Rotating packed beds for CO_2 capture: Technological status and economics

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Advancing CCU Workshop for a Sustainable Energy Transition

Newcastle University

Reuse

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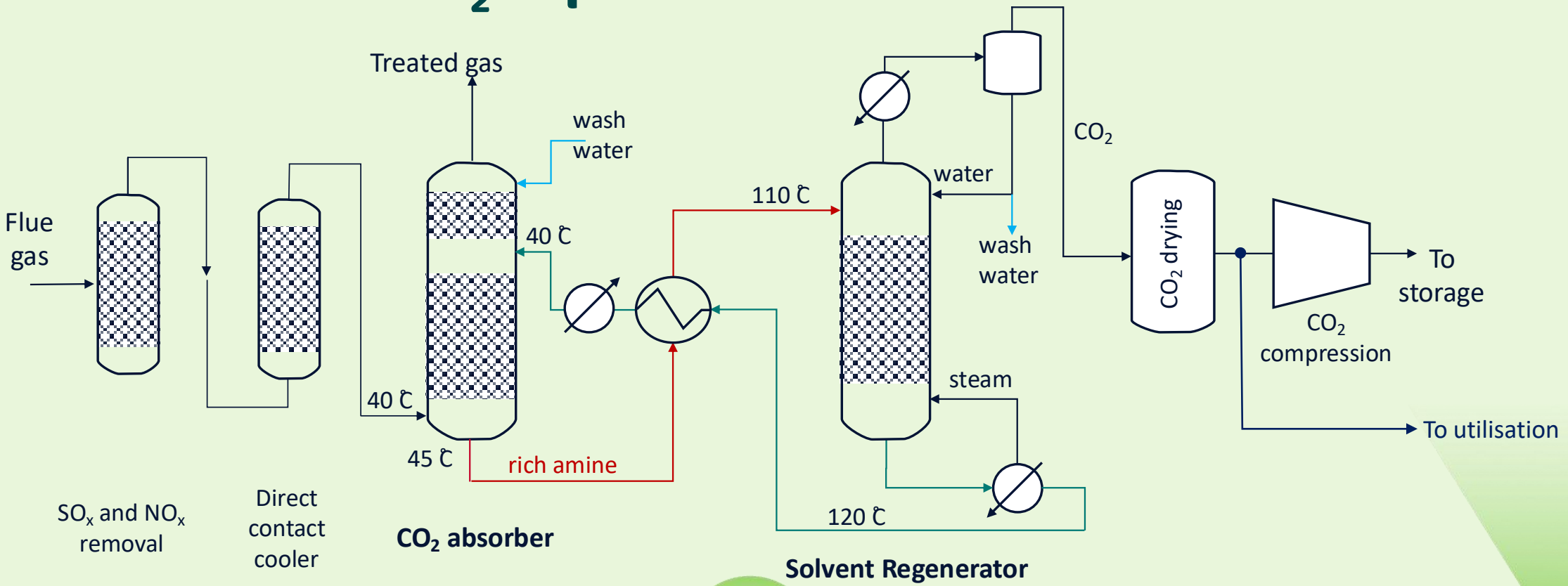
Rotating packed beds for CO_2 capture

- Solvent Based CO_2 Capture
- Why rotating packed beds?
- What is a rotating packed bed?
- Scale up challenges
- Technological Status

Solvent based CO_2 capture

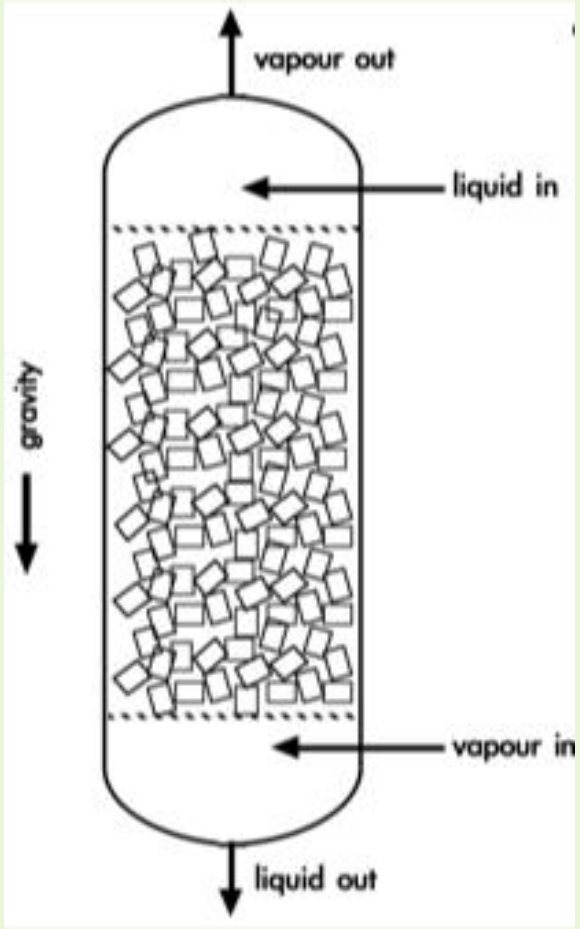


Why rotating packed beds?

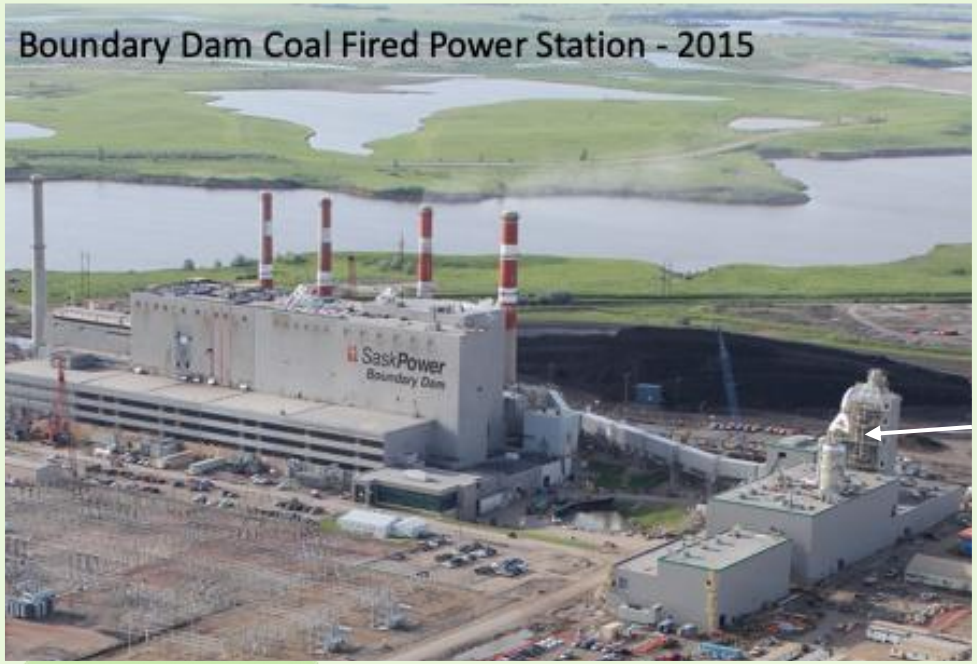
Process Intensification - "the development of novel apparatus and techniques that are expected to bring dramatic improvements in processing, substantially decreasing equipment-size, energy consumption, or waste production, and ultimately resulting in cheaper, sustainable technologies."

