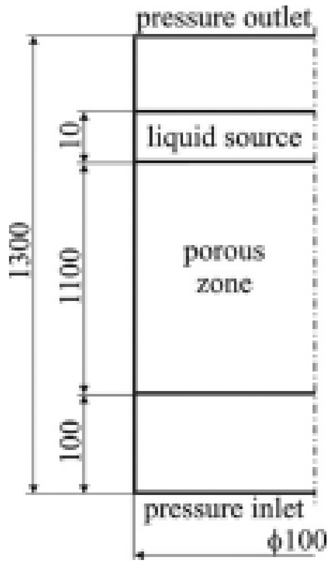
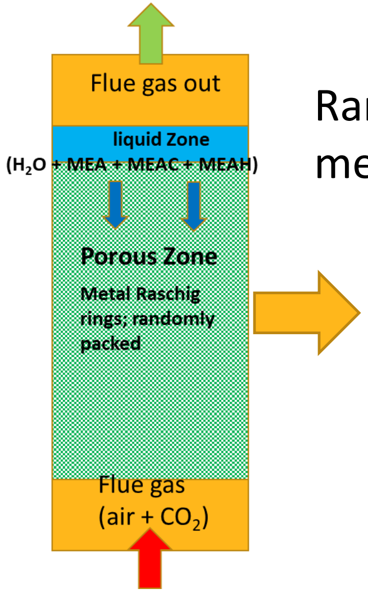
Post-Combustion Carbon Capture – Chemical Absorption

- Absorption using Amine Solvent
- The process flow diagram for CO_2 absorption and the geometry considered for investigation are shown below:







Randomly packed metal Raschig rings

- Objective: To determine the concentration of CO2 at the flue gas outlet and compare it with experimental data

Source: *P. Niegodajew, D. Asendrych. Amine based CO2 capture – CFD simulation of absorber performance, Applied Mathematical Modelling, 40 (2016), 10222-10237*

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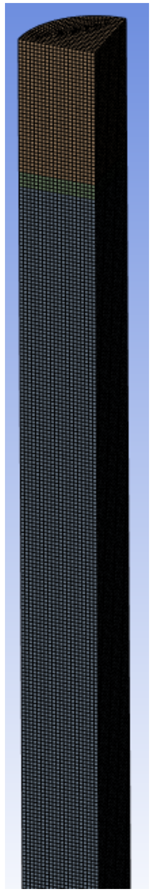
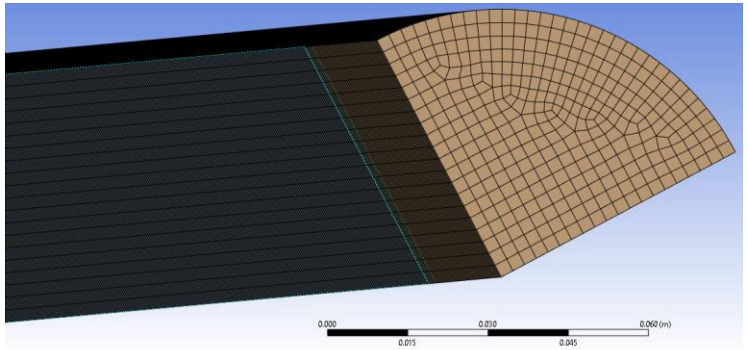
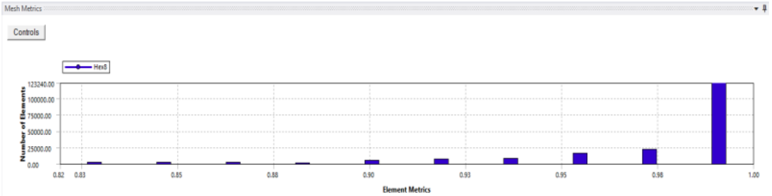
Post-Combustion Carbon Capture – Chemical Absorption

3 Dimensional – 1/4th of the geometry (even a pi slice would work!)





Statistics	
Nodes	206837
Elements	187200



A mesh sensitivity analysis has been carried out to determine the optimal number of elements

Operating conditions for the flue gas and amine solvent

	Flue gas	Amine solvent
Volumetric flux [m^3/h]	8	0.054
Mass fraction [%]	Air – 88 CO_2 - 12	H2O – 64.42 MEA+MEAH+MEAC – 35.58
Temperature [K]	298.5	313

The mass fractions of amine species in liquid bulk equal to:

Y_{MEA} = 5.52% (mass fraction of Mono-Ethanol Amine (MEA))
Y_{MEAH} = 11.23% (mass fraction of protonated MEA)
Y_{MEAC} = 18.83% (mass fraction of carbamated MEA)

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Post-Combustion Carbon Capture – Chemical Absorption

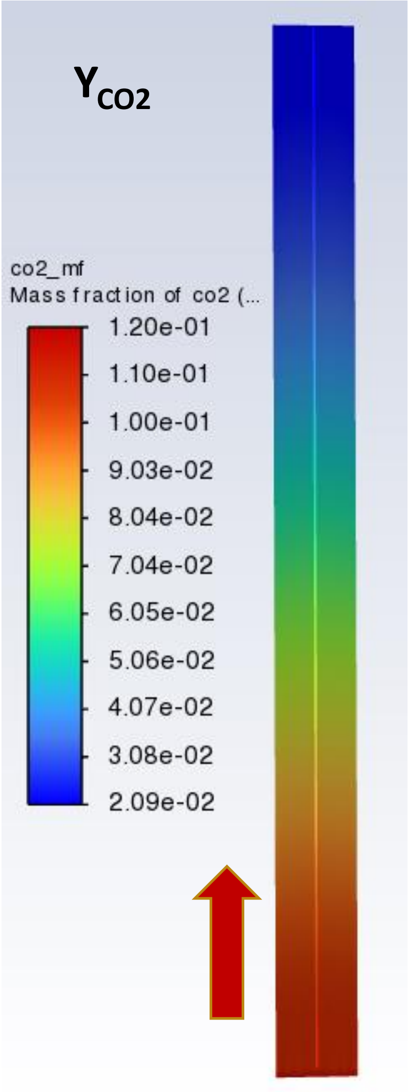
- Governing Equations:
  - Euler-Euler formulation
  - Chemistry of CO2 absorption by aqueous monoethanolamine solution is regarded as a non-reversible equation of the form

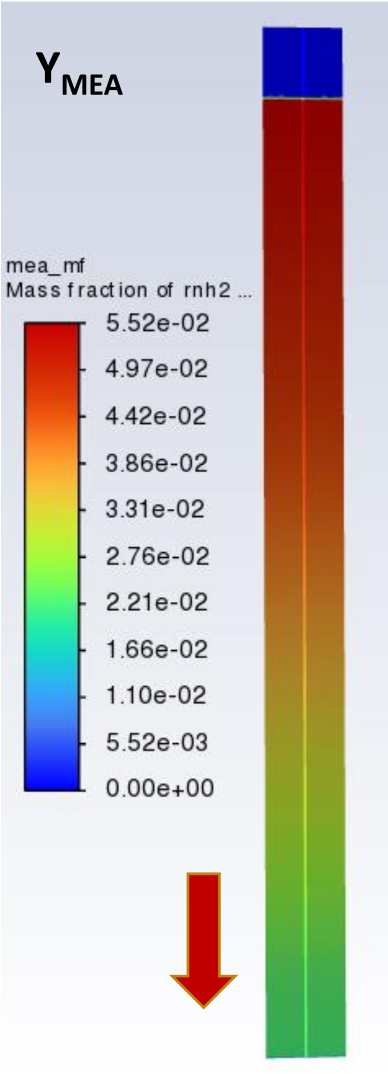
$$CO_2 + 2RNH_2 \rightarrow RNHCOO^- + RNH_3^+$$

  - First term on the right hand is carbamated MEA and the second one is protonated MEA
  - The reaction rate constant as a function of temperature may be approximated by the following expression

$$\log(k) = 10.99 - 2152/T$$

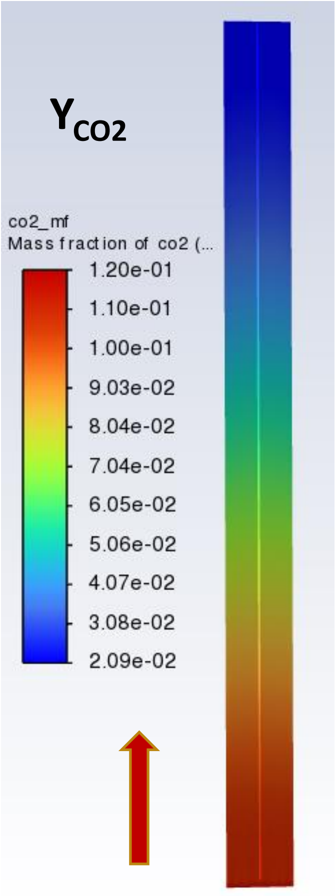
  - The collision frequency and the activation energy are obtained from this eqn.

