Project Notes:

Project Title: **CO2 Filtration Device for Automobile Exhausts**
Name: Vo, Dasha

Note Well: There are NO SHORT-cuts to reading journal articles and taking notes from them. Comprehension is paramount. You will most likely need to read it several times, so set aside enough time in your schedule.

Contents:

Knowledge Gaps:

This list provides a brief overview of the major knowledge gaps for this project, how they were resolved and where to find the information.

Knowledge Gap	Resolved By	Information is located	Date resolved
Current Carbon Capture Technologies	Reading article about Current Progress on Carbon Capture	https://www.sciencedirect.com/science/article/pii/S0048969720367346	9/28/2025
Current most effective CC	Reading a review paper global Carbon capture use	https://www.proquest.com/pq1sustainability/docview/3180988994/8761899E96BE48BBPQ/7?accountid=29120&sourcetype=Conference%20Papers%20&%20Proceedings	9/28/2025
Current cheapest CC	Reading a review paper global Carbon capture use	https://www.proquest.com/pq1sustainability/docview/3180988994/8761899E96BE48BBPQ/7?accountid=29120&sourcetype=Conference%20Papers%20&%20Proceedings	9/28/2025

Literature Search Parameters:

These searches were performed between 9/1/2025 and XX/XX/2026.
List of keywords and databases used during this project.

Database/search engine	**Keywords**	**Summary of search**
Environmental Science Database	Carbon Capture	Searched for articles and papers relating to Carbon Capture technology.
Nature	Carbon Capture + Renewable Energy	Articles relating to CC in combination with RE, specifically Article #1.
Environmental Science Database + Nature + Engineering Village	Carbon Capture + Drone	I couldn't find any experiments done about combining carbon capture technology into a mobile drone.

Tags:

Tag Name	

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Article #0 Notes: Title

Article notes should be on separate sheets

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Source Title	
Source citation (APA Format)	
Original URL	
Source type	
Keywords	
#Tags	
Summary of key points + notes (include methodology)	
Research Question/Problem/ Need	
Important Figures	
VOCAB: (w/definition)	
Cited references to follow up on	
Follow up Questions	

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Article #1 Notes: Low carbon optimization for wind integrated power systems with carbon capture and energy storage under carbon pricing *Formal Article*

Article notes should be on separate sheets

Source Title	Low carbon optimization for wind integrated power systems with carbon capture and energy storage under carbon pricing
Source citation (APA Format)	Meng, Q., He, Y., Hussain, S., Lu, J., & Guerrero, J. M. (2025). Low carbon optimization for wind integrated power systems with carbon capture and energy storage under carbon pricing. *Scientific Reports*, *15*(1), 32714. https://doi.org/10.1038/s41598-025-17463-7
Original URL	https://doi.org/10.1038/s41598-025-17463-7
Source type	Scientific Article
Keywords	Wind Power; Carbon Capture; Pre-Combustion; Post-Combustion; Energy Storage System; Cost efficiency
#Tags	#System #Model

Summary of key points + notes (include methodology)	• Wind power enables low-carbon energy transition
	• Model evaluates impact of CC prices on energy storage & unit power supply costs under high winds
	• Increased wind power capacity = cheaper cost of electricity, and improves stability with energy storage
	
	• Wind power plays a critical role in “decarbonizing electricity generation”
	• Current wind power utilization is unreliable and unstable
	• Because wind power isn’t constantly available, energy is wasted, and we instead rely on fossil fuels.
	  ○ Energy Storage Systems mitigate these negative effects
	  ○ However, ESS are costly and not easy to use at large volumes
	• Combine CCS and ESS to control carbon emissions, and optimize storage utilization & renewable penetration
	  ○ However, current models don’t do this.
	• Optimization of wind energy systems is currently done by analyzing wind patterns and attempting to adjust, but these are still limited:
	  ○ Isolate economic or stability goals
	  ○ Limited consideration of carbon pricing impacting mechanisms.
	  ○ GAs are also insufficient
	• Critical gap = lack of models that unify CCS, ESS and wind power

- Current frameworks don’t quantify how CC prices influence storage or power generation costs.
- The study proposes a model that includes wind power, CCS, and ESS within a unified “optimization framework”.
  - CCS & ESS work together to optimize CC charging cycles, saving 22% more power.
  - Links carbon prices to optimal ESS capacity reavling nonlinear cost-emission trade-offs.
  - Improved GA (an algorithm that solves for the best possible solution) has a 98% convergence (point at best solution) reliability
- Increasing wind power usage from 30 to 50% reduces electricity costs by 19% while ESS is deployed at 127MWh at carbon price of 100 CNY per ton, producing 75 MW power output
  - This is one optimal design the researchers came up with using their model, that when carbon price is 100CNY, the most cost-effective low-carbon way to tun the model is to build a system that stores 127 MWh (ESS), which will then deliver 75 MW of power, and reduce costs by 19%.
- Quantifying carbon price creates actionable insights
- Improved GA allows for function on a larger scale.
- CCS + ESS combination creates a good framework for targeting net-zero emissions.

Section 2

- Low-carbon optimization model for power systems with high wind power usage.
  - Incorporates CC to reduce carbon emissions and enhance WP generation
  - Analyzes carbon capture costs and all other costs (operating, investment, etc.) to find optimal allocation of energy storage.
  - Uses arithmetic examples and an improved GA to solve
- Through all of this, the model derives the optimal capacity allocation.

- Post-combustion decarbonization proved to be the most efficient at a relatively low cost, so that is what is used in the model.
- Used to find power used by CC device. (P=input power, P_{co2}=energy consumed by CC device):

$$P = P_{co_2} + P_e$$

$$P_{co_2} = P_{run} + P_s$$

  -

- Used to find power output of wind turbines. (P_wv=output power of fan, P_r=rated power of fan)

$$P_w(v) = \begin{cases} 0, v < v_{in} or v > v_{in} \\ P_r \dfrac{v - v_{in}}{v_r - v_{in}}, v_{in} \leqslant v \leqslant v_r \\ P_r, v_r \leqslant v \leqslant v_{out} \end{cases}$$

$$P_r = \frac{1}{2}\pi r^2 \rho v^3 C_p$$

    ○

- Power used by Thermal Power units (F_it = Coal consumption, $P_{Gi.down}$ = Lower limit of creepage rate of thermal unit, U_{Gi}t = Status marker of Thermal unit)

$$F_i(t) = a_i P_{Gi}^2(t) + b_i P_{Gi}(t) + c_i$$

    ○

$$U_{Gi}(t)P_{Gi.\min} \leqslant P_{Gi}(t) \leqslant U_{Gi}(t)P_{Gi.\max}$$

$$P_{Gi.down} \leqslant P_{Gi}(t) - P_{Gi}(t-1) \leqslant P_{Gi.up}$$

    ○

- Charge and discharge of battery

$$U_{bt.ch}(t)P_{bt.ch.\min} \leqslant P_{bt.ch}(t) \leqslant U_{bt.ch}(t)P_{bt.ch.\max}$$
$$U_{bt.dis}(t)P_{bt.dis.\min} \leqslant P_{bt.dis}(t) \leqslant U_{bt.dis}(t)P_{bt.dis.\max}$$

    ○

- Load state constraints (must meet these electrical demands)

$$SOC_{bt}(t) = SOC_{bt}(t-1) + (\eta_{bt.ch}P_{bt.ch}(t) - P_{bt.dis}(t)/\eta_{bt.dis})\Delta t$$
$$SOC_{bt}^{\min} \leqslant SOC_{bt}(t) \leqslant SOC_{bt}^{\max}$$

    ○

- Battery degradation and life-cycle considerations are excluded. Integrating these to assess long-term economics is good ground for future work.

Section 3

- Function representing model's goal of minimizing cost of supplying electricity

- C = System unit cost of Supplying electricity
- C_f = System unit cost of electricity supply
- P_L = Total System Load

$$\min C = \frac{C_F}{P_L}$$

$$C_F = C_h + C_{cb} + C_{wind} + C_b + C_{qw} + C_{loss}$$

$$C_h = \sum_{t=1}^{24}\sum_{i=1}^{N} k_f U_{Gi}(t) F_i(t)$$

$$C_{cb} = \sum_{t=1}^{24}\sum_{i=1}^{N} dv_i F_i(t)$$

$$C_{wind} = \sum_{t=1}^{24} k_w P_w(t)$$

$$C_{bt} = \sum_{t=1}^{24} \left(k_e P_{bt}(t) + k_p E_{bt}(t)\right)$$

$$C_{qw} = \sum_{t=1}^{24} k_{qw} \left(P_w^{pre}(t) - P_w(t)\right)$$

$$C_{loss\_load} = \sum_{t=1}^{24} k_{ql} \left(\sum_{i=1}^{N} P_{Gi}(t) + P_w(t) - P_l(t)\right)$$

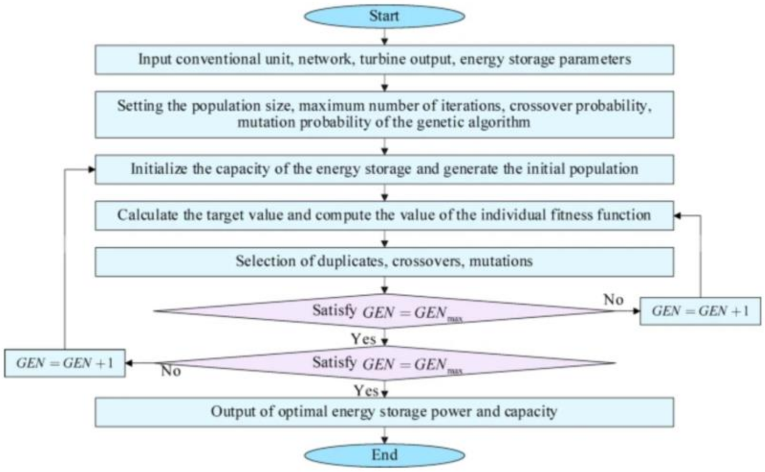
<u>Section 4</u>

- The GA is an algorithm that emulates natural selection, in which the best traits are selected, crossed over, and mutated until the algorithm's completion (when it determines the optimal outcome)
- Improved GA incorporates adaptive functions to address changing probability of crossover (P_c) and probability of mutation (P_m)gt

  - This makes the algorithm automatically adjust how much it explores (tries new solutions) and how much it exploits (refines old solutions) based on findings of each step.
  - Explained by the expressions:

$$p_c = \begin{cases} k_1 \dfrac{f\text{max} - f'}{f\text{max} - f_{avg}}, f' \geqslant f_{avg} \\ k_2, f' < f_{avg} \end{cases}$$

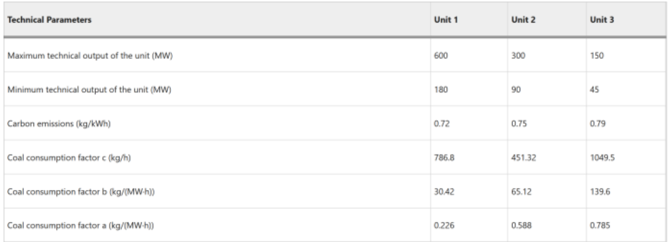
$$p_m = \begin{cases} k_3 \dfrac{f\text{max} - f'}{f\text{max} - f_{avg}}, f' \geqslant f_{avg} \\ k_4, f' < f_{avg} \end{cases}$$



- The flow chart of an improved GA algorithm.