Stankiewicz, A., Moulijn, J.A., 2000, "Process Intensification: Transforming Chemical Engineering", Chemical Engineering Progress, 96, 22-33.

Why rotating packed beds?

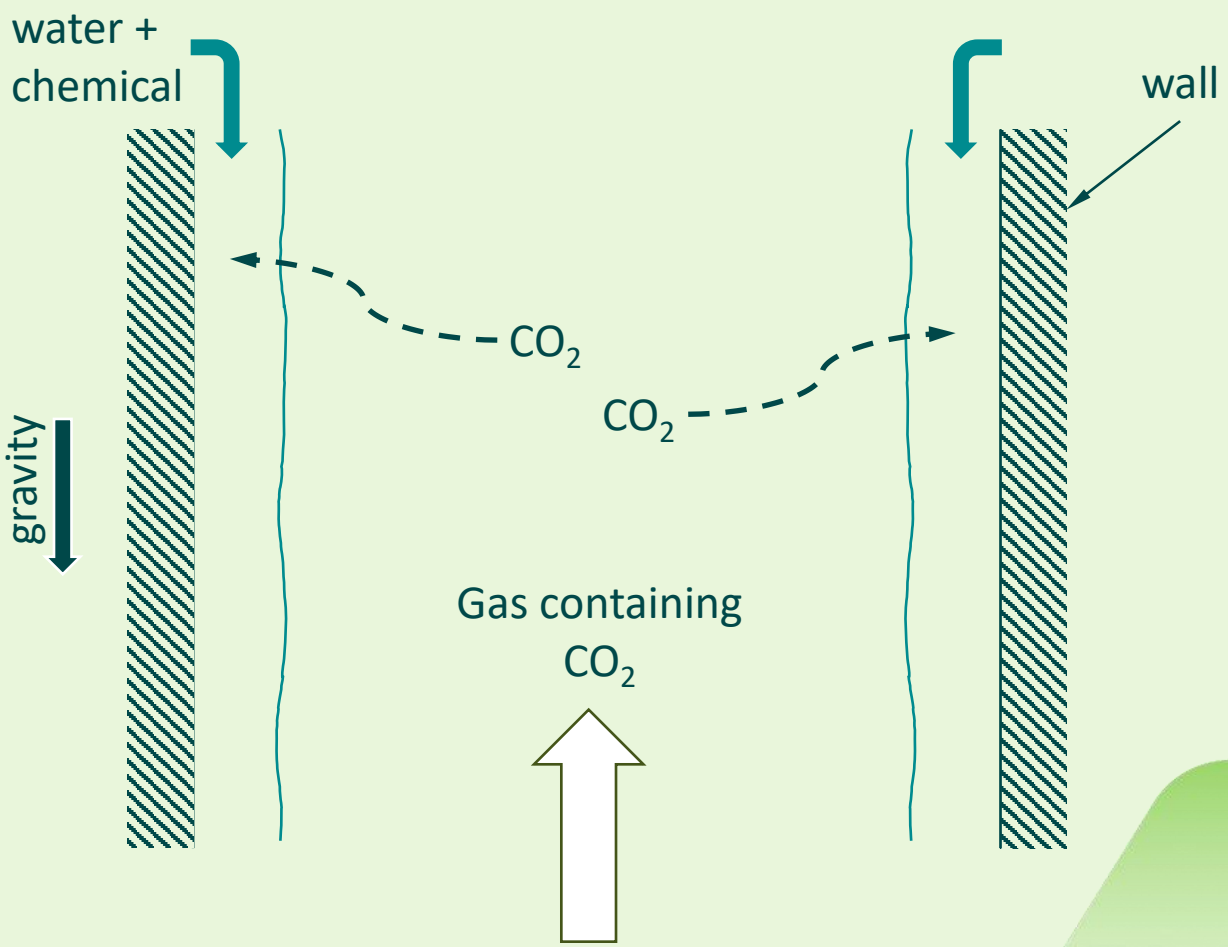


- Solvent based CO_2 capture requires counter current gas-liquid contact.
- Packed columns are used to achieve this.
- The acceleration acting on the liquid can influence performance.



Packed CO_2 absorber column

Why rotating packed beds?



- CO_2 absorbs into the liquid where it reacts

  Solvent based carbon capture

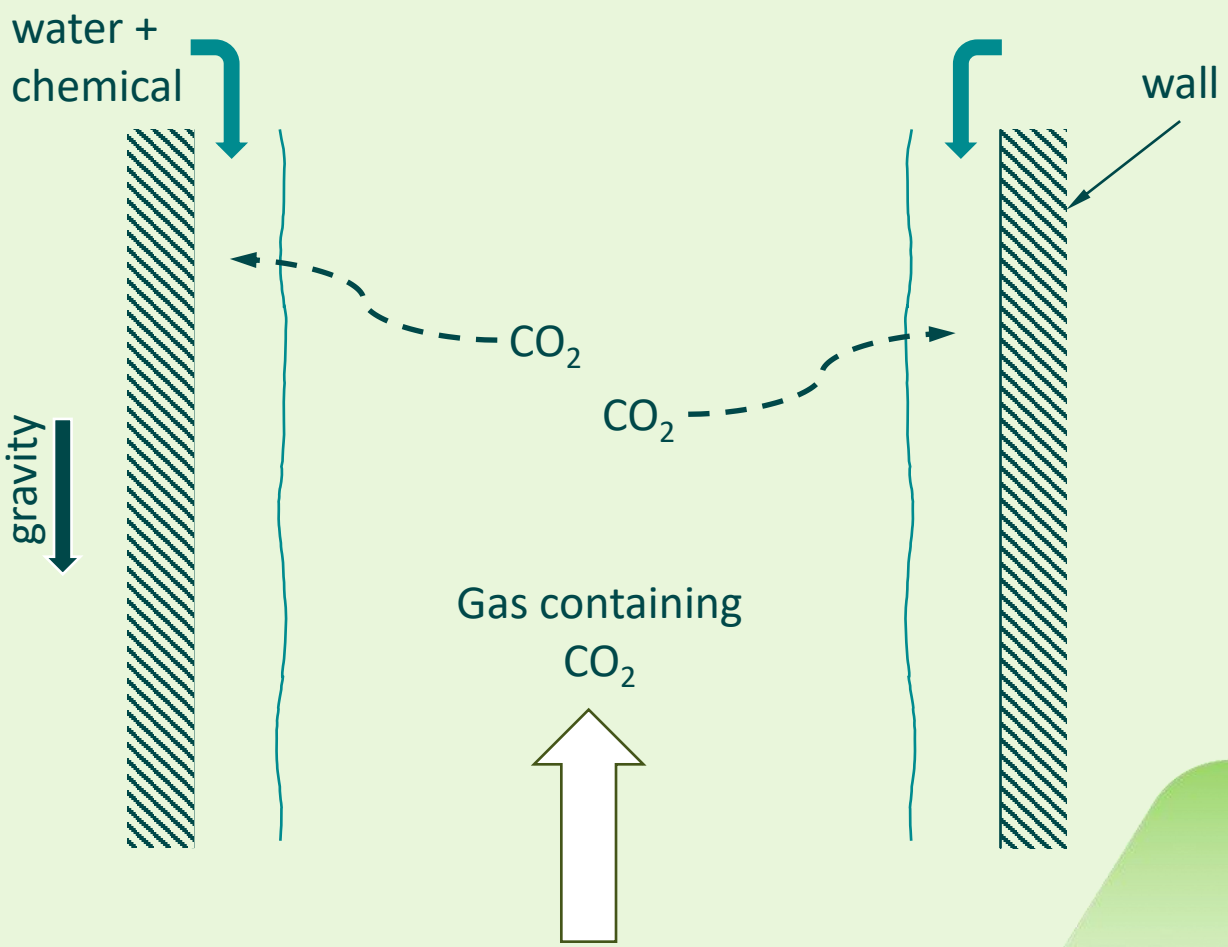
  $amine + CO_2 \rightarrow carbamate$

  Reuse Project

  $water + CO_2 \xrightarrow{\text{enzyme}} bicarbonate\ ion$

- Reaction increases the rate of CO_2 absorption
- Reactive absorption is ***Process Intensification***

Why rotating packed beds?