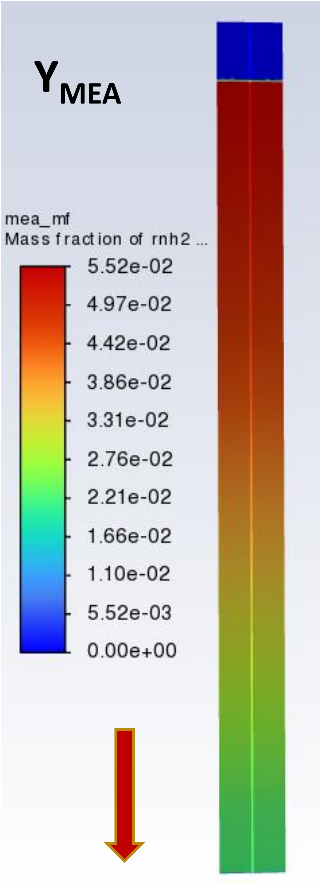


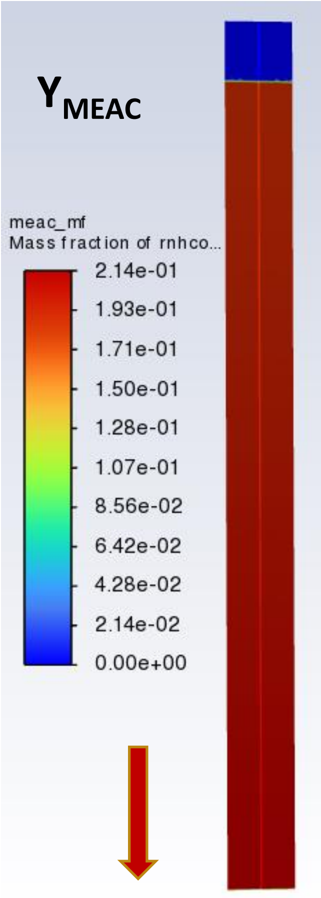


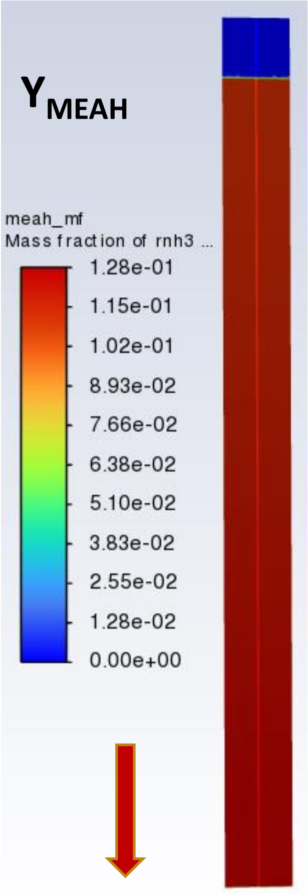
Post-Combustion Carbon Capture – Chemical Absorption

- Contours of species mass fraction after the chemical absorption process is complete









Comparison of Simulation Results with Experimental Data

	Simulation Results	Experimental Data
CO_2 mass fraction [%]	1.6	1.2
Temperature of the solvent [K]	313.2	313.2
Temperature of the gas [K]	313	311

Post-combustion carbon capture – Adsorption

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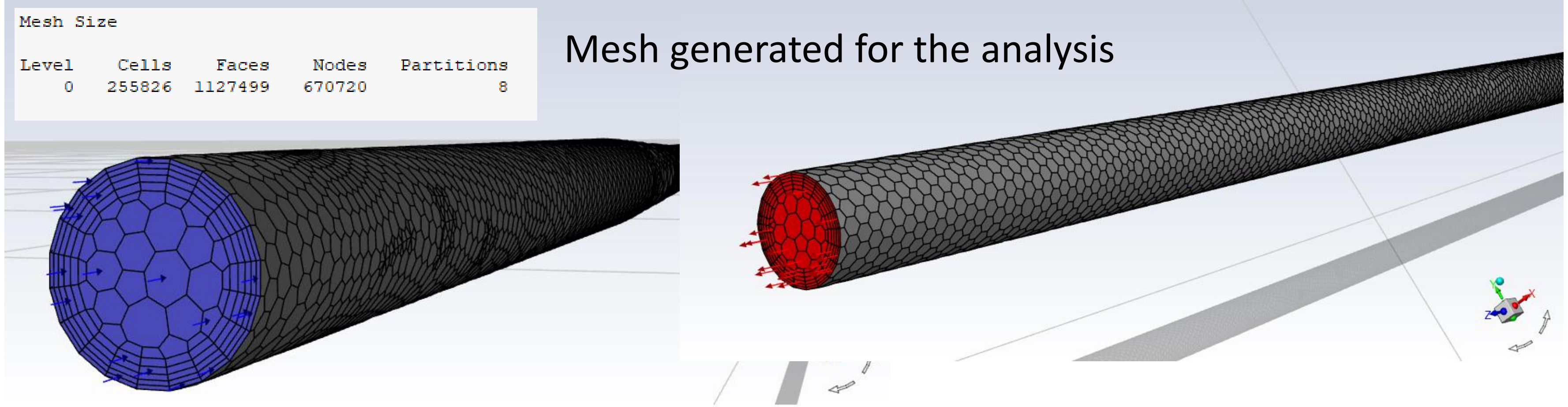
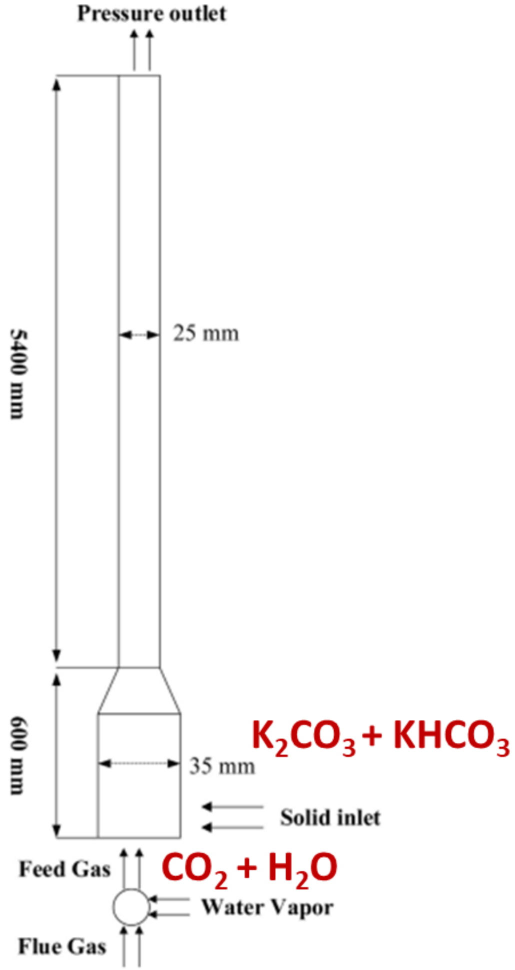
Post-combustion carbon capture – adsorption using K_2CO_3

Numerical modeling of CO_2 removal from flue gases by K_2CO_3 in an absorber column*.

- Problem Set-up
  - 3 Dimensional
  - Multi-phase gas-liquid counter streams – 2 fluid Eulerian model
  - Chemical reaction
  - Heat transfer



Mesh generated for the analysis



Source: M. Nouri, G. Rahpaima, M. M. Nejad, M. Imani. Computational simulation of CO2 capture in a fluidized-bed reactor. Computers and Chemical Engineering, 108 (2018), 1-10.

Post-combustion carbon capture – adsorption using K_2CO_3

- Operating conditions for the feed gas (CO_2 + H_2O) and potassium carbonate (K_2CO_3)

	Feed gas	K_2CO_3 + $KHCO_3$
Velocity at the Inlet [m/s]	1.7, 2, 2.5 and 3	-
Mass flux [kg/m^2s]	-	21
Mass fraction [%]	CO_2 – 9.6 H_2O – 19.6 N_2 – 70.8	K_2CO_3 – 100 $KHCO_3$ - 0

- Particle diameter = 98 microns (mention parcel diameter)
- Particle density = 1100 kg/m^3
- Euler-Granular; 2-Phases; Secondary Phase
  - Sorbent – K_2CO_3 + $KHCO_3$