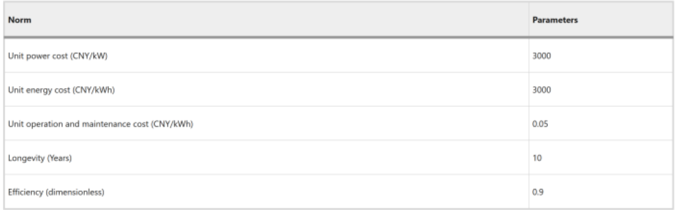
Section 5 **(Testing)**

- To test, a system configuration is established:
  - 3 thermal power units
  - One wind power unit
  - One carbon capture device
  - Coal/Carbon price is 700 CNY per ton
  - Cost per unit of wind power electricity is 0.045 CNY per kWh
  - Wind abandonment = 0.3 CNY/kWh
  - Load abandonment = 8 CNY/kWh
- By using the given configurations and data, they evaluated parameters of the model:
  - Parameters relating to a Thermal Power Unit



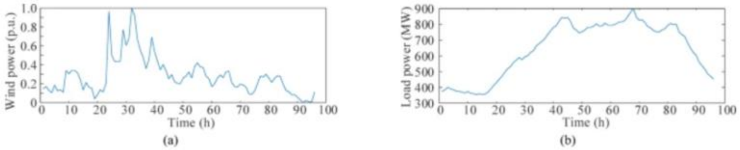
Technical Parameters	Unit 1	Unit 2	Unit 3
Maximum technical output of the unit (MW)	600	300	150
Minimum technical output of the unit (MW)	180	90	45
Carbon emissions (kg/kWh)	0.72	0.75	0.79
Coal consumption factor c (kg/h)	786.8	451.32	1049.5
Coal consumption factor b (kg/(MW·h))	30.42	65.12	139.6
Coal consumption factor a (kg/(MW·h))	0.226	0.588	0.785

- Parameters relating to Energy Storage



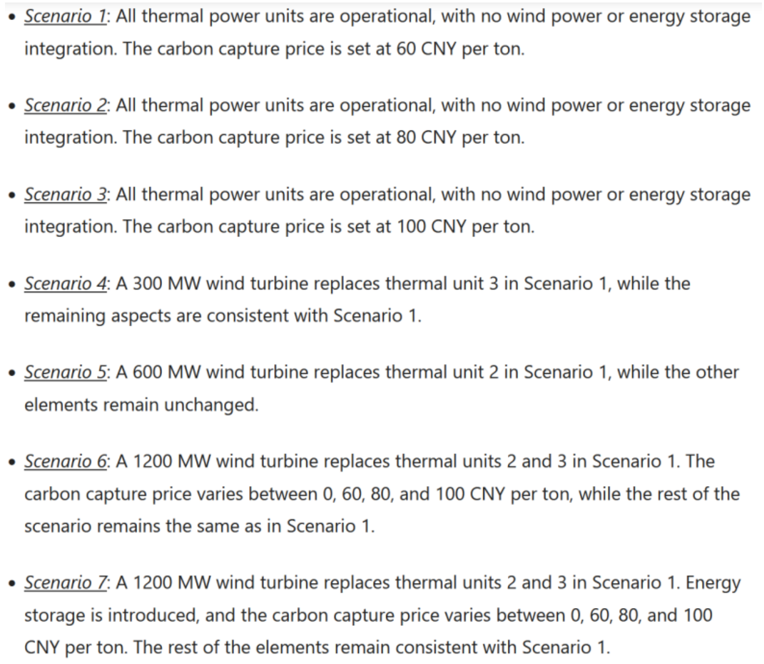
Norm	Parameters
Unit power cost (CNY/kW)	3000
Unit energy cost (CNY/kWh)	3000
Unit operation and maintenance cost (CNY/kWh)	0.05
Longevity (Years)	10
Efficiency (dimensionless)	0.9

- Wind Power + Load Power



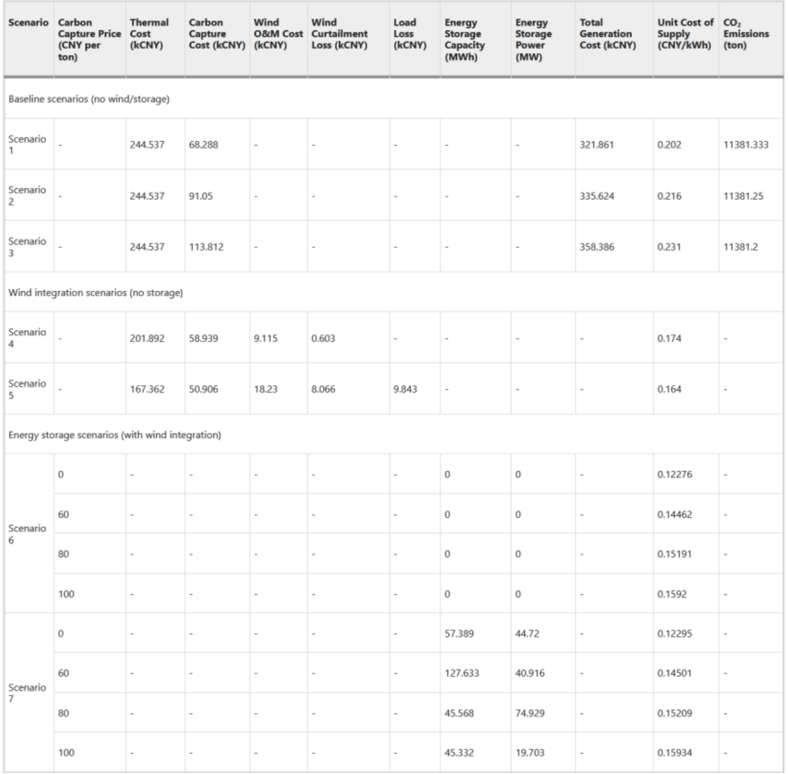
- From here they could use this data in their model equation to solve System unit cost of supplying electricity, but they did not.

- To then evaluate the impact of carbon pricing, wind power use, and energy storage integration respectively, the authors created 7 different scenarios to test:



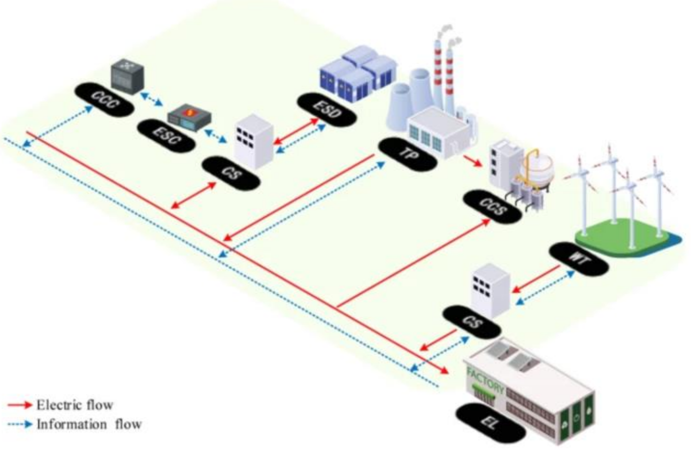
- *Scenario 1*: All thermal power units are operational, with no wind power or energy storage integration. The carbon capture price is set at 60 CNY per ton.
- *Scenario 2*: All thermal power units are operational, with no wind power or energy storage integration. The carbon capture price is set at 80 CNY per ton.
- *Scenario 3*: All thermal power units are operational, with no wind power or energy storage integration. The carbon capture price is set at 100 CNY per ton.
- *Scenario 4*: A 300 MW wind turbine replaces thermal unit 3 in Scenario 1, while the remaining aspects are consistent with Scenario 1.
- *Scenario 5*: A 600 MW wind turbine replaces thermal unit 2 in Scenario 1, while the other elements remain unchanged.
- *Scenario 6*: A 1200 MW wind turbine replaces thermal units 2 and 3 in Scenario 1. The carbon capture price varies between 0, 60, 80, and 100 CNY per ton, while the rest of the scenario remains the same as in Scenario 1.
- *Scenario 7*: A 1200 MW wind turbine replaces thermal units 2 and 3 in Scenario 1. Energy storage is introduced, and the carbon capture price varies between 0, 60, 80, and 100 CNY per ton. The rest of the elements remain consistent with Scenario 1.

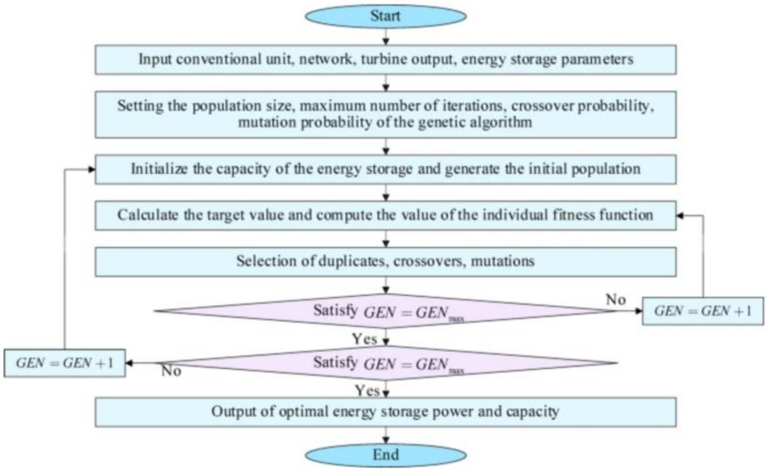
- Impact of different CC prices



Scenario	Carbon Capture Price (CNY per ton)	Thermal Cost (kCNY)	Carbon Capture Cost (kCNY)	Wind O&M Cost (kCNY)	Wind Curtailment Loss (kCNY)	Load Loss (kCNY)	Energy Storage Capacity (MWh)	Energy Storage Power (MW)	Total Generation Cost (kCNY)	Unit Cost of Supply (CNY/kWh)	CO_2 Emissions (ton)
Baseline scenarios (no wind/storage)											
Scenario 1	-	244.537	68.288	-	-	-	-	-	321.861	0.202	11381.333
Scenario 2	-	244.537	91.05	-	-	-	-	-	335.624	0.216	11381.25
Scenario 3	-	244.537	113.812	-	-	-	-	-	358.386	0.231	11381.2
Wind integration scenarios (no storage)											
Scenario 4	-	201.892	58.939	9.115	0.603	-	-	-	-	0.174	-
Scenario 5	-	167.362	50.906	18.23	8.066	9.843	-	-	-	0.164	-
Energy storage scenarios (with wind integration)											
Scenario 6	0	-	-	-	-	-	0	0	-	0.12276	-
	60	-	-	-	-	-	0	0	-	0.14462	-
	80	-	-	-	-	-	0	0	-	0.15191	-
	100	-	-	-	-	-	0	0	-	0.1592	-
Scenario 7	0	-	-	-	-	-	57.389	44.72	-	0.12295	-
	60	-	-	-	-	-	127.633	40.916	-	0.14501	-
	80	-	-	-	-	-	45.568	74.929	-	0.15209	-
	100	-	-	-	-	-	45.332	19.703	-	0.15934	-

- As CC price increases
    - unit power supply cost increases
    - Total CC cost increases
    - Total power generation cost increases
    - CO_2 emissions decrease
    - Cost of Thermal power stays the same
    - Rises in carbon capture price create a system with positive outcomes for energy conservation and emission reduction, but negative outcomes for cost reduction.
- Increased wind power integration =
    - Cost of thermal power decreases
    - Total CC cost decreases
    - Unit power supply cost decreases
    - Increased wind power integration lowers costs and is more environmentally friendly, leading to a more sustainable energy system. However input and output powers in the system must stay relatively balanced, so increasing wind power too much will cause instability in power supply. (more output than in)
- Impact of Energy Storage
    - Balances out power fluctuations caused by wind power integration, making it more stable and reliable
    - Adds no significant cost increase to unit power supply and is therefore very economically feasible.
    - As CC prices rise, Energy storage is utilized more heavily to reduce high-emission thermal unit use.