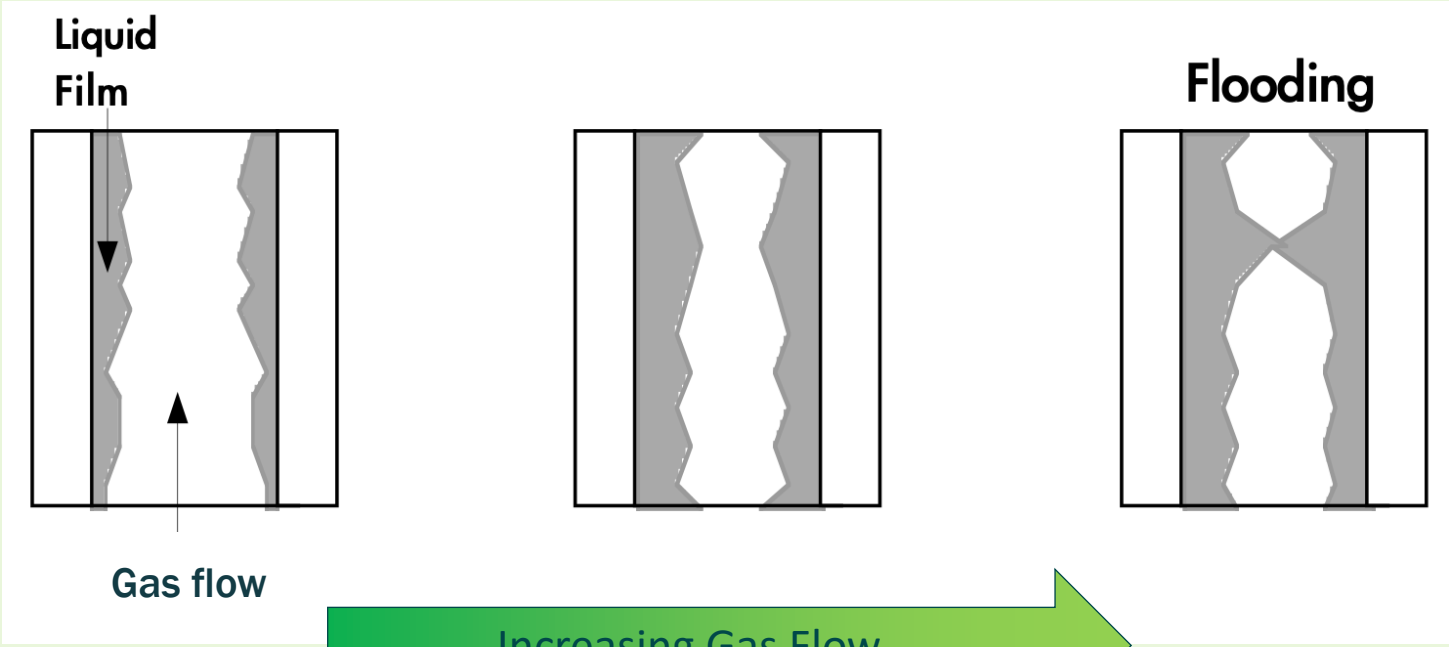


For carbon capture the gas flows are very big

100s of m^3 per second

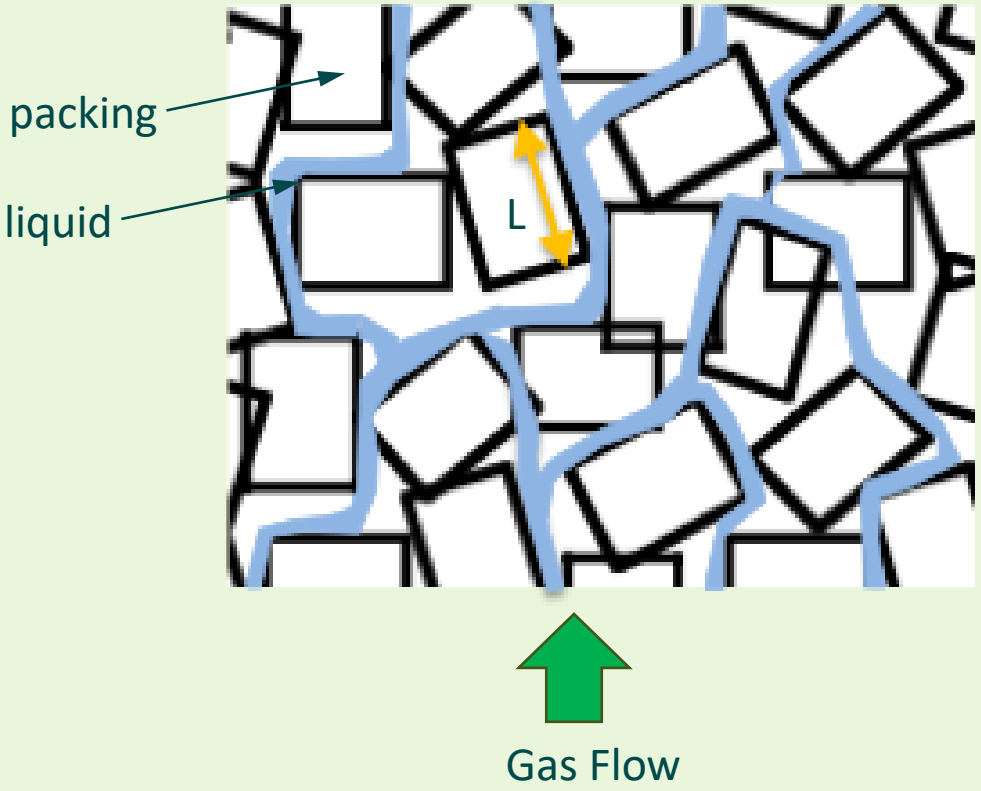
Why rotating packed beds?

Gas flow is limited by the speed of the liquid film



Liquid film flow is driven by gravitational acceleration → increase acceleration and liquid film velocity increases

Why rotating packed beds?



- Packing increases the contact area between the gas and liquid.
- Continuous liquid film mixing in the flow over the packing.

$$t_{mix} \propto \frac{L}{liquid\ velocity}$$

$$rate\ of\ mass\ transfer \propto \sqrt{\frac{1}{t_{mix}}}$$

- If acceleration increases, the rate of mass transfer increases.