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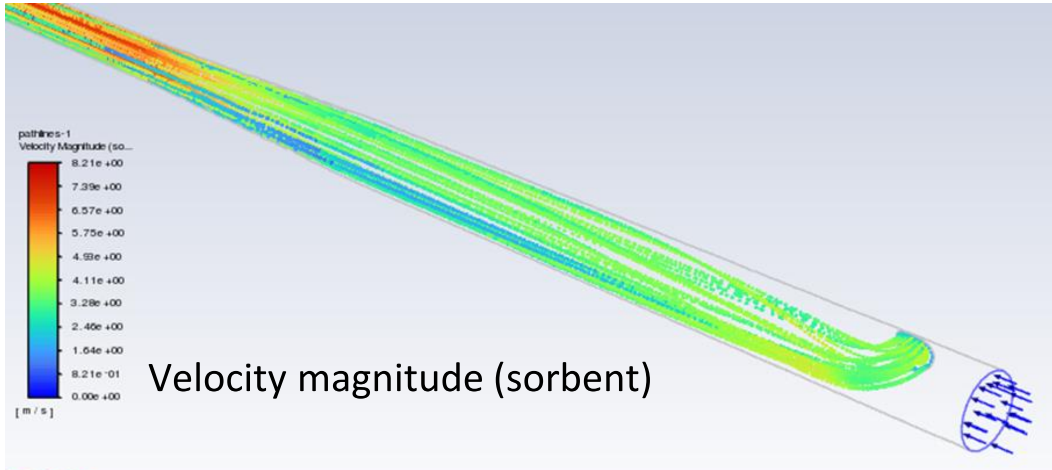
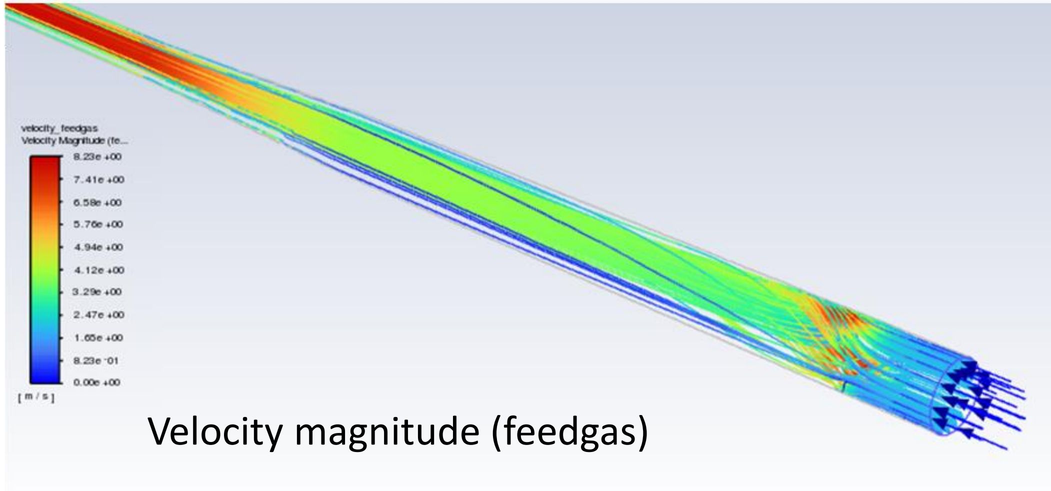
Post-combustion carbon capture – adsorption using K_2CO_3



Velocity magnitude (sorbent)



Velocity magnitude (feedgas)

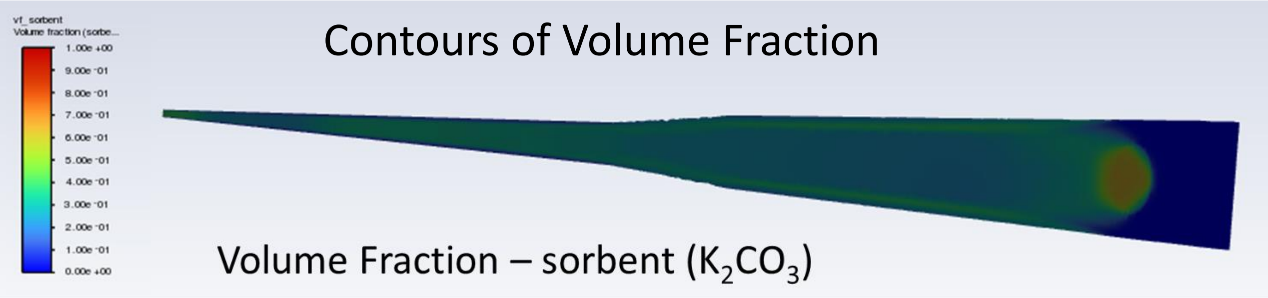
Heterogenous Reaction:

Chemistry of CO2 adsorption by the solid sorbent Potassium Carbonate in the carbonation reaction is described as follows:

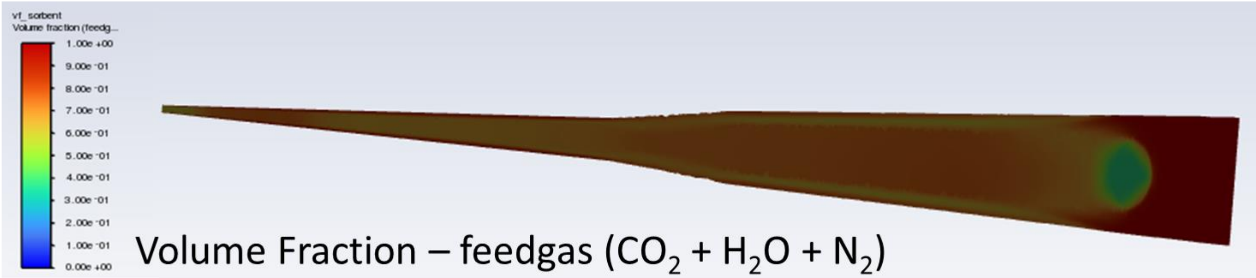
$$K_2CO_3 + H_2O + CO_2 \rightarrow 2KHCO_3$$

$$k = 55.0 \exp(3609/RT_g)$$

Contours of Volume Fraction

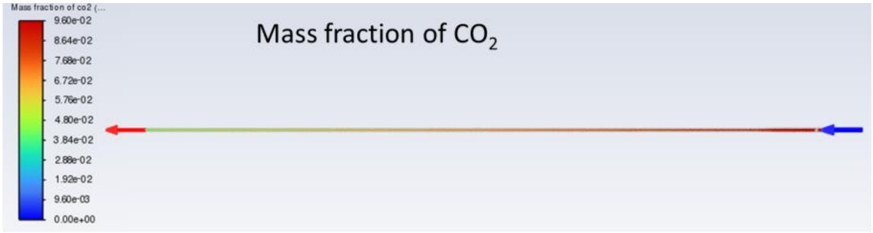


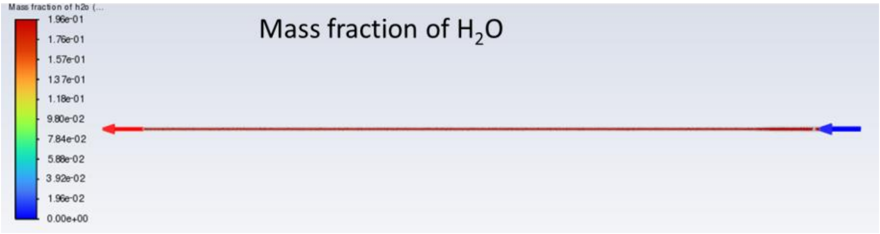
Volume Fraction – sorbent (K_2CO_3)

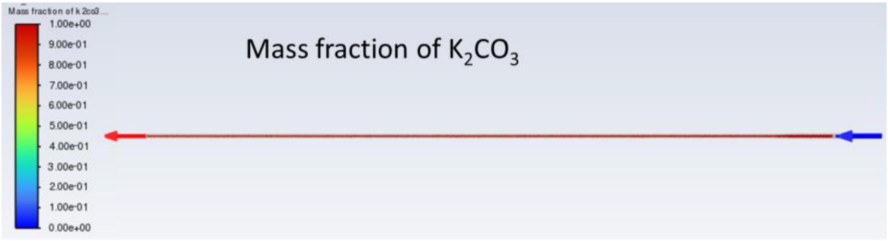


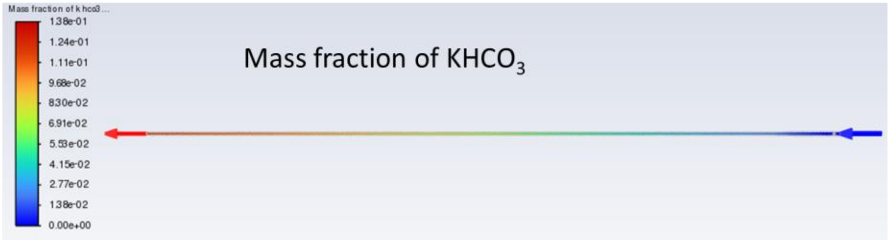
Volume Fraction – feedgas ($CO_2 + H_2O + N_2$)