	Section 6 • Successfully developed a “low-carbon optimal scheduling model” that integrated wind power, aiming for energy sustainability, carbon emission reduction, and cost efficiency. • Key Findings: ○ Wind power decreased costs significantly while maintaining a balanced system with the assistance of ESS. ○ Increasing CC price led to higher total costs but also reduced CO_2 emissions. Showing the trade-off between cost and environmental benefits. ○ Energy Storage Systems enabled the system to use more wind power and be more economically efficient. • The model will also work under wind deviations or price spikes, due to the adjustable factors included in the model. • The model showed the importance of a balanced approach involving wind power, carbon capture, and energy storage technologies to create a low-carbon, stable, and cost-effective system. • Future Work: ○ Use stochastic programming (optimizing a solution to fit multiple outcomes) to quantify the results ○ Incorporate different Renewable Energy, or possibly multiple simultaneously. ○ Update with new Carbon Capture technology?
Research Question/Problem/ Need	Develop a model for optimizing low-carbon levels incorporating post-combustion CC technology, energy storage and an improved GA to optimize efficiently.
Important Figures	• Shows all parts involved in the System:  ○

	 The flow chart of an improved GA algorithm.
VOCAB: (w/definition)	• GA ○ Genetic Algorithm • ESS ○ Energy Storage System • CAES ○ Compressed Air Energy Storage • CCS ○ Carbon Capture and Storage • WGANs ○ Wasserstein Generative Adversarial Networks • MWh ○ Megawatt per hour • kWh ○ Kilowatt per hour • CNY ○ The carbon price that is paid for every ton of carbon dioxide released into the atmosphere.
Cited references to follow up on	Østergaard, P. A., Duic, N., Noorollahi, Y., & Kalogirou, S. (2022). Renewable energy for sustainable development. *Renewable Energy*, *199*, 1145–1152. https://doi.org/10.1016/j.renene.2022.09.065 Østergaard, P. A., Duic, N., Noorollahi, Y., & Kalogirou, S. (2023). Advances in renewable energy for sustainable development. *Renewable Energy*, *219*, 119377. https://doi.org/10.1016/j.renene.2023.119377
Follow up Questions	• How will the model change when incorporating other renewable energy sources? • Could multiple renewable energy sources be combined? • What about multiple Energy Storage Units?

Article #2 Notes: Progress in carbon capture technologies

Article notes should be on separate sheets

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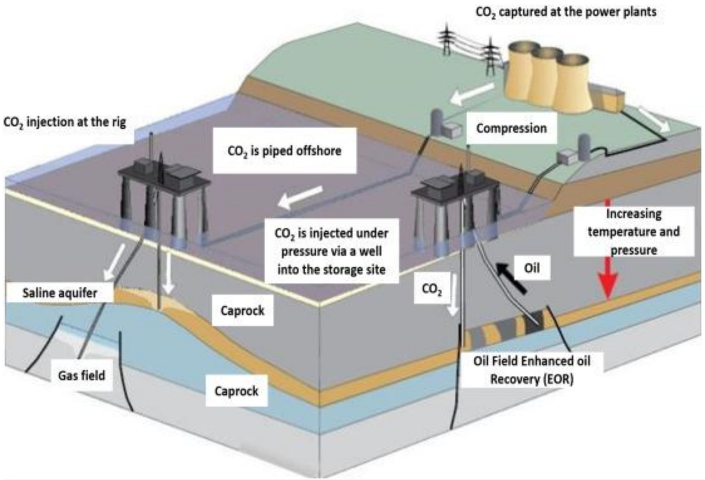
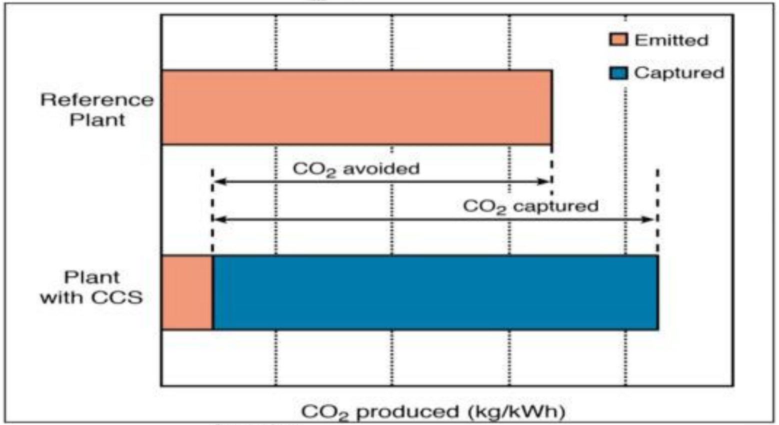
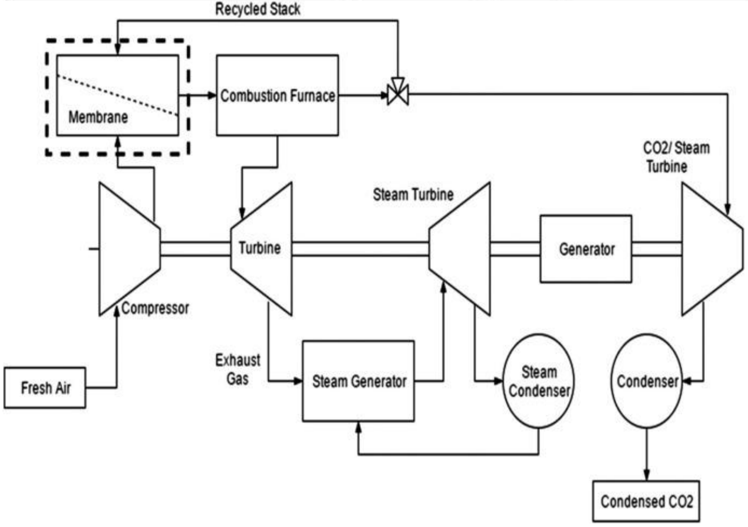
Source Title	Progress in carbon capture technologies
Source citation (APA Format)	Wilberforce, T., Olabi, A. G., Sayed, E. T., Elsaid, K., & Abdelkareem, M. A. (2021). Progress in carbon capture technologies. *Science of The Total Environment*, *761*, 143203. https://doi.org/10.1016/j.scitotenv.2020.143203
Original URL	https://doi.org/10.1016/j.scitotenv.2020.143203
Source type	Scientific Article
Keywords	Carbon Capture; Combustion; Transportation; Diffusion
#Tags	#Current Progress
Summary of key points + notes (include methodology)	Human-related factors are the key contributors to carbon dioxide emissions. Carbon Capture and storage are reliable tools that can address this global challenge CCS is the separation of CO2 to a regulated location for ideal storage. We continue to rely on fossil energy and therefore CCS is critical. Most CCS technologies can absorb 85-95% of CO2, but at the cost of 10-40% more energy. The use and advancement of CCS is limited by the cost and energy required to utilize it.
Research Question/Problem/ Need	What current Carbon Capture technologies are available, and what are the advantages & disadvantages of each?

Important Figures	  
VOCAB: (w/definition)	• CCS ○ Carbon Capture & Storage • PSA ○ Pressure Swig Absorber • WGS ○ Water Gas Shift

	• MOF ○ Metal Organic Framework
Cited references to follow up on	Abdelkareem, M. A., El Haj Assad, M., Sayed, E. T., & Soudan, B. (2018). Recent progress in the use of renewable energy sources to power water desalination plants. *Desalination*, *435*, 97–113. https://doi.org/10.1016/j.desal.2017.11.018 Abdelkareem, M. A., Elsaid, K., Wilberforce, T., Kamil, M., Sayed, E. T., & Olabi, A. (2021). Environmental aspects of fuel cells: A review. *Science of The Total Environment*, *752*, 141803. https://doi.org/10.1016/j.scitotenv.2020.141803
Follow up Questions	• Where is Carbon Capture Technology now? • What is the cheapest Carbon Capture Technology? • What is the most effective Carbon Capture Technology?

Article #3 Notes: Carbon capture technology to produce clean fuel from air

Article notes should be on separate sheets

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Source Title	Carbon capture technology to produce clean fuel from air
Source citation (APA Format)	University of Surrey. (2025, April 3). Carbon capture technology to produce clean fuel from air. *ScienceDaily*. Retrieved October 9, 2025, from www.sciencedaily.com/releases/2025/04/250403122938.htm
Original URL	https://www.sciencedaily.com/releases/2025/04/250403122938.htm
Source type	Science Journal
Keywords	Carbon Capture; DFM; DAC; Synthetic Fuel
#Tags	#Synthetic Fuel
Summary of key points + notes (include methodology)	• Unique carbon capture technology offers a more cost-effective way to turn CO2 from the air into clean synthetic fuel.

	• Dual-Function Material is a process that combines carbon capture and conversion. It uses green hydrogen from renewable electricity and carbon from the atmosphere to create fuel. This fuel could allow industries to effectively have zero net emissions. • DFM is capable of removing carbon at a cost of below $400 per ton, but currently operates at $740 per ton. DFM holds promise for future large-scale deployment.
Research Question/Problem/ Need	Current Carbon Capture technologies are too expensive and offer little in the way of converting it back into clean usable energy.
Important Figures	None given
VOCAB: (w/definition)	• DFM ○ Dual-Function Material • DAC ○ Direct Air Capture • Superstructure optimization ○ An advanced modeling technique
Cited references to follow up on	Meshkat Dolat, Kamran Keynejad, Melis S. Duyar, Michael Short. Superstructure optimization of direct air capture integrated with synthetic natural gas production. *Applied Energy*, 2025; 384: 125413 DOI: 10.1016/j.apenergy.2025.125413
Follow up Questions	• Are there other energy sources that would function with this process? Maybe solar or wind energy?