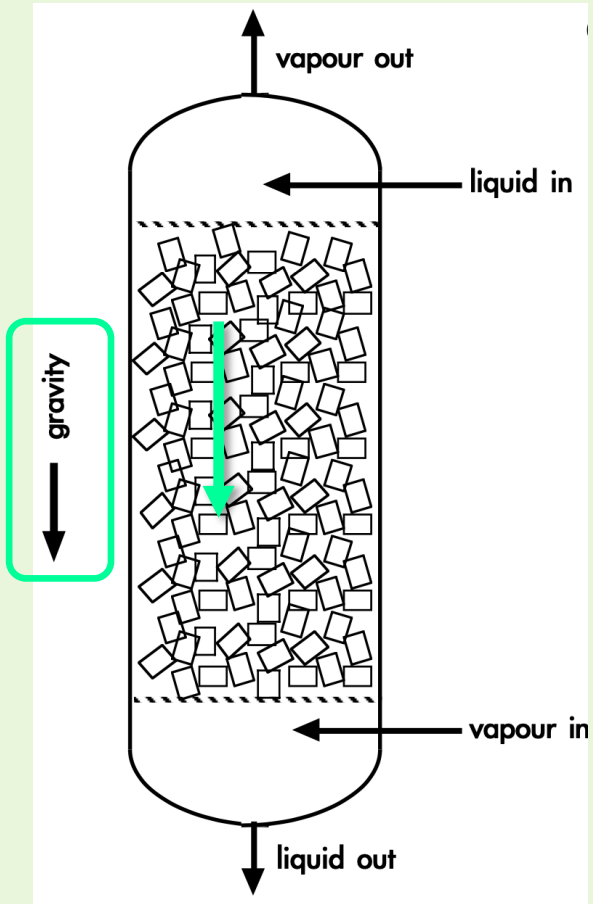
Why rotating packed beds?

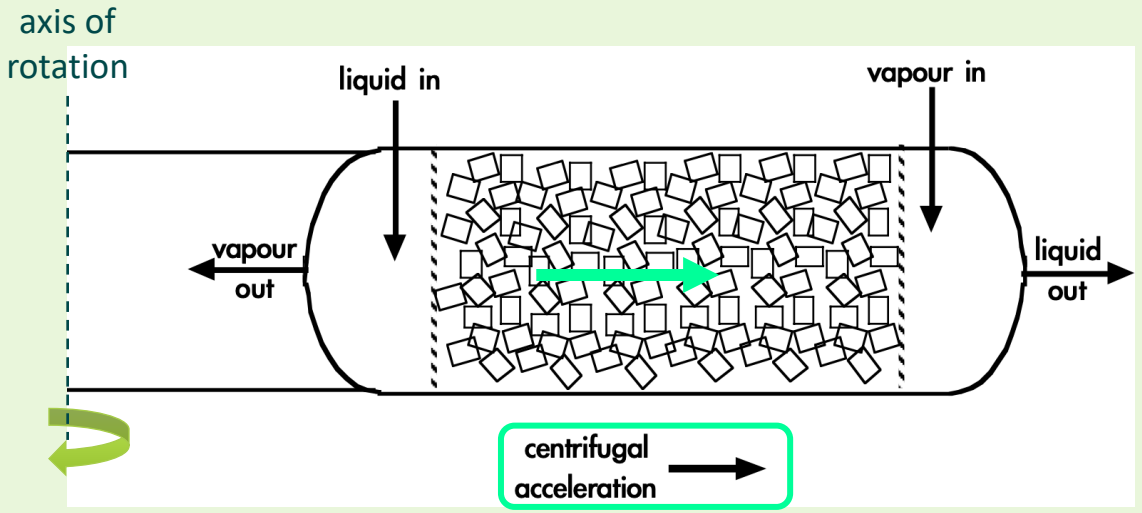
- Increase the acceleration applied to a counter current gas-liquid flow
- The flooding limit increases → column diameter decreases
- Rate of mass transfer increases → height of the column decreases

- Packing volume is decreased
- Capital costs decreases by up to 40%
  - $Cost(GBP, 2025) = 35030\ V_{RPB}^{0.326}$, V_{RPB} = packing volume in litres
- For CO_2 capture the solvent flow can be reduced leading to operating cost savings

How is this achieved ?

What is a rotating packed bed (RPB) ?

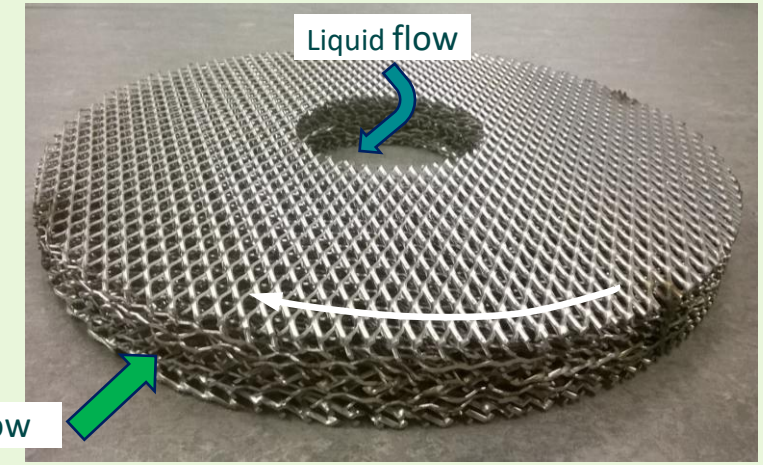




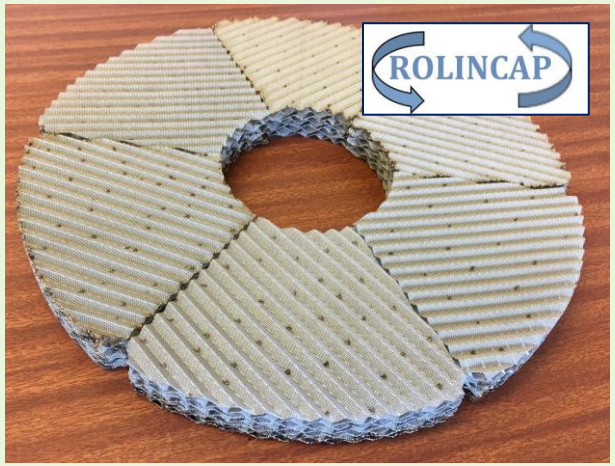
g replaced with. $\omega^2 r$

Increase g using rotation

What is a rotating packed bed (RPB) ?