Post-combustion carbon capture – adsorption using K_2CO_3

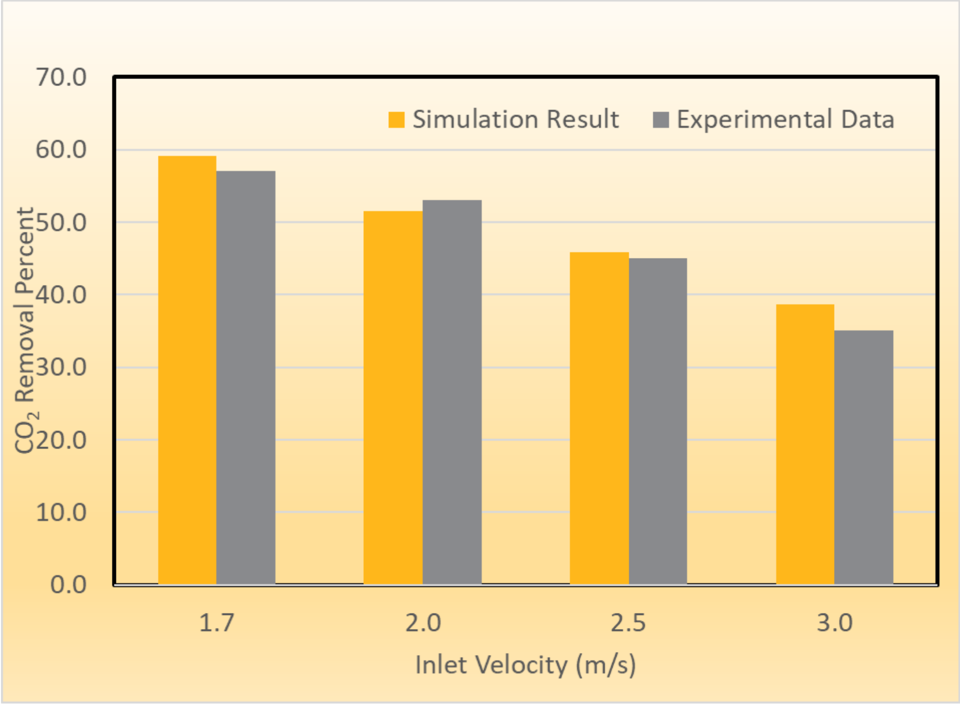








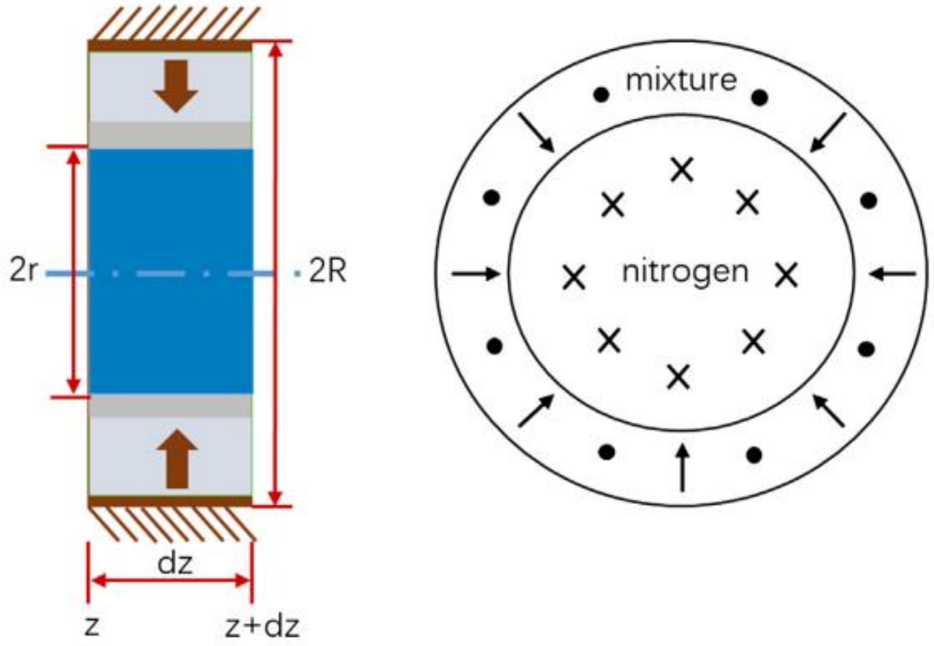
Inlet Velocity [m/s]	Simulation Results	Experimental Data	% Variation
1.7	59.2	57.0	3.8
2.0	51.5	53.0	-2.9
2.5	45.8	45.0	1.9
3.0	38.6	35.0	10.4

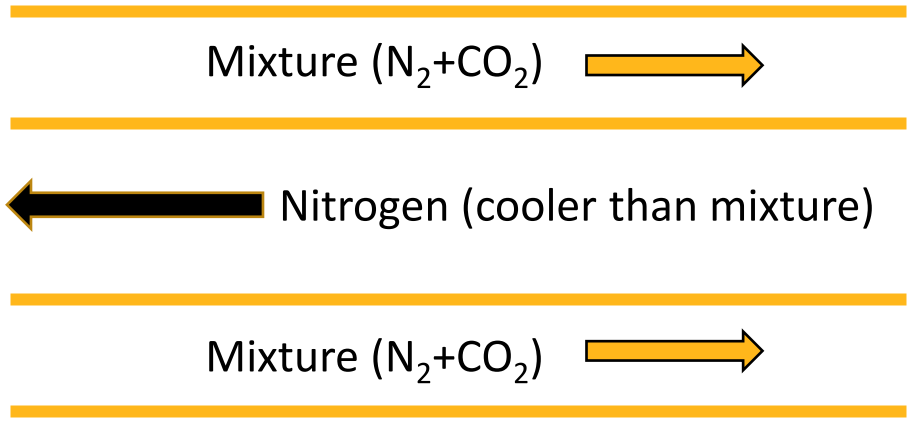


Cryogenic Distillation

Analysis – Test Case

- The inner diameter and wall thickness of the stainless-steel tube through which nitrogen coolant flows is 30 mm and 1.5 mm respectively.
- The inner diameter and wall thickness of the outer glass tube is 50 mm and 3 mm respectively.



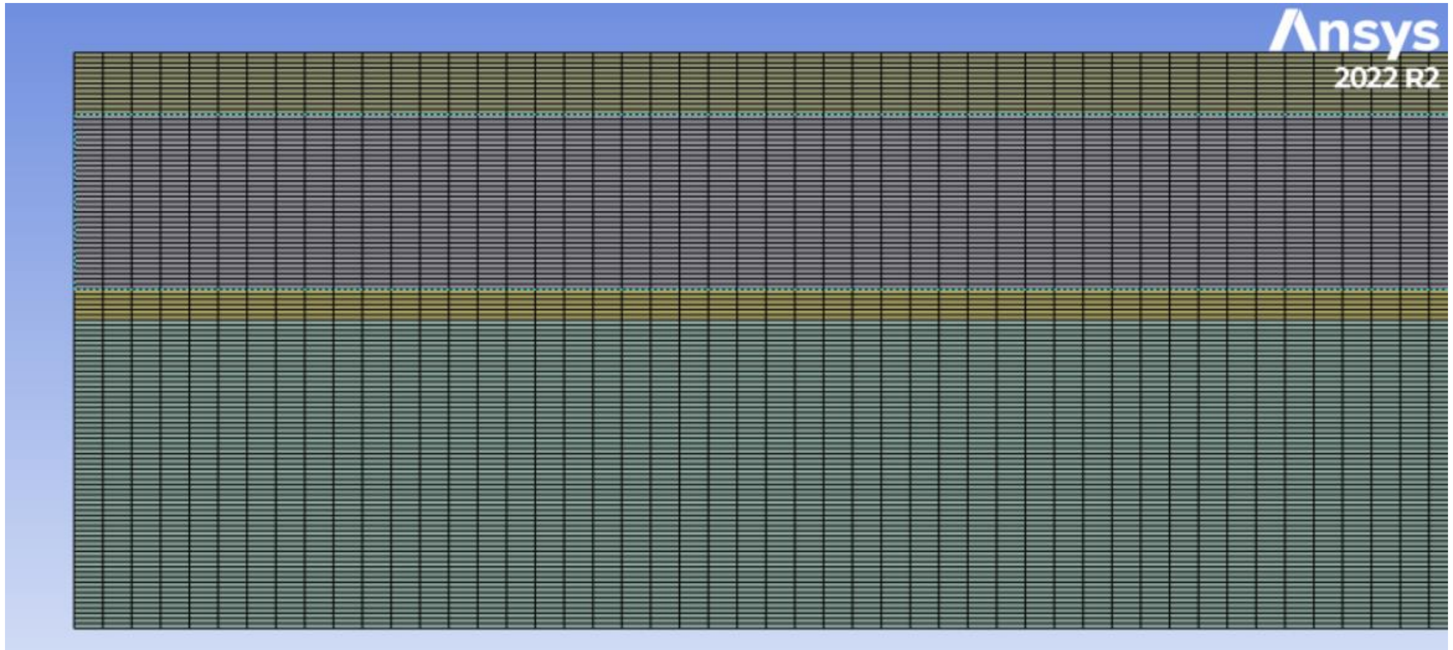


Mesh Generated

- Geometry considered for the analysis is axisymmetric
- Number of elements used for the current study is 56000