Article #4 Notes: Carbon Capture Marches Toward Practical Use

Article notes should be on separate sheets

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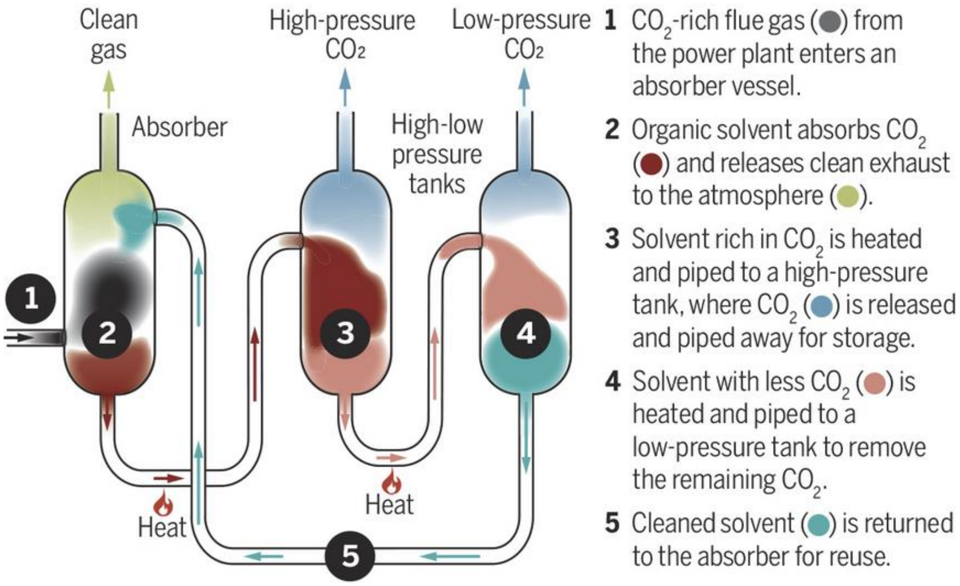
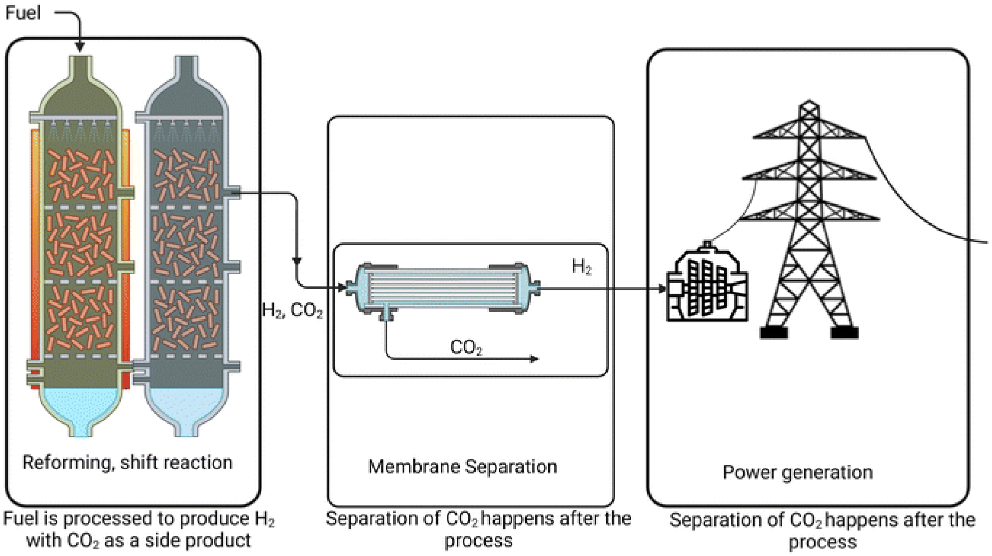
Source Title	Carbon Capture Marches Toward Practical USe
Source citation (APA Format)	Service, R. F. (2021). Carbon capture marches toward practical use. *Science*, *371*(6536), 1300–1300. https://doi.org/10.1126/science.371.6536.1300
Original URL	https://doi.org/10.1126/science.371.6536.1300
Source type	Science Article
Keywords	Amines; Molecules; Carbon Capture; Organic Water Solvent
#Tags	#Amines #Water Solvent
Summary of key points + notes (include methodology)	Carbon Capture is necessary to “Stave off the worst of Climate Change” Most popular form of carbon capture is too expensive New chemical CO2 trap reduces cost by 20% Nearing Commercial Viability Amines dissolved in water grab CO2 in the air, but must be boiled and recondensed to reuse (increasing energy and cost) In order to increase to necessary levels, carbon capture must drop from $58 per ton collected, to $30 per ton. PPNL created liquid organic solvents, containing CO2 grabbing amines with no need to be boiled or recondensed. Unsuccessful at first, so they tweaked it creating a molecule called 2-EEMPA which worked much better. 2-EEMPA requires %17 less energy and dropped the cost to $47 per ton.

	2-EEMPA has inspired other researchers to make their own solvents, and has garnered support from the government ($4.9 billion for carbon capture projects!)
Research Question/Problem/ Need	Create a more efficient organic water solvent for Carbon Capture to save energy and money.
Important Figures	 **1** CO_2-rich flue gas (●) from the power plant enters an absorber vessel. **2** Organic solvent absorbs CO_2 (●) and releases clean exhaust to the atmosphere (●). **3** Solvent rich in CO_2 is heated and piped to a high-pressure tank, where CO_2 (●) is released and piped away for storage. **4** Solvent with less CO_2 (●) is heated and piped to a low-pressure tank to remove the remaining CO_2. **5** Cleaned solvent (●) is returned to the absorber for reuse.
VOCAB: (w/definition)	- 2-EEMPA ○ Name of solvent created by authors
Cited references to follow up on	Gensheng Li, Jinsheng Sun, Zhangxin Chen, Zhenhua Rui. Editorial for the Special Issue on Carbon Capture, Utilization, and Storage. *Engineering*, 2025, 48(5): 1-2 DOI:10.1016/j.eng.2025.04.004
Follow up Questions	In what ways could this solvent be improved? How long/what will it take to make this commercially viable?

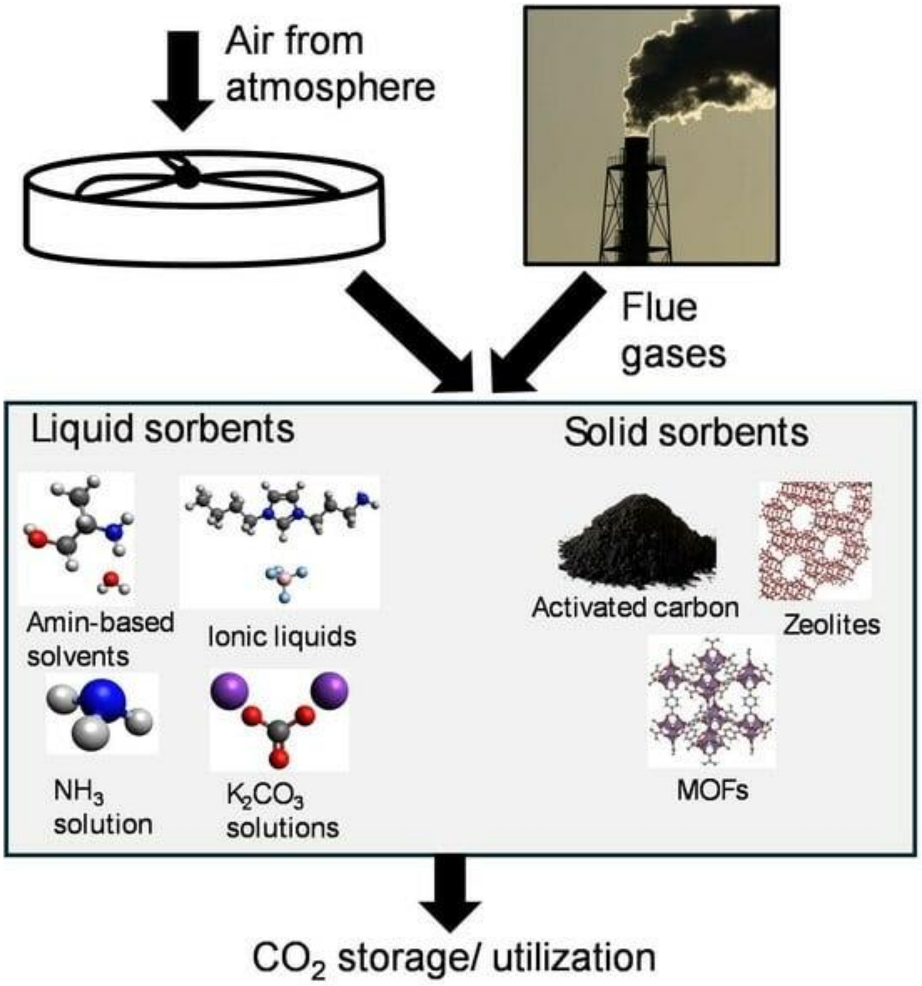
Article #5 Notes: Polymeric membranes in carbon capture, utilization, and storage: current trends and future directions in decarbonization of industrial flue gas and climate change mitigation

Source Title	Polymeric membranes in carbon capture, utilization, and storage: current trends and future directions in decarbonization of industrial flue gas and climate change mitigation
Source citation (APA Format)	Mollahosseini, A., Nikkhah Dafchahi, M., Khoshhal Salestan, S., Chew, J. W., Mozafari, M., Soroush, M., Hrapovic, S., Hemraz, U. D., Giro, R., Steiner, M. B., La, Y.-H., Seyedpour Taji, S. F., Azyat, K., Islam, M. A., Kavyani, S., Wang, X., Cho, J.-Y., & Sadrzadeh, M. (2025). Polymeric membranes in carbon capture, utilization, and storage: Current trends and future directions in decarbonization of industrial flue gas and climate change mitigation. *Energy & Environmental Science*, *18*(11), 5025–5092. https://doi.org/10.1039/D4EE05328A
Original URL	https://doi.org/10.1039/D4EE05328A
Source type	Scientific Article
Keywords	polymeric membranes; flue gas; CO_2/N_2 separation; process simulation; carbon utilization; computational design
#Tags	#Membranes #FlueGas
Summary of key points + notes (include methodology)	This review surveys recent advances in polymeric membranes designed for carbon capture from industrial flue gas streams. It covers materials, membrane module design, separation performance (e.g. permeance and selectivity), stability, and integration with broader CCUS (Carbon Capture, Utilization, and Storage) systems. The paper emphasizes the role of computational methods—including AI—to accelerate materials discovery, structure-performance prediction, and optimization of membrane-modifier combinations. It discusses challenges: dealing with impurities in flue gas (SOx, NOx, moisture), tradeoff between permeability (how much CO_2 gets through quickly) and selectivity (how pure that separated CO_2 stream is), and membrane long-term stability (mechanical, thermal).

	Methodologically, the review draws from lab experiments, pilot-scale tests, process simulations, and techno-economic comparisons across membrane technologies.
Research Question/Problem/ Need	How can polymeric membrane technologies be improved (in materials, module design, and integration) to reach high performance, long durability, and economic viability for capturing CO_2 from industrial flue gas under real operating conditions?
Important Figures	
VOCAB: (w/definition)	• **Permeance** — measure of how much gas passes through a membrane per unit time, area, and pressure difference. • **Selectivity** — ratio of how well a membrane separates CO_2 relative to another gas (often N_2 in flue gas). • **Membrane module** — the hardware setup of membrane sheets or fibers, housing, flow channels, etc., through which gas passes. • **Computational materials design** — using simulations, AI, and modelling to predict how material structure and composition will affect performance, so fewer trial-and-error lab tests are needed.
Cited references to follow up on	• Studies of pilot-scale polymeric membrane modules under real flue gas conditions (with impurities) to assess durability.
Follow up Questions	• What other impurities in flue gas are apparent?