Expanded mesh (SS316) sheets
a_P =663 m^2 m^{-3} ε = 0.80

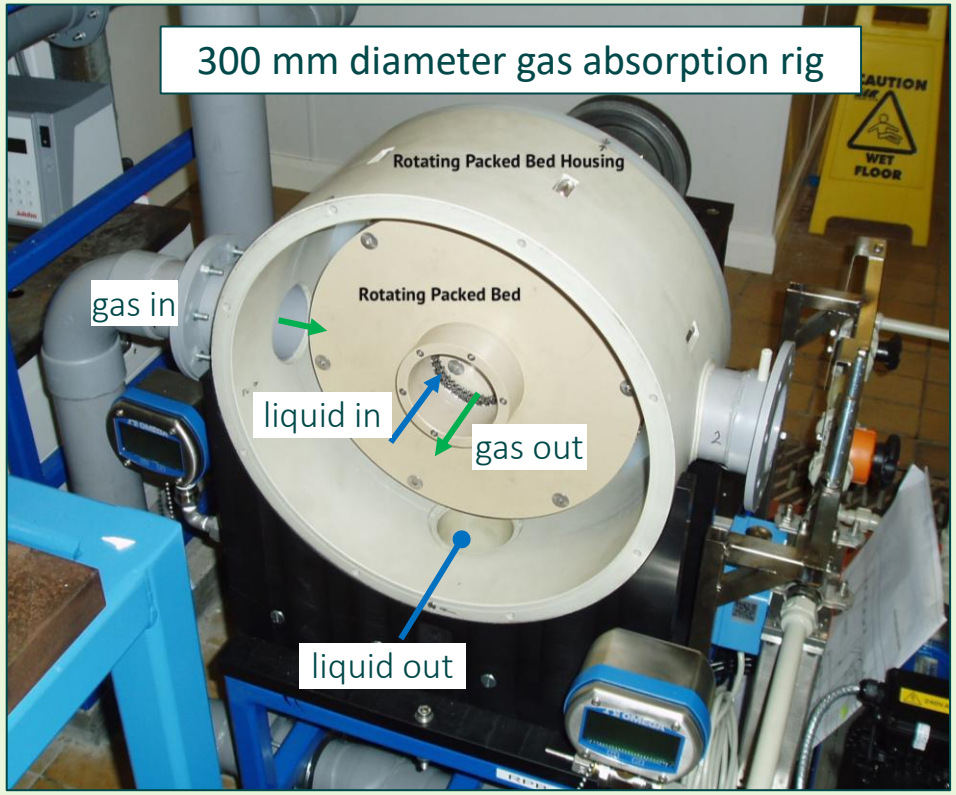


Montz structured packing (SS316)
a_P =830 m^2 m^{-3} ε = 0.94

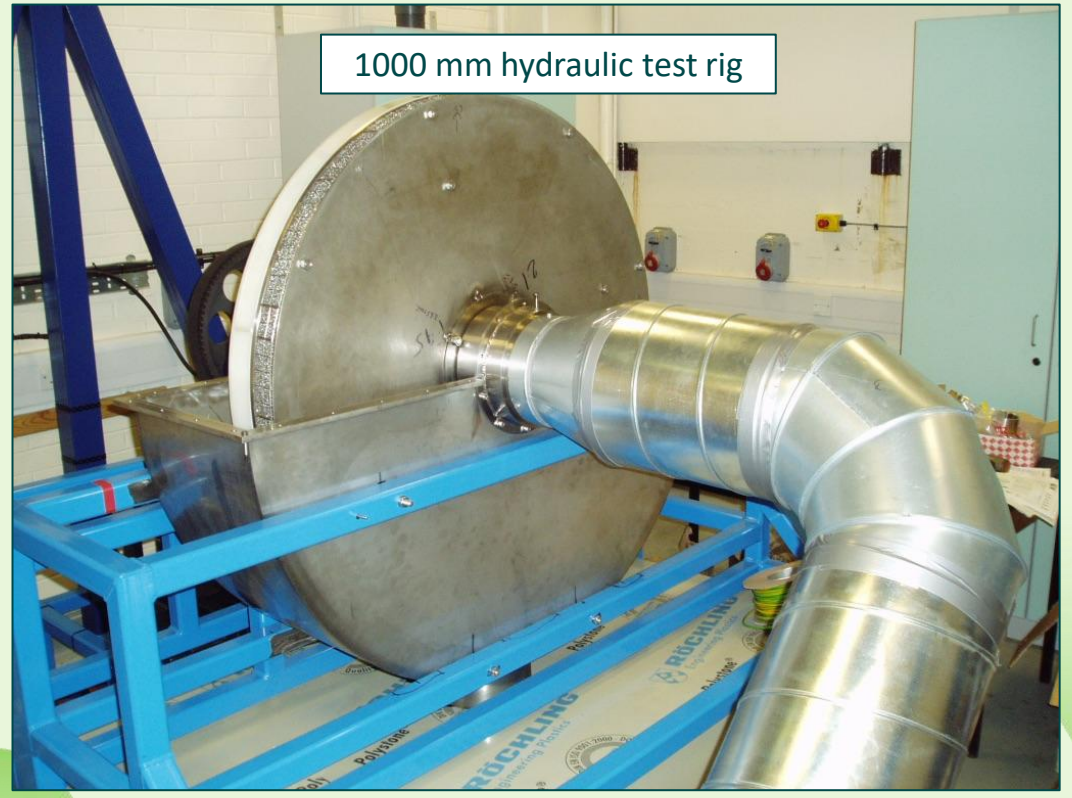
$$Intensification\ Factor(IF) = \frac{Packed\ column\ volume}{Rotating\ Packed\ Bed\ volume} \qquad 10 \leq IF \leq 80$$

For CO_2 capture applications $\quad 15 \leq IF \leq 30$

Scale up Challenges



rate of absorption, flooding and gas ΔP



flooding and gas ΔP

Scale up Challenges

Artemis Project with Carbon Clean Solutions

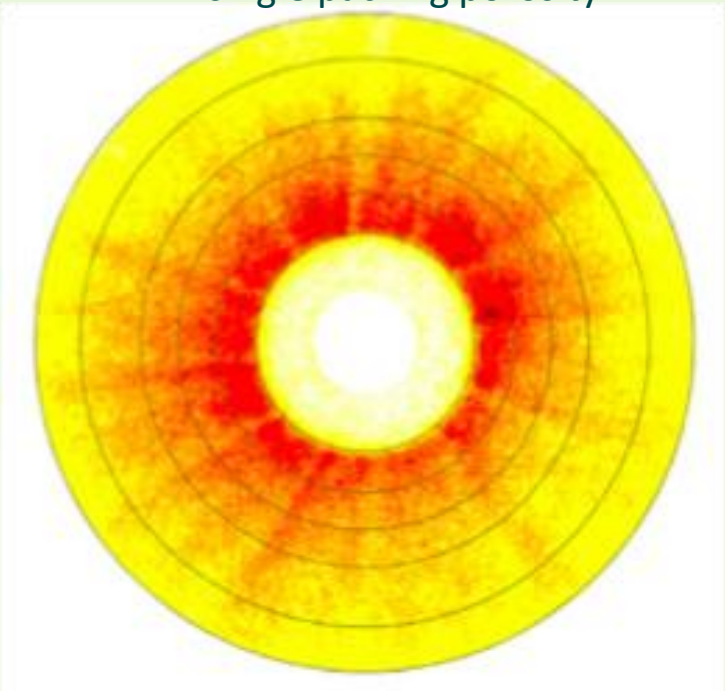
- Flooding limit and pressure drop predictions were correct.
- Initial tests showed 63% CO_2 capture
- Target was 90% CO_2 capture