Details of "Mesh"

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	Default (3.5028e-002 m)
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Quality	
Inflation	
Batch Connections	
Advanced	
Statistics	
Nodes	56613
Elements	56000



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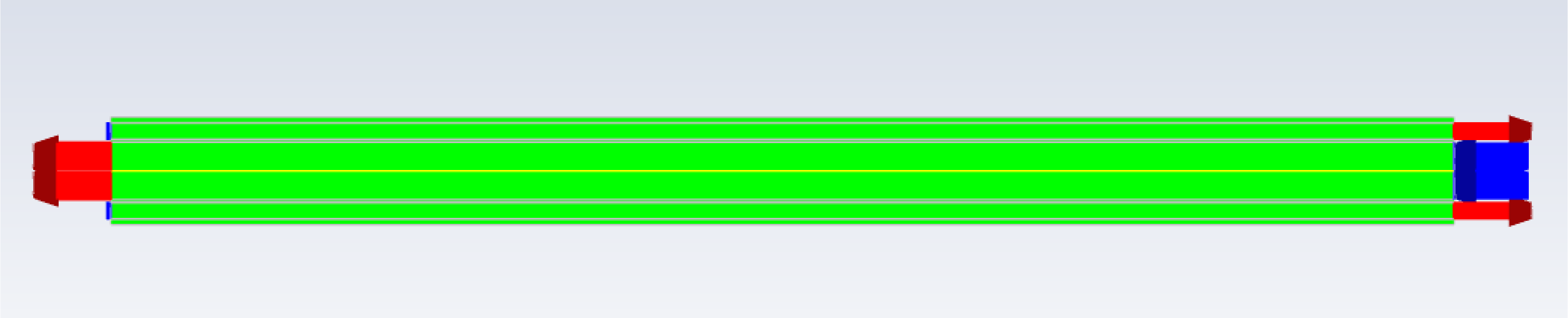
Boundary Conditions

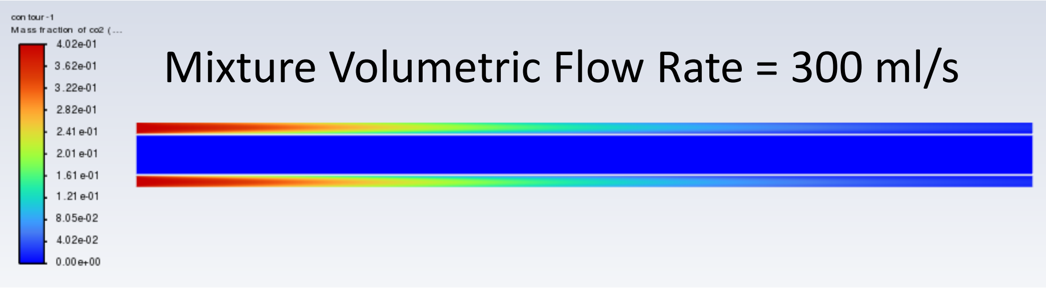
- Inlet volumetric flow rate = 300ml/s
- Inlet temperature of the mixture = 179K
- Mole fraction of CO_2 in the mixture = 0.2

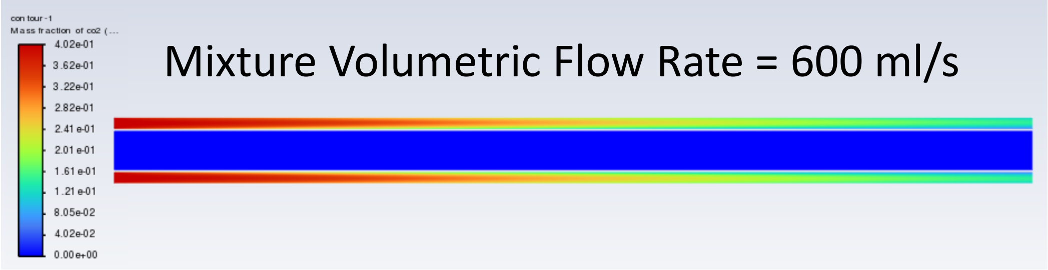
- Inlet volumetric flow rate of coolant/Nitrogen = 600ml/s
- Inlet temperature of the coolant/Nitrogen = 96K

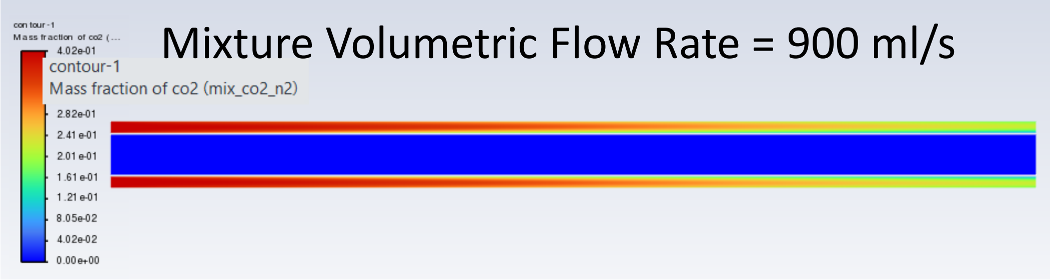


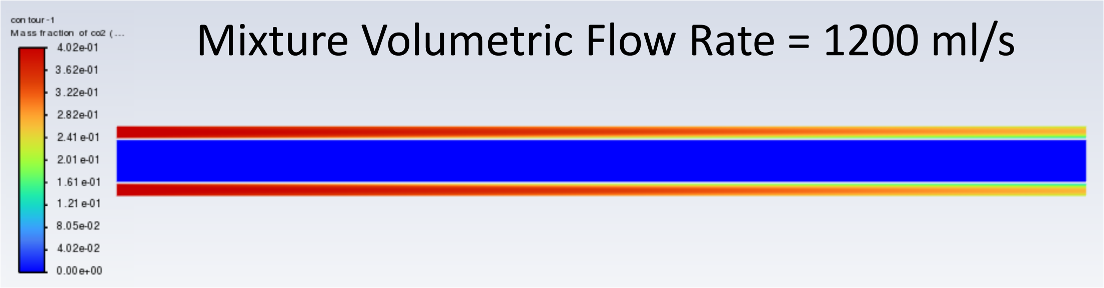
Ansys

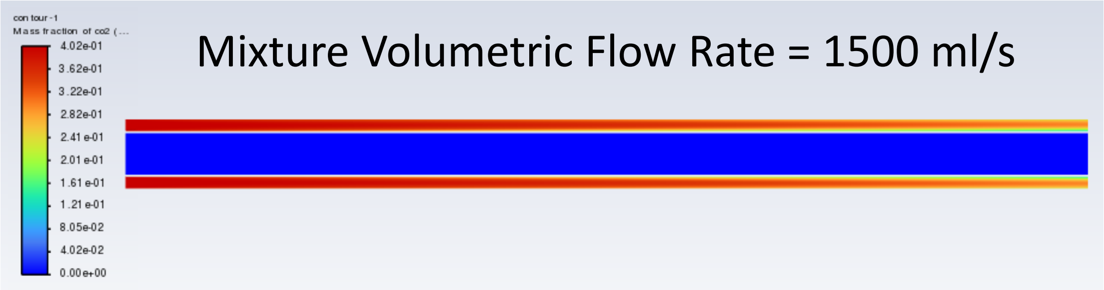
Results - Effect of Volumetric Flow Rate on CO_2 Capture