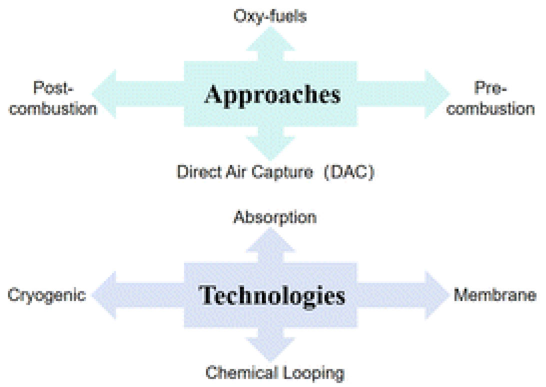
Article #6 Notes: A Review of Materials for Carbon Dioxide Capture

Source Title	A Review of Materials for Carbon Dioxide Capture
Source citation (APA Format)	School for Engineering of Matter, Transport, and Energy, Arizona State University. (2025). *A Review of Materials for Carbon Dioxide Capture.* Catalysts, 15(3), 273. https://doi.org/10.3390/catal15030273
Original URL	https://doi.org/10.3390/catal15030273
Source type	Review Article
Keywords	CO_2 capture; sorbents; materials design; adsorption; industrial applications
#Tags	#Materials #Sorbents #CO2Capture
Summary of key points + notes (include methodology)	The article surveys recent advancements in materials used for CO_2 capture, including adsorbents, membranes, and hybrid systems. It describes performance metrics (capacity, selectivity, regeneration energy) and highlights gaps in scalability and durability of many lab-scale materials. Methodology: meta-analysis of published performance data, classification of materials by type and capture scenario (post-combustion, pre-combustion, direct air capture). The review identifies key research directions: reducing regeneration energy, improving cycle stability, and bridging lab performance to real-world conditions (impurities, moisture, large scale).
Research Question/Problem/ Need	Which next-generation sorbent or material systems can both achieve high capture performance and meet practical durability, cost, and operational conditions for industrial CO_2 capture?

Important Figures	
VOCAB: (w/definition)	Regeneration energy — the energy required to restore a sorbent to its original state so it can capture CO_2 again. Selectivity — the ability of a material to preferentially capture CO_2 over other gases (e.g., N_2 in flue gas).
Cited references to follow up on	Zhu, Q., & Wang, X. (2024). Durable adsorbents for carbon capture: bridging lab and industry. *Journal of CO_2 Utilization*, 60, 102056. https://doi.org/10.1016/j.jcou.2024.102056
Follow up Questions	What are the main degradation mechanisms for high-capacity sorbents when exposed to real flue-gas impurities over thousands of cycles? How do the energy penalties of different material regeneration methods compare when scaled to a full-scale industrial CO_2 capture plant? What cost thresholds ($/ton CO_2 captured) must next-generation materials meet to be commercially viable in major industries like cement or steel?

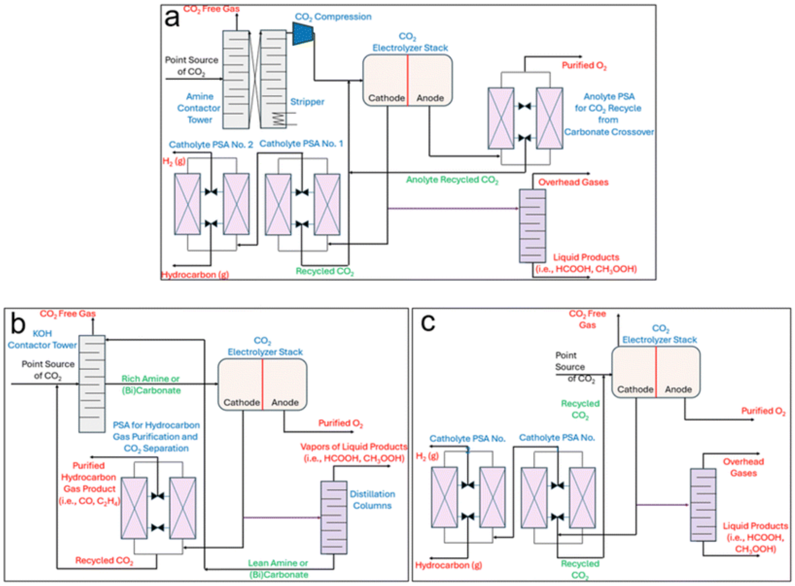
Article #7 Notes: Recent advancements in carbon capture materials research: Innovative optimization of materials synthesis and engineering applications

Source Title	Recent advancements in carbon capture materials research: Innovative optimization of materials synthesis and engineering applications
Source citation (APA Format)	Wang, Y., Gao, F., Niu, Y., Chen, K., Yi, H., Zhang, J., Zhou, Y., Tang, X., & Zhao, S. (2025). Recent advancements in carbon capture materials research: Innovative optimization of materials synthesis and engineering applications. *Journal of Materials Chemistry A*, 13, 23323-23353. https://doi.org/10.1039/D5TA01304F
Original URL	https://doi.org/10.1039/D5TA01304F
Source type	Review Article
Keywords	MOFs; porous polymers; adsorbent engineering; material synthesis; scale-up
#Tags	#MOFs #Adsorbents
Summary of key points + notes (include methodology)	This review focuses on material-level innovations: metal–organic frameworks (MOFs), porous organic polymers (POPs), functional carbon-based adsorbents, and composites engineered for CO_2 capture under realistic conditions. It emphasizes structural optimization (pore size, surface chemistry), advanced synthesis methods (microwave, solvent-free, templating), and engineering applications (module design, process embedding). Methodology: systematic survey of literature between circa 2022-2025, classification of advancements by material type and performance improvements, highlighting “engineering readiness”. Challenges noted: cost of synthesis, reproducibility, integration into modules, and moving from bench to pilot scale.
Research Question/Problem/ Need	How can advanced materials (MOFs, POPs, composites) be synthesized and engineered in ways that maintain high performance while being cost-effective and scalable for industrial CO_2 capture?

Important Figures	
VOCAB: (w/definition)	MOFs — Metal–Organic Frameworks: a type of porous crystalline material constructed from metal nodes and organic linkers, with high surface area and tunable chemistry. POPs — Porous Organic Polymers: amorphous polymeric materials with controlled porosity used for gas adsorption.
Cited references to follow up on	Smith, A. J., & Lee, M. (2023). Cost modeling of MOF synthesis for carbon capture applications. ACS Applied Materials & Interfaces, 15(4), 2345-2357. https://doi.org/10.1021/acsami.2c10382 Chen, Y., et al. (2024). Scale-up and module-integration of porous polymer adsorbents: from lab to pilot. Industrial & Engineering Chemistry Research, 63(12), 4489-4503. https://doi.org/10.1021/ie403345h
Follow up Questions	What synthesis methods show the most promise for reducing cost of advanced adsorbents while retaining high CO_2 capture performance? How does the performance of material modules (not just powders) degrade when exposed to real-world flue gas (moisture, SO_x, NO_x) over time? What are the key bottlenecks in bundling advanced adsorbent materials into full-scale capture systems (including system engineering, lifetime, maintenance)?

Article #8 Notes: A critical appraisal of advances in integrated CO_2 capture and electrochemical conversion

Source Title	A critical appraisal of advances in integrated CO_2 capture and electrochemical conversion
Source citation (APA Format)	Badreldin, A., & Li, Y. (2025). A critical appraisal of advances in integrated CO_2

	capture and electrochemical conversion. Chemical Science, 16, 2483-2513. https://doi.org/10.1039/D4SC06642A
Original URL	https://pubs.rsc.org/en/content/articlelanding/2025/sc/d4sc06642a
Source type	Scientific Article
Keywords	Electrochemical CO_2 capture; reactive capture; adsorptive capture; conversion to value-added products
#Tags	#ElectrochemicalCCS #Conversion #ReactiveCapture
Summary of key points + notes (include methodology)	The paper examines integrated processes where CO_2 capture and conversion are combined (rather than separate). Two routes: (1) electrochemical reactive capture (e.g., amine/bicarbonate mediated) and (2) adsorptive capture & conversion (ACC) from flue gas. The authors highlight key technological metrics (energy input per mole CO_2, Faradaic efficiencies, catalyst durability) and compare these to conventional sequential capture + conversion systems. Methodology: review of recent literature (2020-2024), benchmarking performance of emerging systems, identifying techno-economic and scaling challenges (materials, system integration). The article points to major gaps: system stability, separation of product and CO_2 stream purity, realistic cost modelling and lifecycle assessment.
Research Question/Problem/ Need	How can integrated capture-and-conversion systems be engineered to reduce overall energy and cost penalties and achieve commercial readiness, while maintaining durability and product quality?
Important Figures	

VOCAB: (w/definition)	Faradaic efficiency — fraction of electric charge that accomplishes the desired chemical reaction (here CO_2 reduction) rather than side reactions. Reactive capture — process where CO_2 is captured and immediately converted in one step or tightly coupled step, reducing intermediate handling.
Cited references to follow up on	Wang, H., & Zhang, S. (2023). Integrated capture and electrochemical conversion of CO_2: system modelling and optimization. Energy & Environmental Science, 16(11), 5496-5512. https://doi.org/10.1039/D3EE02060
Follow up Questions	Which capture + conversion pathway (eRCC or ACC) offers the lowest projected cost per tonne of CO_2 removed and useful product generated? What are the key durability and maintenance issues in integrated capture-conversion cells under industrial flue-gas conditions? How realistic are current techno-economic projections for value-added product generation from captured CO_2 (e.g., fuels, chemicals) at scale?