- Calculated outer diameter based on data from 300mm diameter RPB

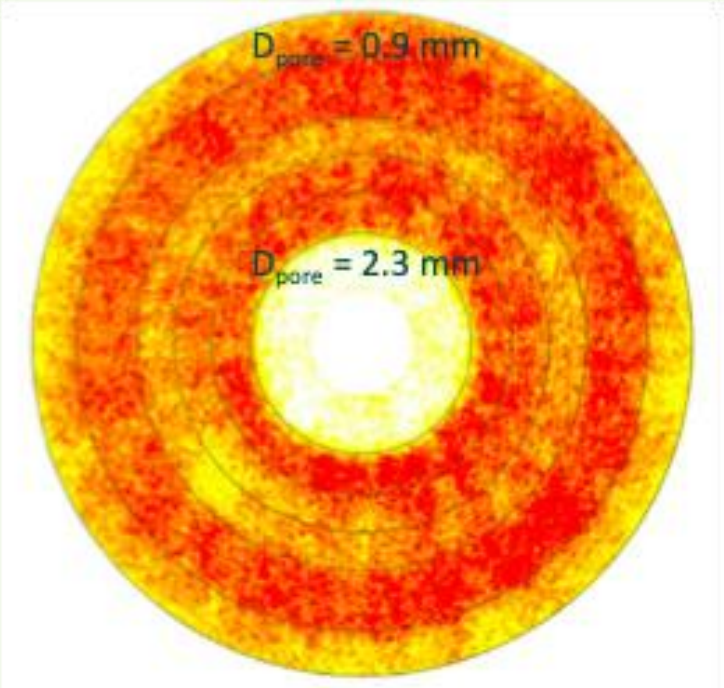
- In 300mm RPB
  - overall rate of mass transfer was higher
  - reaction rate was higher

Scale up Challenges

Gamma ray computed tomography of an RPB single packing porosity



Variable porosity packing to increase liquid residence time

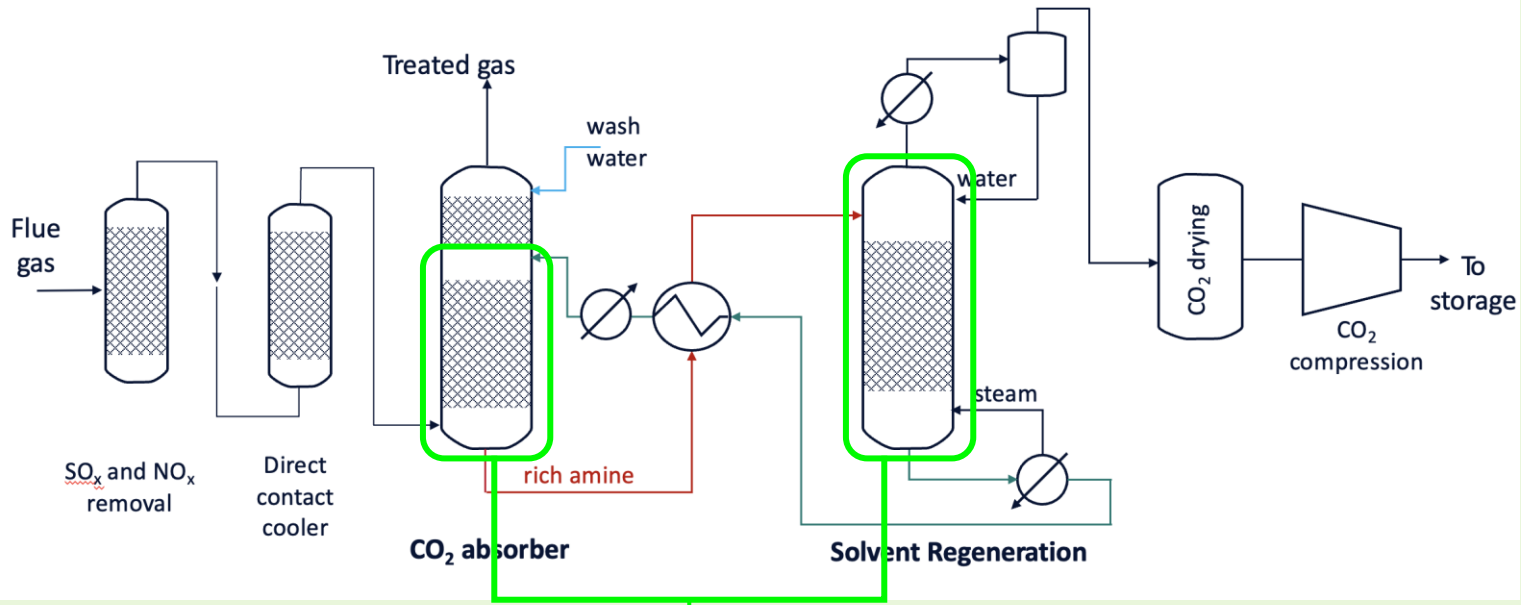


Variable porosity RPB packing from Montz

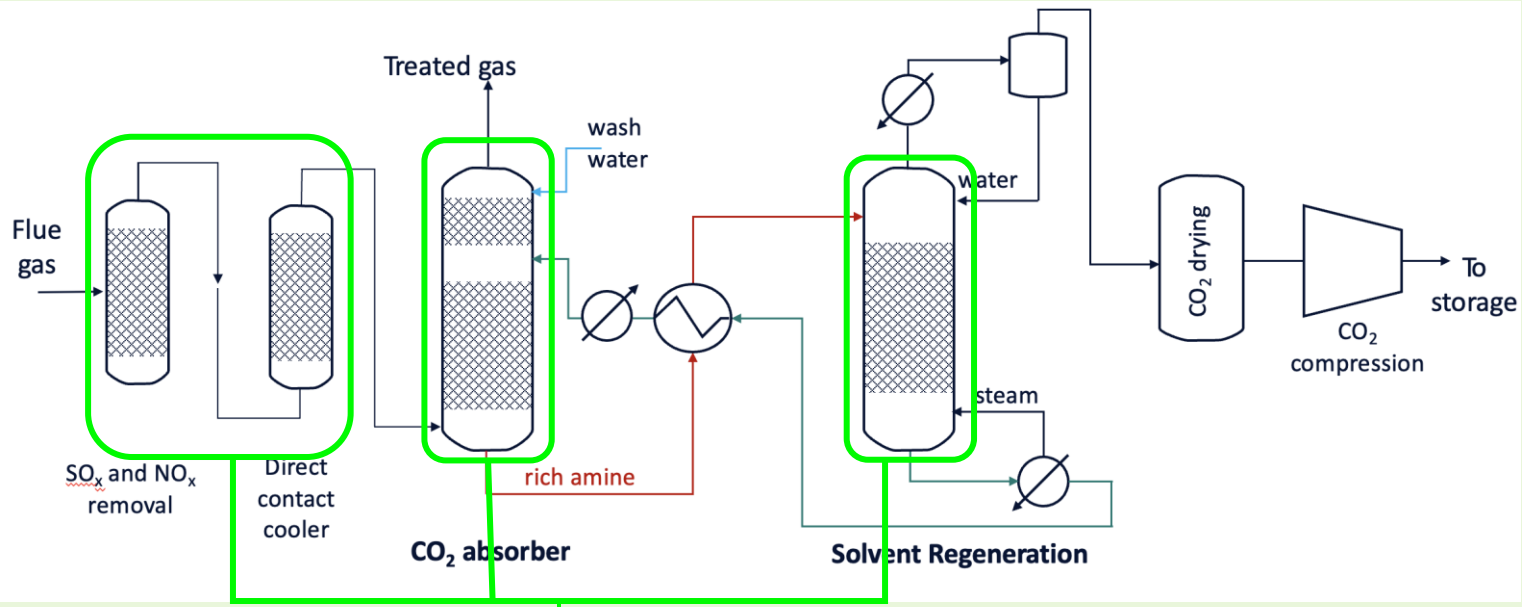
Konrad Gładyszewski, Kai Groβ, Andre Bieberle, Markus Schubert, Marvin Hild, Andrzej Górak, Mirko Skiborowski, 2021, “Evaluation of performance improvements through application of anisotropic foam packings in rotating packed beds”, *Chemical Engineering Science*, 230, 116176, https://doi.org/10.1016/j.ces.2020.116176