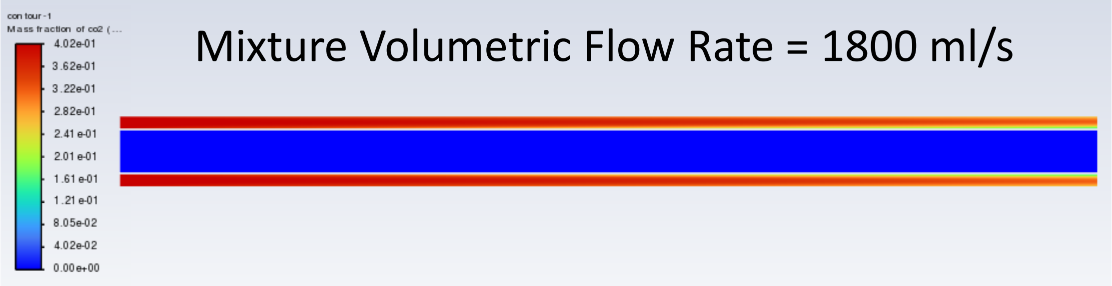






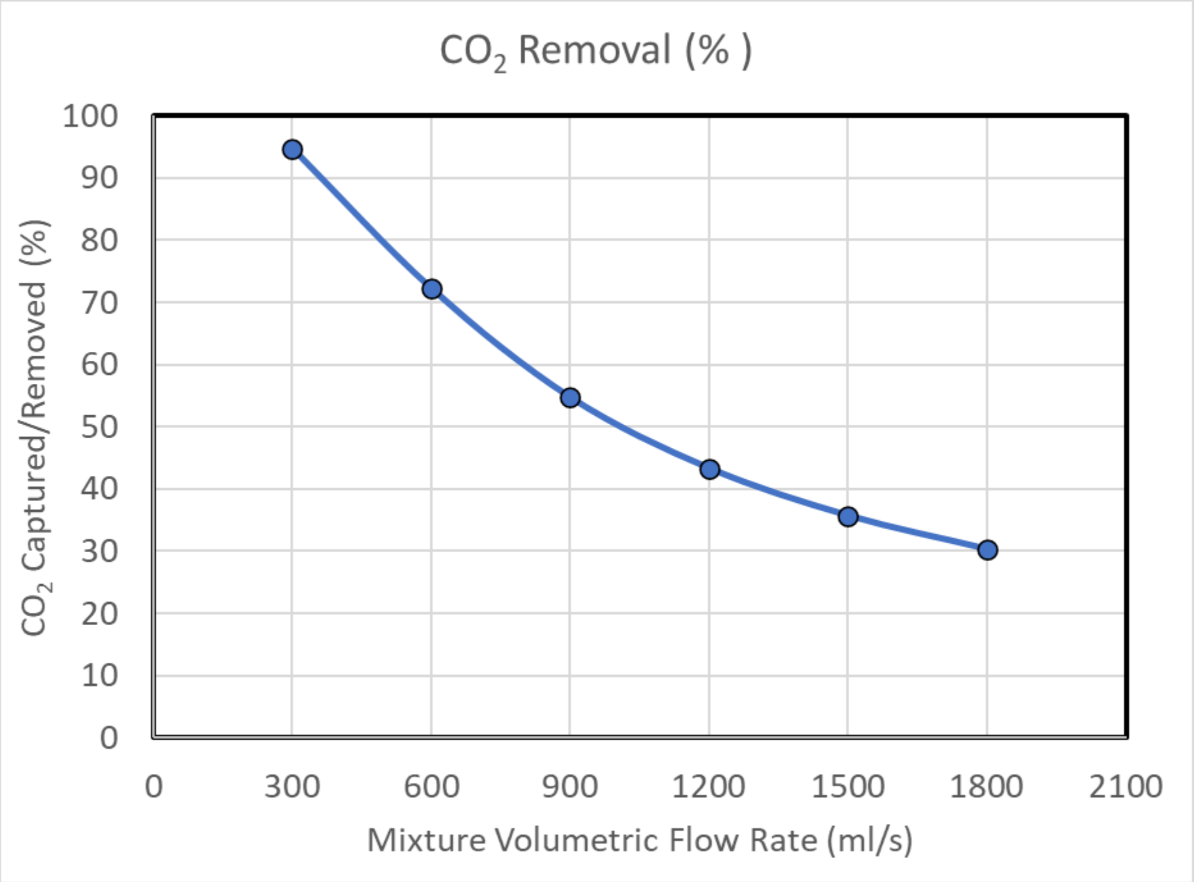






Ansys

Results - Effect of Volumetric Flow Rate on CO2 Capture



Volumetric Flow Rate (ml/s)	CO2 Removal (%)
300	94.7
600	72.2
900	54.7
1200	43.3
1500	35.7
1800	30.3

38

Other Studies from Literature

CO_2 Capture in Gasification System—Adsorption

Customer Goals

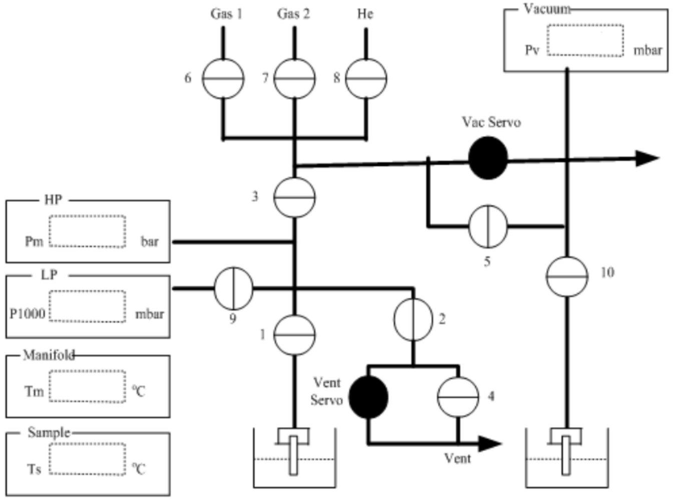
- **Investigate** the feasibility of activated carbon derived from agricultural waste, palm mesocarp fiber, as an adsorbent for CO_2 capture
- Determine **optimum** range of operating conditions, gas inlet feed flow rate and inlet feed composition particle diameter

Solution

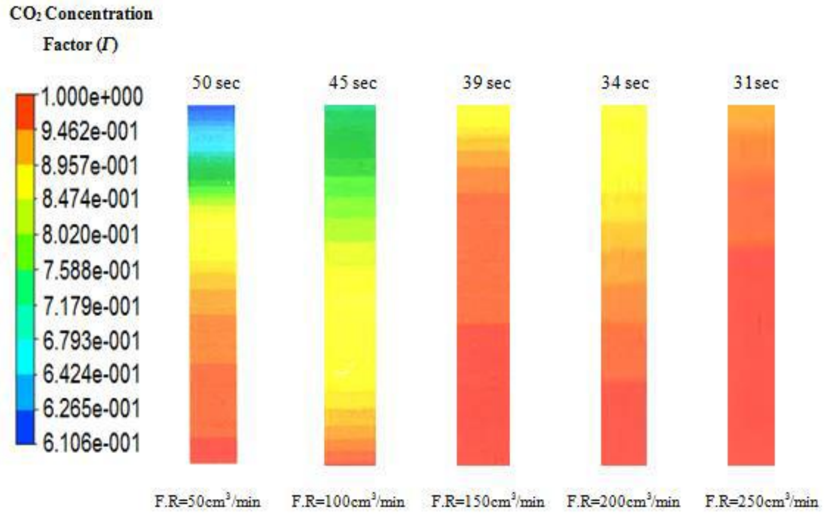
- **Multiphase flow modeling** analysis with capability to model gas-solid flows to accurately capture the flow hydrodynamics
- **Mass transfer** to describe carbon adsorption by the activated carbon media
- **High speed HPC** for design and troubleshooting

Benefits

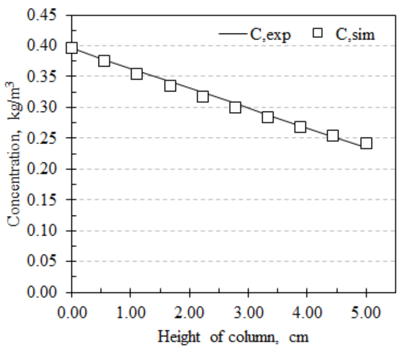
- **Better insight in virtual environment** to design efficient, cleaner and reliable system
- **Good** comparison with experimental data
- **Efficient scale-up** from lab to commercial



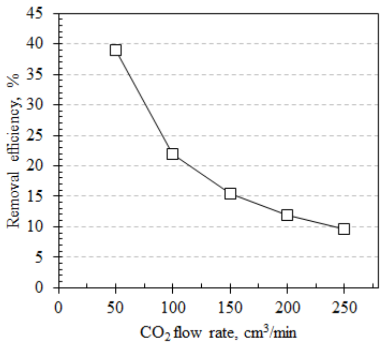
Schematic Diagram of Experimental Apparatus (HPVA)



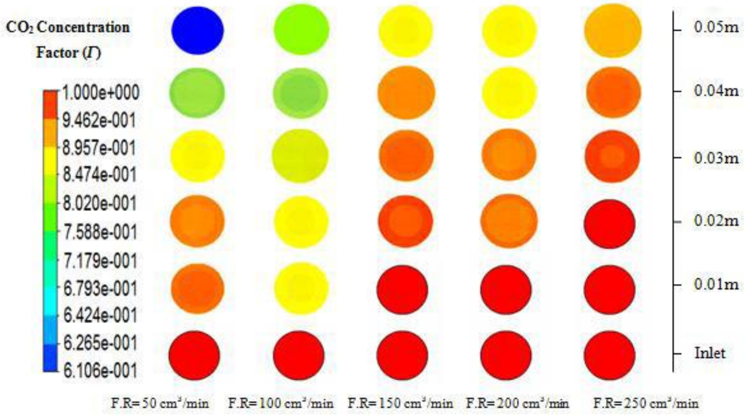
Effect of Feed Flow Rate on Bed CO_2 Concentration Factor



Comparison between experimental and simulated adsorbed concentrations for CO_2



Effect of feed flow rate on CO_2 removal efficiency



Radial Profile for CO_2 Concentration Factor at Different Flow Rate

Abdullah and Qasim, “Parametric Analysis of Carbon Dioxide Adsorption on Nanoporous Activated Carbon Using Computational Approach,” Procedia Engineering 148 (2016) 1416-1422