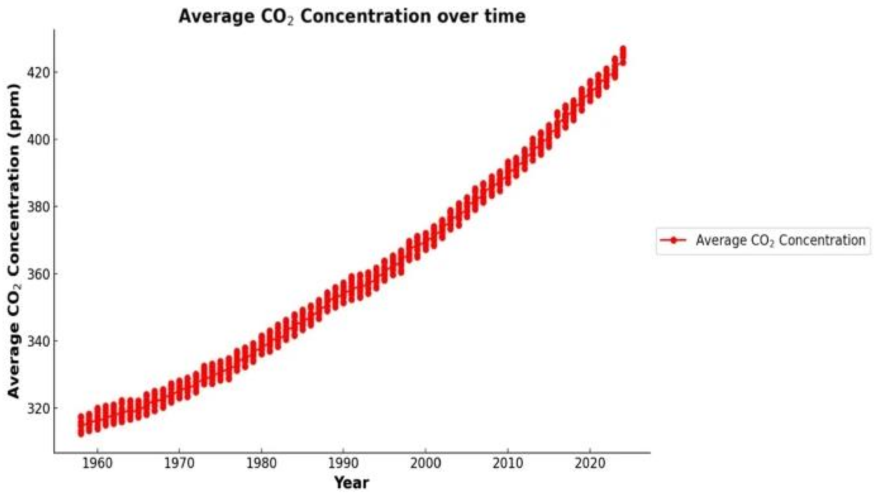
Article #9 Notes: Carbon Capture by Biological Methods

Source Title	Carbon Capture by Biological Methods
Source citation (APA Format)	Fu, W., Liu, Y., & et al. (2025). Carbon capture by biological methods. Cambridge Prisms: Carbon Technologies, 1, e5. https://doi.org/10.1017/cat.2025.10005
Original URL	https://www.cambridge.org/core/journals/cambridge-prisms-carbon-technologies/article/carbon-capture-by-biological-methods/2F7142CC35A605AC298301253E437F26
Source type	Review Article
Keywords	Bio-capture; algae; microorganisms; biofilm; carbon uptake
#Tags	#BiologicalCCS #BioCapture #Microorganisms
Summary of key points + notes (include methodology)	This review covers carbon capture via biological methods: plants, algae, microbes, biofilms, and their potential role in industrial CO_2 capture and utilization. It discusses natural pathways (photosynthesis, biofilm formation), engineered systems (microbial electrosynthesis, algae bioreactors capturing flue CO_2), and their real-world constraints (land/space, growth rates, contamination,

	scalability). Methodology: literature review of recent (2020-2024) biological capture systems, analysis of performance metrics (capture rate per area, cost, energy input), and discussion of integration into industrial or waste-gas streams.
Research Question/Problem/ Need	What biological systems (organisms, bioreactors) can capture CO_2 at sufficient rates, cost-effectively and sustainably, to contribute meaningfully to industrial carbon removal efforts?
Important Figures	Graphs of CO_2 uptake rate by algae vs land area; comparison of bio-capture vs engineered sorbents in terms of energy and land footprint. (image didn't paste)
VOCAB: (w/definition)	Biofilm — a thin, often microscopic layer of microorganisms that adhere to surfaces and form communities, sometimes used for CO_2 uptake or conversion. Microbial electrosynthesis — using microorganisms to convert CO_2 (often with electricity) into chemicals or fuels.
Cited references to follow up on	Li, J., et al. (2024). Biofilm-based CO_2 conversion to methane: advances and challenges. Energy Conversion and Management, 285, 116682. https://doi.org/10.1016/j.enconman.2023.116682 Smith, G., & Thompson, R. (2023). Algal bioreactors for industrial flue-gas CO_2 capture: operational performance and cost-analysis. Bioresource Technology, 367, 128948. https://doi.org/10.1016/j.biortech.2023.128948
Follow up Questions	How does the land/space requirement of biological capture systems compare to conventional sorbent or membrane-based systems for the same tonnage of CO_2 removed? What are the lifecycle environmental impacts (e.g., nutrients, water, energy) of large-scale biological CO_2 capture systems? Can biological capture systems be integrated with industrial waste streams (e.g., cement, steel) and still maintain performance under flue-gas contaminant conditions?

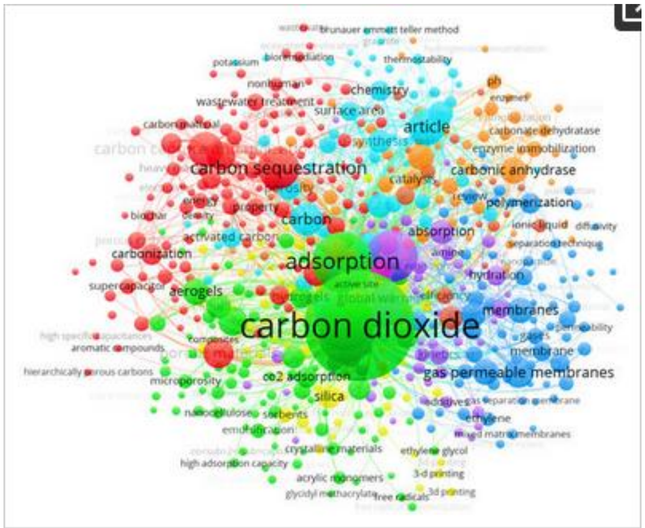
Article #10 Notes: Carbon Capture, Utilization, and Storage in the MENA Region: A Regional Review of Projects and Challenges

Source Title	Carbon Capture, Utilization, and Storage in the MENA Region: A Regional Review of Projects and Challenges
Source citation (APA Format)	Al-Subhan, K., Haddad, M., & et al. (2025). Carbon Capture, Utilization, and Storage in the MENA Region: A Regional Review of Projects and Challenges. Arabian Journal for Science and Engineering, 50, 4529-4549. https://doi.org/10.1007/s13369-025-09999-7
Original URL	https://link.springer.com/article/10.1007/s13369-025-09999-7
Source type	Review Article
Keywords	CCUS; Middle East and North Africa; oil & gas industry; policy & infrastructure; CO_2 utilization
#Tags	#CCUS #MENA #RegionalReview
Summary of key points + notes (include methodology)	This article reviews CCUS (carbon capture, utilization, storage) projects and potential in the Middle East & North Africa (MENA) region, focusing on oil & gas sectors, emerging renewables, and regional policies. It examines technical readiness of capture technologies, CO_2 storage potential in local geology, utilization pathways (e.g., enhanced oil recovery, chemical feedstocks), and key obstacles (regulations, cost, infrastructure). Methodology: survey of regional project databases, policy and regulatory frameworks, infrastructure and geology assessments, and comparison with global benchmarks.
Research Question/Problem/ Need	How can CCUS technologies be adapted and scaled in the MENA region, given unique technical, economic, and policy landscapes, to maximize CO_2 mitigation and utilization benefits?

Important Figures	Fig. 1  Average CO_2 concentration in ppm over time (Data obtained from [8])
VOCAB: (w/definition)	CCUS — Carbon Capture, Utilization & Storage: capturing CO_2, using it (e.g., in chemicals, fuels), and storing it (usually underground) to reduce net emissions. EOR — Enhanced Oil Recovery: injecting CO_2 into oil fields to increase extraction; also a utilization pathway for CO_2.
Cited references to follow up on	Al-Kaabi, A., & Kumar, P. (2024). Storage potential of CO_2 in Gulf region basalts: modelling and field data. International Journal of Greenhouse Gas Control, 132, 104710. https://doi.org/10.1016/j.ijggc.2024.104710 Haddad, M., et al. (2023). Legal and regulatory frameworks for CCUS deployment in the Middle East: a comparative study. Energy Policy, 178, 113730. https://doi.org/10.1016/j.enpol.2023.113730
Follow up Questions	Which geological formations in the MENA region offer the highest capacity and lowest risk for long-term CO_2 storage, and what are the monitoring/verification costs? How can captured CO_2 be most effectively utilized in MENA economies (e.g., in petrochemicals) and what business models support that? What policy or regulatory gaps in the region are most critical to address for large-scale CCUS deployment (e.g., liability, permanence, transport infrastructure)?

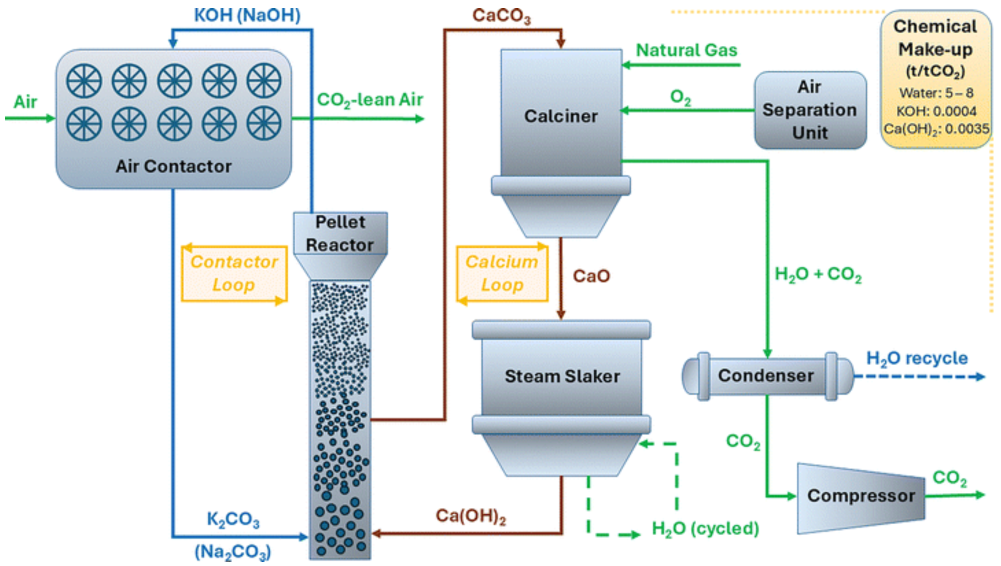
Article #11 Notes: CO_2 Capture: A Comprehensive Review and Bibliometric Analysis of Scalable Materials and Sustainable Solutions

Source Title	CO_2 Capture: A Comprehensive Review and Bibliometric Analysis of Scalable Materials and Sustainable Solutions
Source citation (APA Format)	Carrascal-Hernández, D. C., Grande-Tovar, C. D., Mendez-Lopez, M., Insuasty, D., García-Freites, S., Sanjuan, M., & Márquez, E. (2025). CO_2 Capture: A Comprehensive Review and Bibliometric Analysis of Scalable Materials and Sustainable Solutions. Molecules, 30(3), 563. https://www.mdpi.com/1420-3049/30/3/563
Original URL	https://www.mdpi.com/1420-3049/30/3/563
Source type	Review article with bibliometric analysis
Keywords	CO_2 capture; scalable materials; bibliometric trends; sustainability; market readiness
#Tags	#ScalableMaterials #Bibliometrics #SustainableCCS
Summary of key points + notes (include methodology)	This paper provides a bibliometric analysis of CO_2 capture research (material trends, citation patterns, funding sources) and couples it with a review of scalable materials (adsorbents, membranes, solvents). It highlights which material classes dominate research attention, which remain under-studied, and how research is shifting toward scalable, lower-cost solutions. Methodology: bibliometric data mining of publications 2000-2024, grouping by material type, country/institution, and forward-looking summary of sustainable solutions and material readiness levels.
Research Question/Problem/ Need	What material types (and associated technologies) show the strongest indicators of scaling potential and sustainability in the field of CO_2 capture, and how can research priorities be aligned accordingly?

Important Figures	
VOCAB: (w/definition)	Bibliometrics — quantitative analysis of academic literature (publication counts, citation networks) to identify trends and research hotspots. Readiness level (technology) — a scale that reflects how close a technology is to commercial deployment (lab → pilot → full scale).
Cited references to follow up on	Johnson, L., & Roberts, T. (2023). Trends in CCS research funding and technology maturity. International Journal of Greenhouse Gas Control, 120, 103587. https://doi.org/10.1016/j.ijggc.2023.103587 Nguyen, H., et al. (2024). From lab to market: material readiness assessment in CO_2 capture technologies. Energy Reports, 10, 789-803. https://doi.org/10.1016/j.egyr.2024.02.015
Follow up Questions	According to bibliometric trends, which countries or institutions are emerging as leaders in scalable CO_2 capture material research, and how does that influence global deployment? How do technology readiness level (TRL) assessments align with actual deployment timelines for CO_2 capture technologies? What mechanisms (funding, policy, industry partnerships) are most effective in accelerating transition from promising material research to commercial deployment?