Technology Status

Carbon Clean Solutions - Cyclone CC
www.carbonclean.com/technology/modular



Technology Status



Carbon Clean Solutions - Cyclone CC
www.carbonclean.com/en/press-release

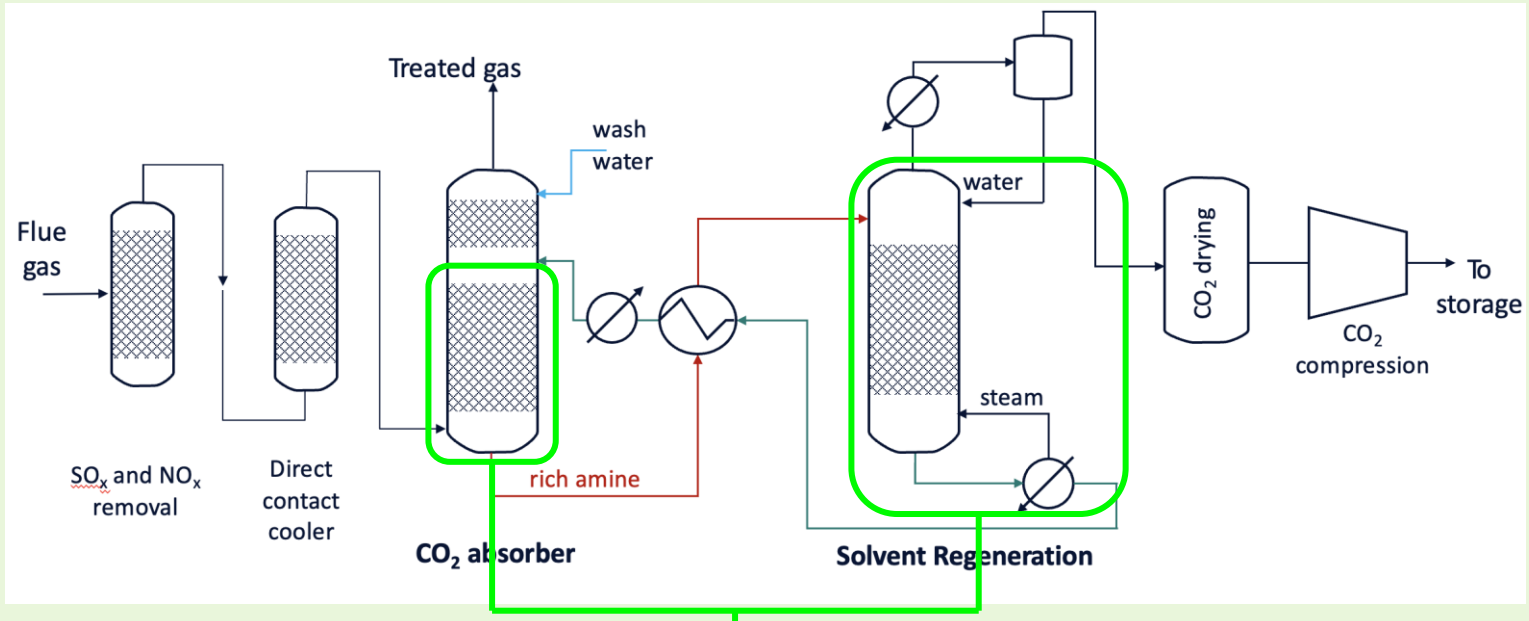

Cyclone CC – C1 Series
10 TPB

Scale up to 100 TPD for a waste to energy plant

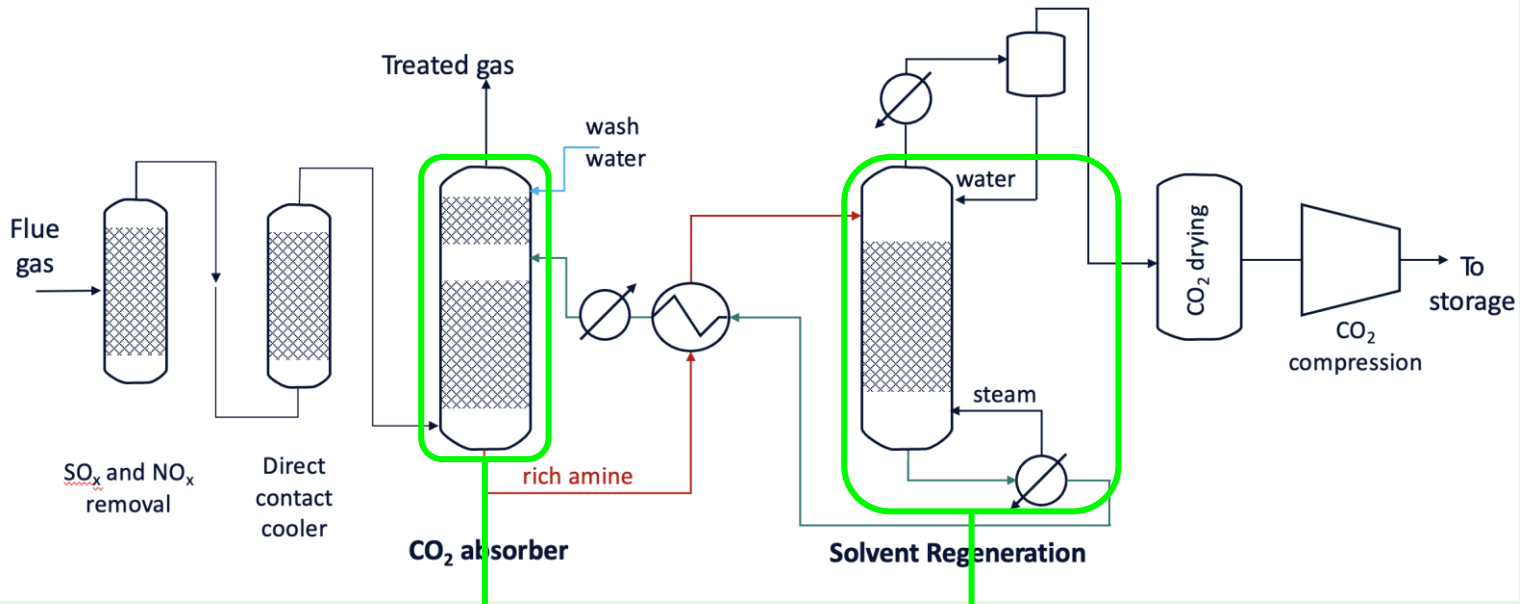
Technology Status

HIRECORD

hirecord.eu



Technology Status



Baker Hughes – Compact CC

www.bakerhughes.com/process-solutions/compact-carbon-capture

Summary

- RPB used to reduce the volume of packed columns for CO_2 capture.
- CAPEX and OPEX savings from using rotating packed beds.
- Technology has been scaled to 10 TPD CO_2 capture.
- Full scale 100 TPD plants using this technology are being designed.