Ansys

Calcination Process

Customer Goals

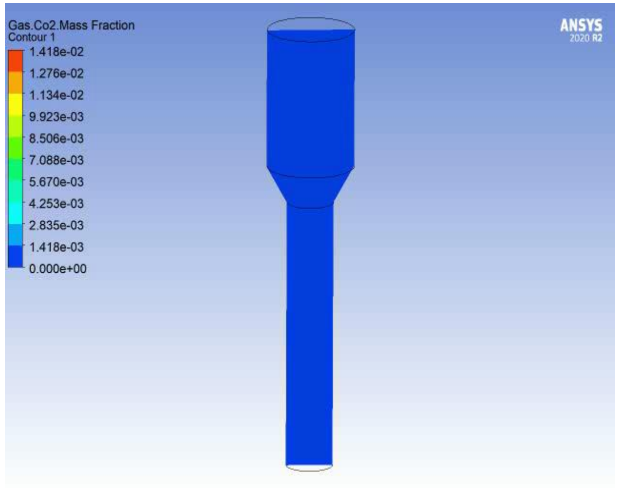
- **Improve efficiency** of carbon capture via calcium looping and calcination processes
- Achieve **optimized design** and **efficient scale-up**
- **Minimize** energy usage in the process

Solution

- **Accuracy** – **Validated solutions** calcium looping and calcination processes
- **High-fidelity** – **Multiphysics** analysis with **HPC** for design and troubleshooting

Benefits

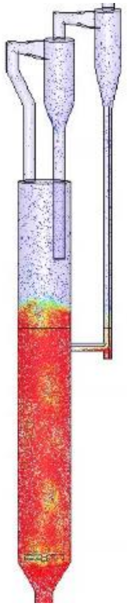
- **Better insight in virtual environment** to design efficient, cleaner and reliable system
- **Reduced physical testing, TTM and R&D costs**
- **Reduced downtime** in retrofitting and revamping
- **Efficient scale-up** from lab to commercial



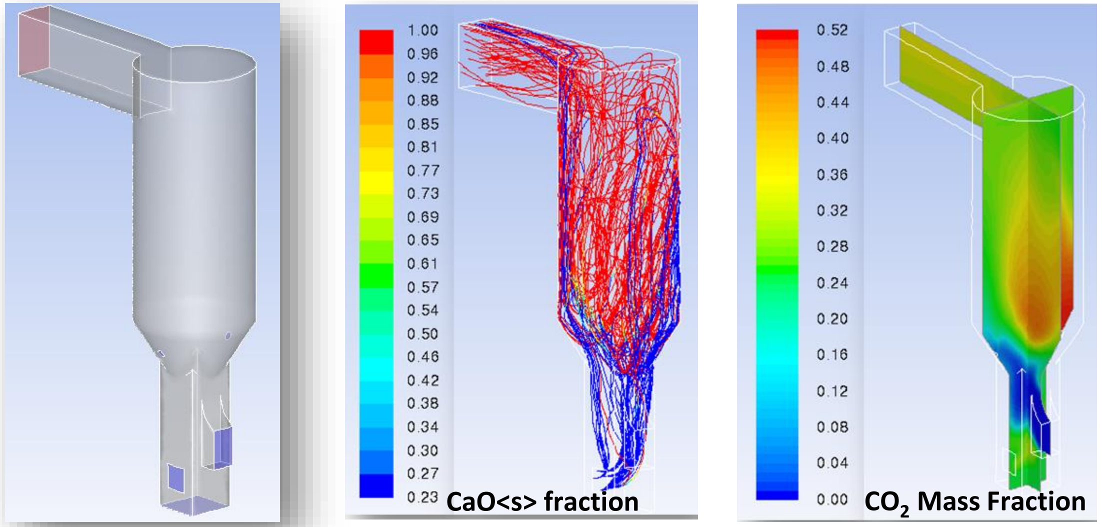
Solution for CO_2 distribution in dense fluidized bed for FCC regenerator

$$(\varphi + 1)C + (\varphi + 0.5)O_2 \rightarrow \varphi\, CO_2 + CO$$

$$CO + 0.5\, O_2 \rightarrow CO_2$$



Fluidized beds and regenerators for sorbent-based CO_2 capture technologies



Calcination process using flash calcinatory to regenerate limestone and release CO_2

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CO_2 Transport and Storage

Ansys

CO_2 Pipeline Transport

Customer Goals

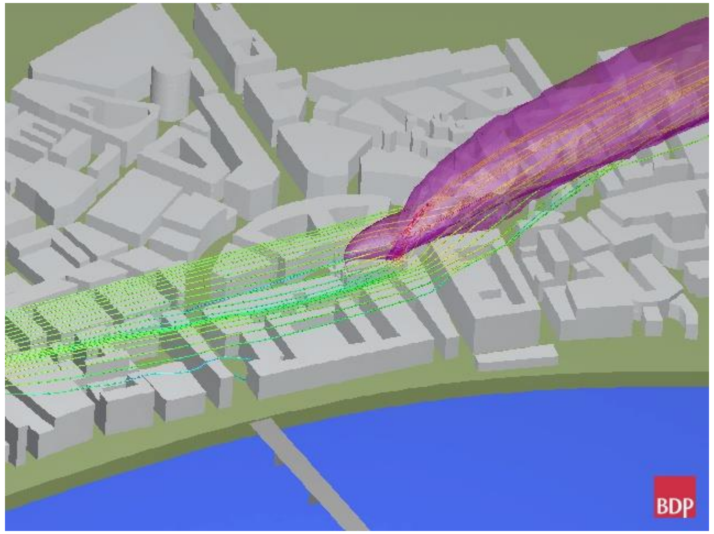
- **Predict CO_2 dispersion pattern in case of leak from pipeline**
  - Assess the impact of CO_2 plum on surrounding environment under different operating conditions

Solution

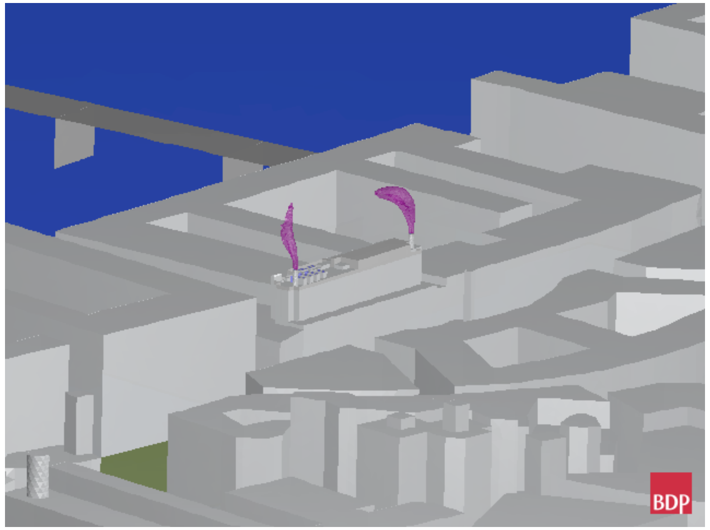
- **Modeling Fidelity** – ability to capture complex terrains and city layout, plume transport
- Investigate different flow conditions and assess impact on environment in case of leak incidents

Benefits

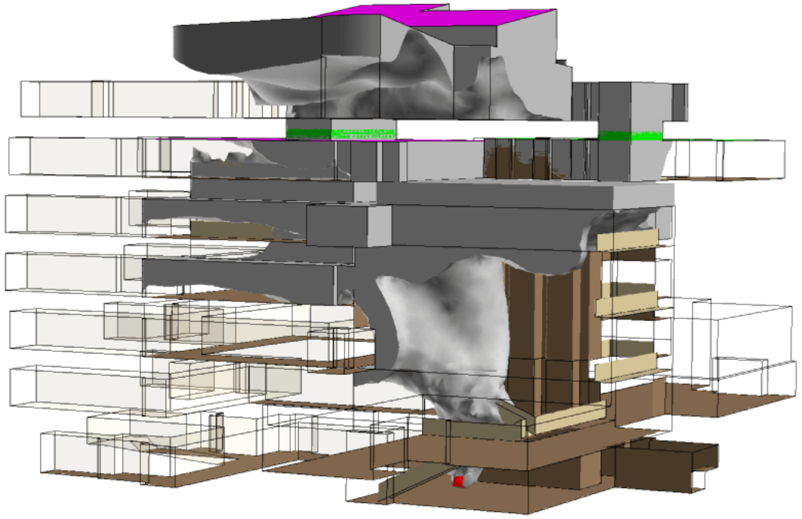
- Using Ansys simulation tools, facility managers, designers, and engineers can **gain valuable insights** into the environmental impact CO_2 leaks
- Ansys simulations can be used to modify layout and/or equipment specifications to remedy unacceptable conditions