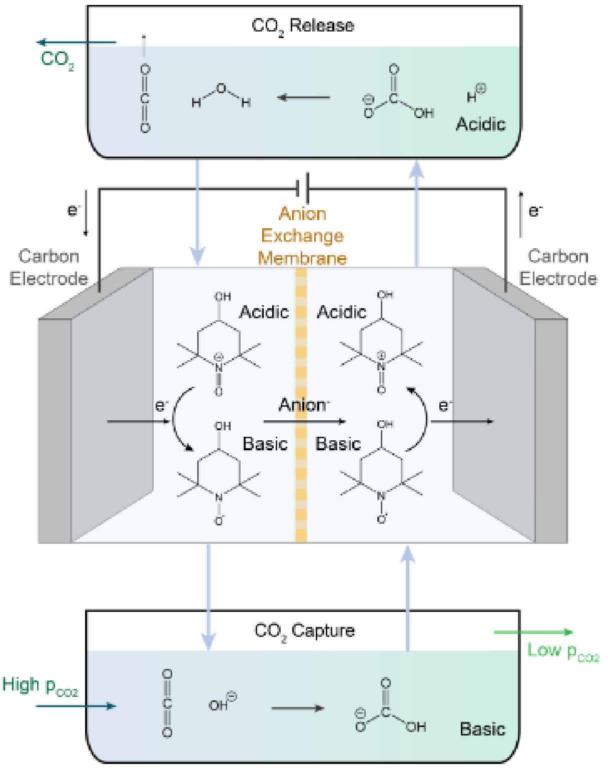
Article #12 Notes: An ecosystem of carbon dioxide removal reviews – part 1: direct air CO_2 capture and storage

Source Title	An ecosystem of carbon dioxide removal reviews – part 1: direct air CO_2 capture and storage
Source citation (APA Format)	van der Spek, M., Bardow, A., Baum, C. M., Bolongaro, V., Dufour-Décieux, V., Esch, C., … Minx, J. C. (2025). An ecosystem of carbon dioxide removal reviews – part 1: direct air CO_2 capture and storage. Energy & Environmental Science, 18, 9713–9785. https://pubs.rsc.org/en/content/articlelanding/2025/ee/d5ee01732g
Original URL	https://pubs.rsc.org/en/content/articlelanding/2025/ee/d5ee01732g
Source type	Research Article
Keywords	DACCS; techno-economic; life cycle; policy; public perception
#Tags	#DAC #Review #Policy
Summary of key points + notes (include methodology)	Reviews over 800 publications on DAC and storage, using structured screening + ML classification Identifies main DAC categories (adsorbents, membranes, mineral looping, cryogenic, etc.) Discusses costs, lifecycle impacts, policy needs, MRV, and social acceptance
Research Question/Problem/ Need	How can DACCS be scaled responsibly given high cost, energy draw, and social barriers?

Important Figures	
VOCAB: (w/definition)	MRV — Monitoring, Reporting, Verification systems for CO_2 removal CDR — Carbon Dioxide Removal
Cited references to follow up on	Deutz, S., & Bardow, A. (2021). Life-cycle assessment of an industrial direct air capture process … Nature Energy, 6(1), 203–213. https://doi.org/10.1038/s41560-020-00771-9 Lück, S., et al. (2024). Machine-learning-assisted systematic review of DACCS literature. Environmental Research Letters, 19(4), 045002. https://doi.org/10.1088/1748-9326/accf82
Follow up Questions	What policy mechanisms (e.g. tax incentives) would best support gigaton-scale DAC deployment? How does public perception of DAC differ across global regions, and how should that affect siting? Which lifecycle uncertainties (energy source, sorbent production) are most critical to reduce?

Article #13 Notes: Electrochemical CO_2 capture with pH-independent redox chemistry

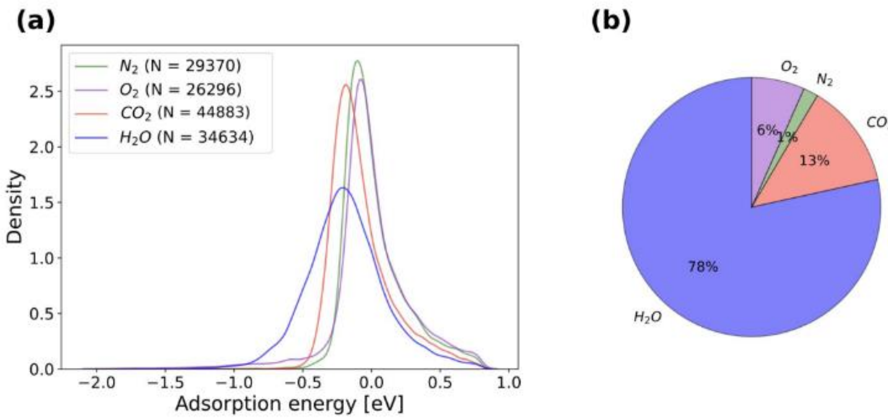
Source Title	Electrochemical CO_2 capture with pH-independent redox chemistry
Source citation (APA Format)	Kim, S. C., Gigantino, M., Holoubek, J., Matthews, J. E., Chen, J., Dho, Y., … Tzeng, Y.-K. (2025). Electrochemical CO_2 capture with pH-independent redox chemistry. arXiv. https://arxiv.org/abs/2502.01028

Original URL	https://arxiv.org/abs/2502.01028
Source type	Experimental Article
Keywords	Redox capture; TEMPO; flow cell; low energy
#Tags	#Electrochemical #DAC #Redox
Summary of key points + notes (include methodology)	Demonstrates a redox-based electrochemical DAC system using TEMPO in a flow cell Achieves ~2.6 kJ/mol CO_2 (very low energy) using pH-independent redox transition Uses computational modeling (MD + DFT) to rationalize molecular behavior
Research Question/Problem/ Need	How can electrochemical DAC operate at ultra-low energy costs using redox molecules?
Important Figures	 **Fig. 1.** Schematic diagram of the pH-independent of the electrochemical CO_2 capture system comprised of an electrochemical cell with symmetrical TEMPO redox reactions connected by a flow system to capture and release tanks.

VOCAB: (w/definition)	Redox chemistry — electron-transfer reactions Flow cell — continuous electrochemical reactor TEMPO — a redox-active radical
Cited references to follow up on	Jaramillo, T. F., et al. (2021). Advances in electrochemical CO_2 capture technologies. ACS Energy Letters, 6(6), 1962–1977. https://doi.org/10.1021/acsenergylett.1c00648 Voskian, S., & Hatton, T. A. (2019). Faradaic electro-swing reactive adsorption for CO_2 capture. Energy & Environmental Science, 12(12), 3530–3547. https://doi.org/10.1039/C9EE02481C
Follow up Questions	What is the long-term stability of TEMPO in cyclic operation? How could a scaled flow-cell system be designed cost-effectively? What renewable electricity sources could power such a system economically?

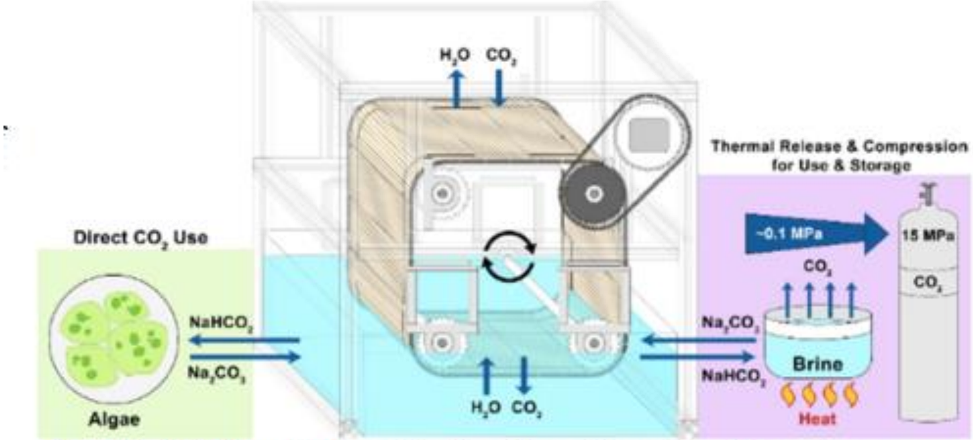
Article #14 Notes: The Open DAC 2025 Dataset for Sorbent Discovery in Direct Air Capture

Source Title	The Open DAC 2025 Dataset for Sorbent Discovery in Direct Air Capture
Source citation (APA Format)	Sriram, A., Brabson, L. M., Yu, X., Choi, S., Abdelmaqsoud, K., Moubarak, E., … Sholl, D. S. (2025). The Open DAC 2025 Dataset for Sorbent Discovery in Direct Air Capture. arXiv. https://arxiv.org/abs/2508.03162
Original URL	https://arxiv.org/abs/2508.03162
Source type	Dataset Article
Keywords	MOFs; DFT; machine learning; high-throughput; CO_2 sorbents
#Tags	#Materials #DAC #MOFs
Summary of key points + notes (include methodology)	Publishes a dataset of ~70 million DFT adsorption calculations (CO_2, H_2O, N_2, O_2) over ~15,000 MOFs Provides ML-trained interatomic potentials for screening sorbent performance Designed to accelerate computational discovery of promising DAC materials
Research Question/Problem/ Need	How can high-throughput computational + ML approaches speed up the discovery of DAC sorbent materials?

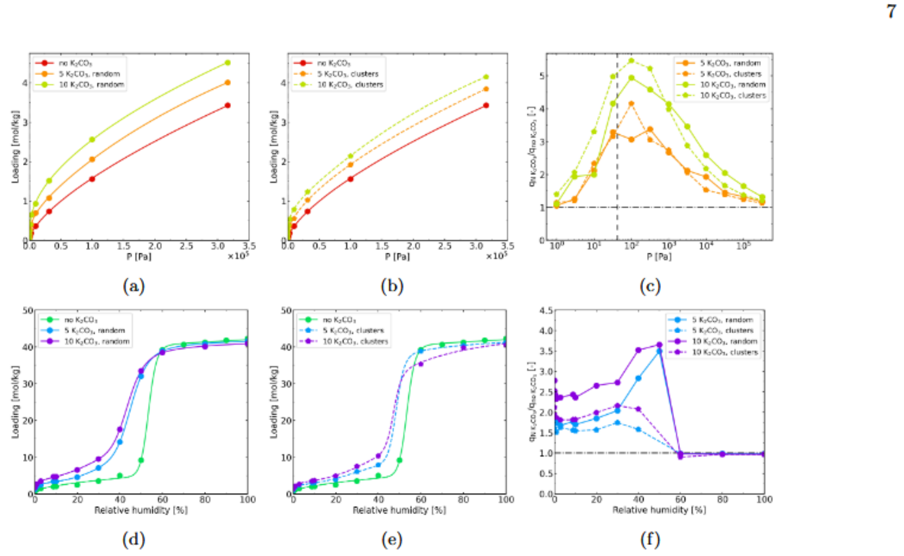
Important Figures	
VOCAB: (w/definition)	DFT — density functional theory (quantum-level calculation) MOF — metal-organic framework Henry's law coefficient — gas uptake per partial pressure
Cited references to follow up on	Sriram, A., et al. (2024). ODAC23 dataset: earlier version for MOFs in DAC screening. ACS Central Science, 10(6), 923–935. https://doi.org/10.1021/acscentsci.4c00323
Follow up Questions	Which MOFs in ODAC25 show favorable adsorption under humid, real-DAC conditions? How quickly can these top computational candidates be validated experimentally? What are the limitations of ML potentials, and how can future models be improved?