Thank you!

Any Questions?

Reuseproject.eu

REUSE - Horizon Europe Project

info@reuseproject.eu

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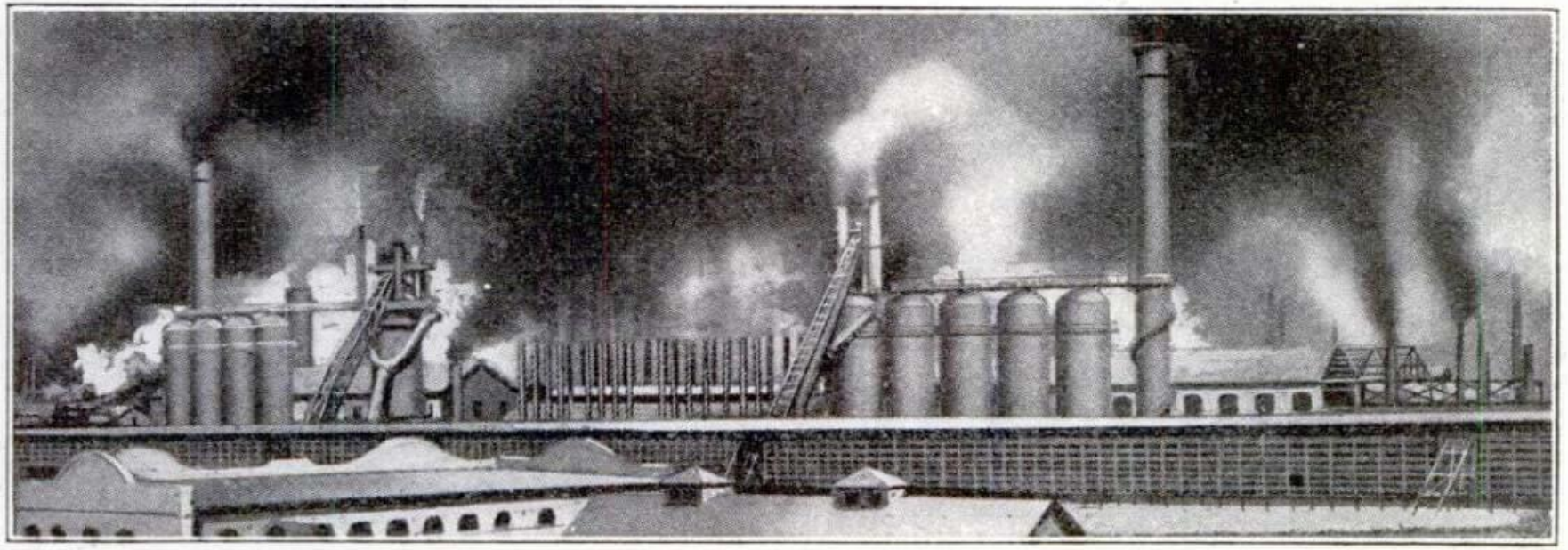
The need for CO_2 capture

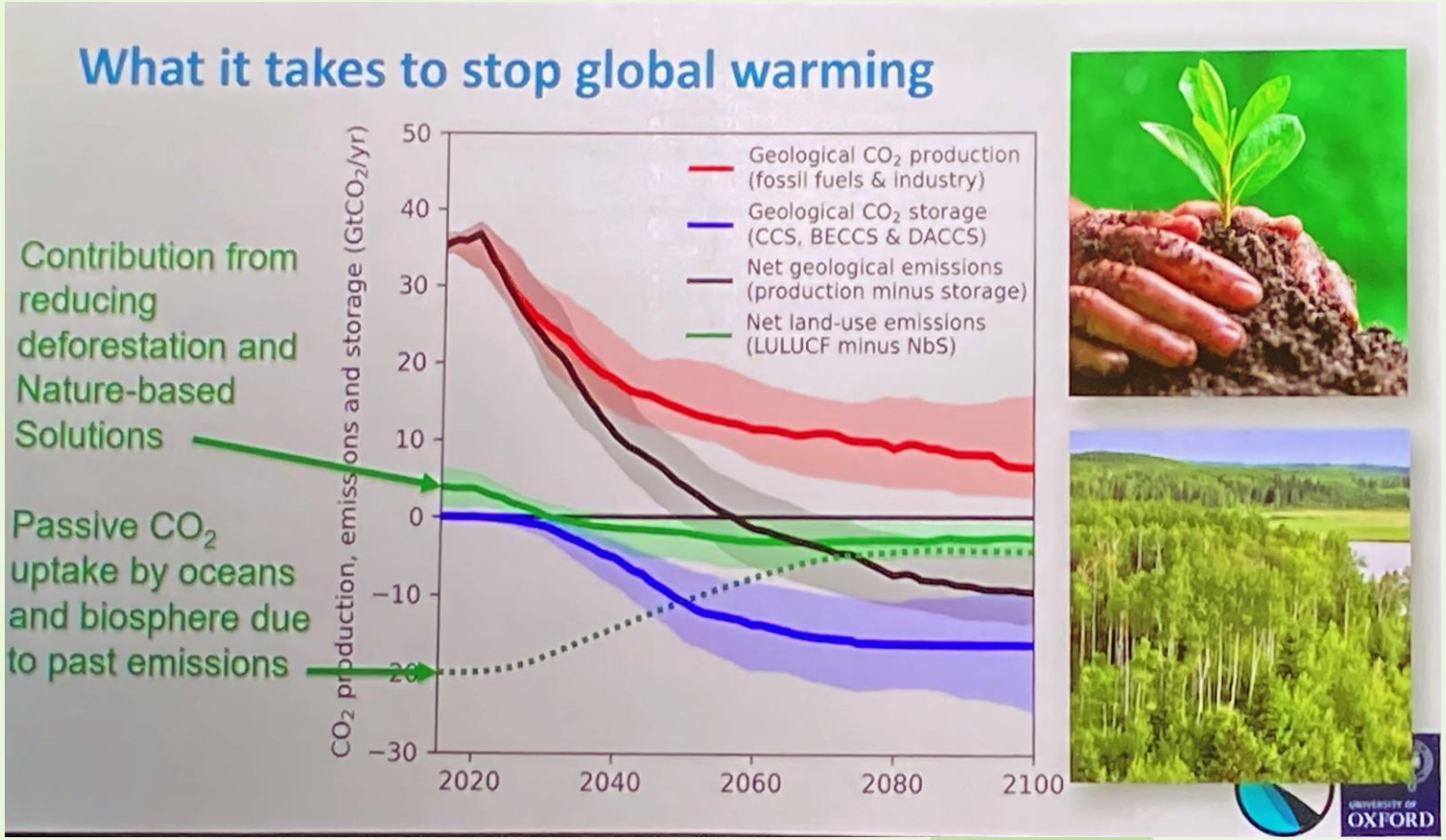
March, 1912 POPULAR MECHANICS 341



The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

Slide courtesy of Dr Greg Mutch, School of Engineering, Newcastle University

The need for CO_2 capture



Slide from a presentation by Professor Miles Allen, University of Oxford, at GHGT-17, 21st October 2024, Calgary.