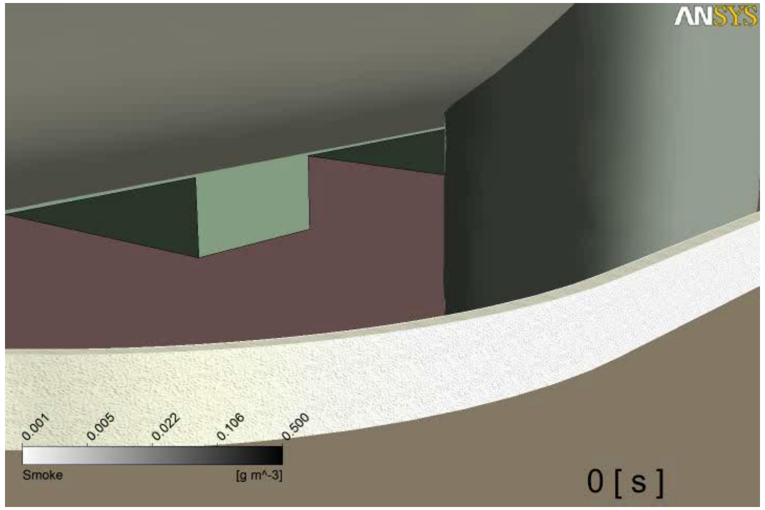


Pollutant plum effect on city buildings



Courtesy of BDP Engineering

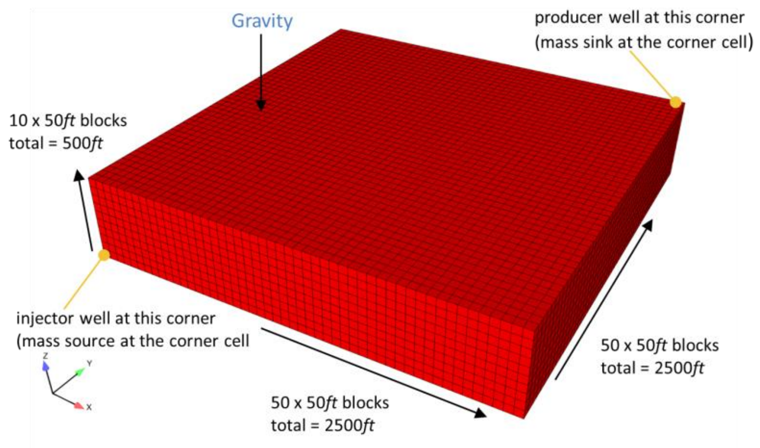




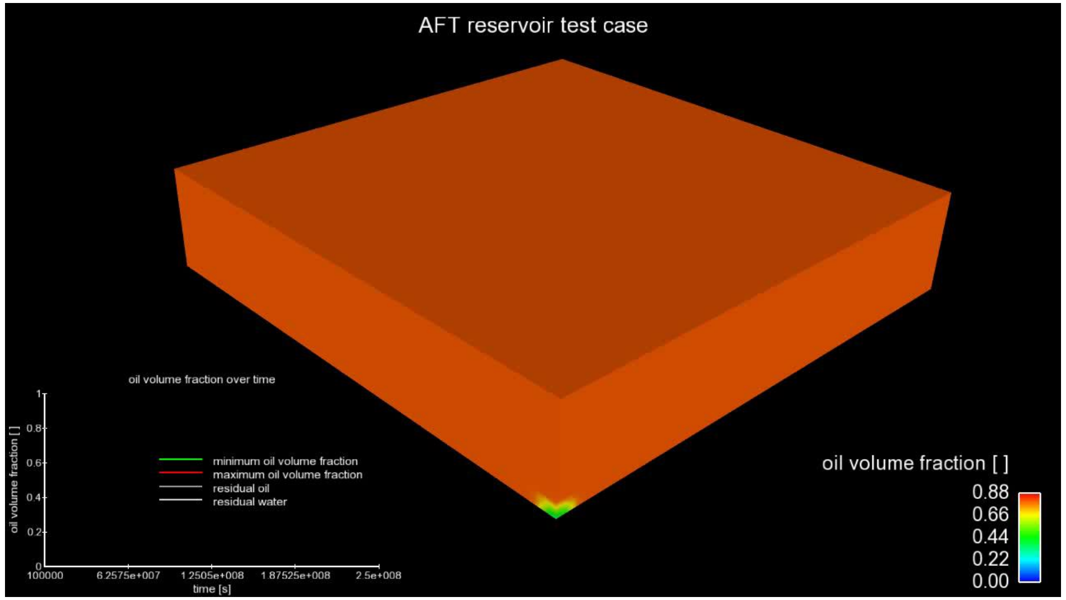
Smoke dispersion in large building

CO_2 Storage

- Captured CO_2 can be stored
  - Geological reservoir (EOR)
  - Ocean
    - Lakes
    - Dissolution

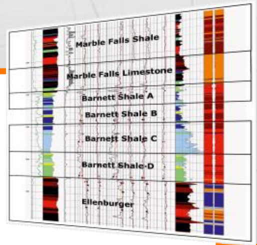


- Need to understand CO_2 flow inside O&G wells (porous media)
  - Wettability
  - Saturation levels



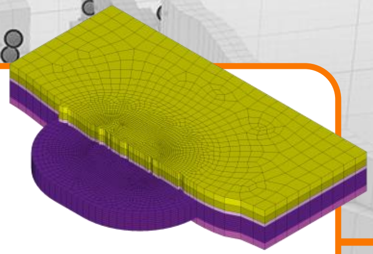
Ansys

CO2 Storage - THM Simulator workflow for fracking Optimization



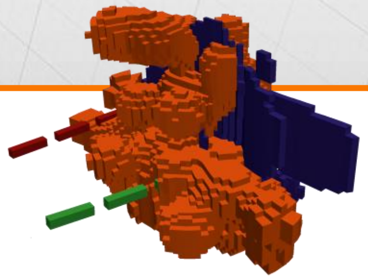
1

Collect available reservoir conditions



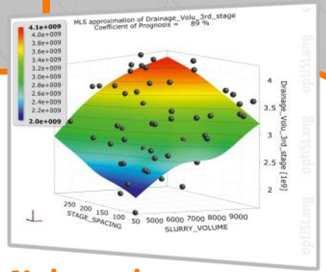
2

Automatic generation of a parametric 3D reservoir model for multiple wells



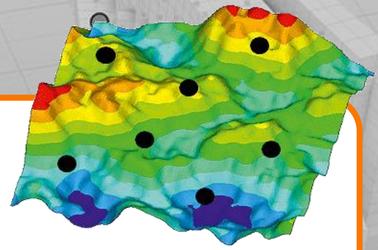
3

Reservoir model calibration to the best available data including micro seismic data



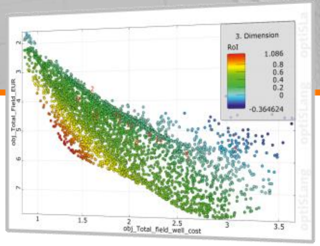
4

Generate ML-based metamodels using upfront simulation regarding reservoir uncertainties and operational variability



5

Find optimal operation under variable (updated) Reservoir conditions



Generate Pareto optimality between estimated ultimate recovery uplift and related unit development costs

Ansys Hydraulic Fracturing Simulator using Ansys Mechanical for FEM based simulation of hydraulic fracturing and optiSLang for calibration, sensitivity study, metamodeling and optimization

Ansys ACE: Martin Husek

Will, J.; Eckardt, S.: Optimization of Hydrocarbon Production from Unconventional Shale Reservoirs using Numerical Modelling

ANSYS Multiphase Flow Modeling Solutions

- Key differentiators
  - Accuracy and speed of the Fluent solver.
  - Customization
  - Platform implementation (DT, ROMs, Optislang)

  - Wide variety of Physical models to address complex multiphase flows with heat/mass transfer and reactions

Particles treated as discrete

Euler-Granular & Mixture Models

- Typically used for uniform size particulate systems

Population Balance Models

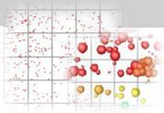
- Systems with particle size distribution evolution

Interface Tracking Models

- VOF implicit or explicit
- Immiscible flows

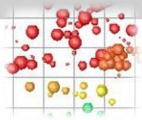
DPM & DDPM

- Dilute to dense systems



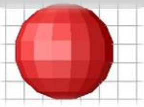
DEM

- Collisions resolved



MPM

- Particles bigger than cell in grid



Key Take-aways

- Carbon dioxide removal is a hot topic of research with lots of projects currently underway both in the government and private sector.
- Ansys solutions are available to share with our clients
  - Application Briefs, Best Practices, Tutorials, Webinars, Demos.
- Ansys Sustainability ACE Team is already engaged with some accounts.
- These solutions are not limited to Oil & Gas. Other industries such as Chemicals, Industrial and manufacturing are good targets too.
- Please contact us, the CCUS Sustainability Team at Ansys, to discuss future opportunities.

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