Article #15 Notes: Design and demonstration of a direct air capture system with moisture-driven CO_2 delivery into aqueous medium

Source Title	Design and demonstration of a direct air capture system with moisture-driven CO_2 delivery into aqueous medium
Source citation (APA Format)	Flory, J., Taylor, S., Li, S., Tiwari, S., Cole, G., Lowe, A., … Vermaas, W. (2025). Design and demonstration of a direct air capture system with moisture-driven CO_2 delivery into aqueous medium. arXiv. https://arxiv.org/abs/2508.02650
Original URL	https://arxiv.org/abs/2508.02650

Source type	Experimental Article
Keywords	Moisture swing; ion-exchange resin; DAC; water evaporation
#Tags	#DAC #Sorbent #MoistureSwing
Summary of key points + notes (include methodology)	Built a DAC prototype using resin beads to absorb CO_2 via moisture swing Outdoor and lab demonstration, achieving ~100 g/day in pilot Techno-economic model: ~$670/t capture; aspirational future: ~$51/t
Research Question/Problem/ Need	Can moisture-swing resin systems achieve DAC at low energy and water cost?
Important Figures	 **Graphical Abstract.** Schematic of moisture-driven direct air capture system with CO_2 delivery into aqueous medium for direct use to cultivate algae or thermal extraction and compression for use, conversion or storage.
VOCAB: (w/definition)	Ion-exchange resin — polymer that exchanges ions with environment Moisture swing — using humidity to drive adsorption/desorption
Cited references to follow up on	Lackner, K. S., et al. (2012). Carbon dioxide extraction from air: is the economics realistic? Energy, 45(1), 110–119. https://doi.org/10.1016/j.energy.2012.03.057
Follow up Questions	How can water use be reduced in a moisture-swing DAC system? What are the degradation mechanisms for resin beads under repeated humidity cycles? Can this technology be powered by intermittent renewables to minimize cost?

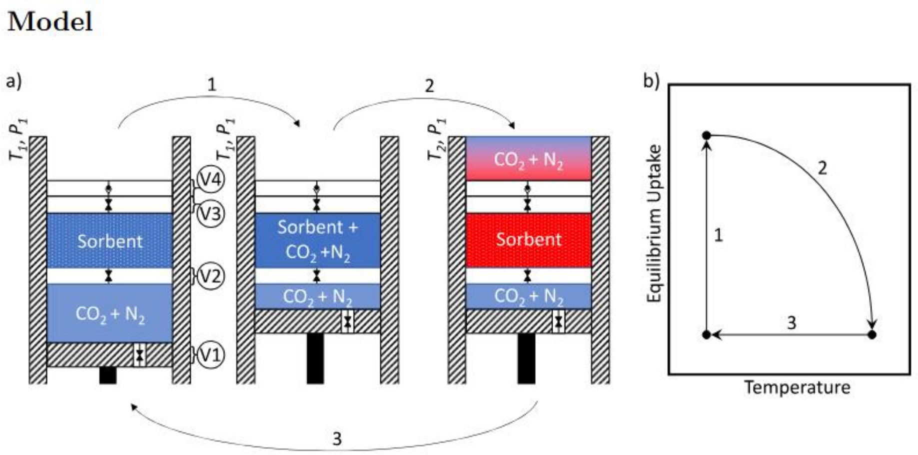
Article #16 Notes: Enhancing Direct Air Capture through Potassium Carbonate Doping of Activated Carbons

Source Title	Enhancing Direct Air Capture through Potassium Carbonate Doping of Activated Carbons
Source citation (APA Format)	van Dongen, N., van Hoof, A. J. F., Calero, S., & Vicent-Luna, J. M. (2025). Enhancing Direct Air Capture through Potassium Carbonate Doping of Activated Carbons. arXiv. https://arxiv.org/abs/2510.06400
Original URL	https://arxiv.org/abs/2510.06400
Source type	Computational Article
Keywords	Activated carbon; K_2CO_3; adsorption; CO_2; humidity
#Tags	#Adsorbents #DAC #CarbonMaterials
Summary of key points + notes (include methodology)	Molecular simulations show K_2CO_3-doped carbon has better CO_2 and water adsorption than undoped; K_2CO_3 clusters provide strong binding sites Doped pores favor CO_2 adsorption at low partial pressure, which is beneficial for DAC
Research Question/Problem/ Need	Can doping activated carbon with K_2CO_3 improve its effectiveness for DAC in humid air?
Important Figures	
VOCAB: (w/definition)	Doping — adding a chemical additive to a material to modify its properties Adsorption isotherm — equilibrium uptake vs pressure

Cited references to follow up on	McPherson, L. R., & Rood, M. J. (1993). Adsorption of CO_2 on activated carbon at low partial pressure. Carbon, 31(4), 599–605. https://doi.org/10.1016/0008-6223(93)90079-H
Follow up Questions	What is the thermal or pressure energy required to regenerate the doped carbon? How stable is the K_2CO_3 in the carbon matrix during many adsorption/desorption cycles? Can experimental samples be produced matching the doped structures from simulation?

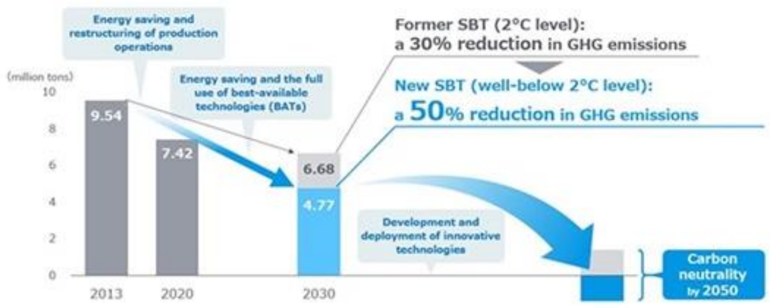
Article #17 Notes: Intrinsic Direct Air Capture

Source Title	Intrinsic Direct Air Capture
Source citation (APA Format)	McDannald, A., Siderius, D. W., DeCost, B., Choudhary, K., Ortiz-Montalvo, D. L., & … (2025). Intrinsic Direct Air Capture. arXiv. https://arxiv.org/abs/2501.04825
Original URL	https://arxiv.org/abs/2501.04825
Source type	Theoretical Article
Keywords	Intrinsic metrics; MOFs; thermodynamics; performance bounds
#Tags	#Theory #MOFs #MaterialScreening
Summary of key points + notes (include methodology)	Defines thermodynamic “intrinsic” metrics for sorbents that are independent of cycle design Applies these metrics to ~11,660 MOFs using equilibrium uptake data Finds that the path through pressure/temperature cycle space strongly influences performance
Research Question/Problem/ Need	How can intrinsic thermodynamic limits improve materials screening for DAC?

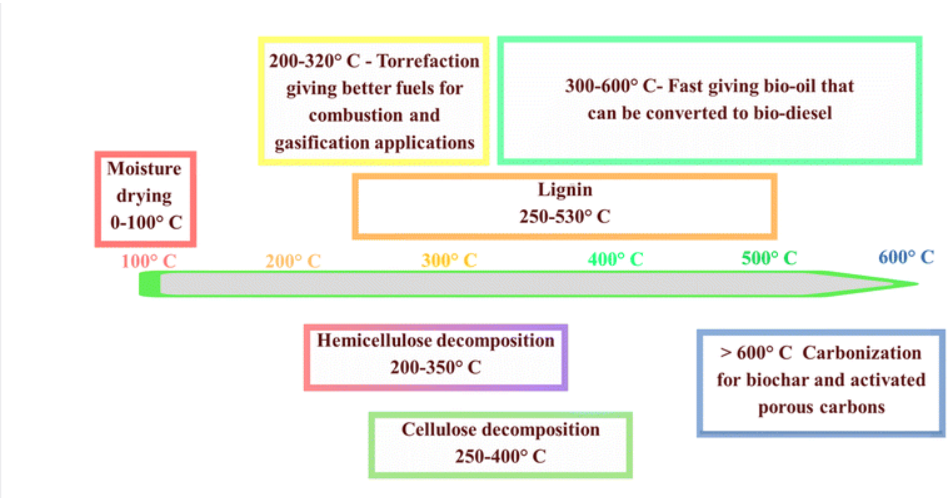
Important Figures	
VOCAB: (w/definition)	Equilibrium uptake — amount of gas held by a sorbent at a given temperature and pressure, at equilibrium Intrinsic metric — a performance measure independent of a specific DAC system design
Cited references to follow up on	DeCost, B., & Sholl, D. S. (2023). A thermodynamic screening metric for CO_2 capture performance of sorbents. The Journal of Physical Chemistry C, 127(10), 4750–4760. https://doi.org/10.1021/acs.jpcc.2c06534
Follow up Questions	Which MOFs approach the intrinsic performance limits defined in this work? How do real DAC cycle performances compare to these intrinsic predictions? Can new MOFs be designed explicitly to maximize these intrinsic metrics?

Article #18 Notes: Carbon capture and recycling technology of carbon resources under the target of carbon neutrality

Source Title	Carbon capture and recycling technology of carbon resources under the target of carbon neutrality
Source citation (APA Format)	Al-Mujtaba, K., Haddad, M., & … (2024). Carbon capture and recycling technology of carbon resources under the target of carbon neutrality. International Journal of Low-Carbon Technologies, 19(6), 2693–2701. https://academic.oup.com/ijlct/article/doi/10.1093/ijlct/ctae229/7901309
Original URL	https://academic.oup.com/ijlct/article/doi/10.1093/ijlct/ctae229/7901309

Source type	Research Article
Keywords	CCU; methanation; hydrogen; CO_2 recycling
#Tags	#CCU #Methanation #Hydrogen
Summary of key points + notes (include methodology)	Reviews technologies to recycle CO_2 into synthetic fuels using green hydrogen Emphasizes potential CO_2 capture efficiency >90% and integration with existing gas infrastructure Discusses economic and logistic hurdles (H_2 production, transport, emissions)
Research Question/Problem/ Need	How can CCU (capture + recycling) be made economically and environmentally viable using renewable hydrogen?
Important Figures	 **Figure 3** Magnificent plan to reach carbon neutrality-to achieve carbon neutrality, CCS, or CCUS, is essential.
VOCAB: (w/definition)	Methanation — $CO_2 + H_2 \rightarrow CH_4$ reaction Carbon recycling — using CO_2 as a feedstock rather than simply storing it
Cited references to follow up on	Aramco, S., & Linde, B. (2023). CO_2 utilization for synthetic methane: process design and techno-economic analysis. Journal of CO_2 Utilization, 69, 102798. https://doi.org/10.1016/j.jcou.2023.102798
Follow up Questions	What scale of green hydrogen production is needed to support CCU at gigaton CO_2/year? How do lifecycle emissions compare for CCU vs CCS? What business models make CCU financially viable, considering infrastructure and policy?

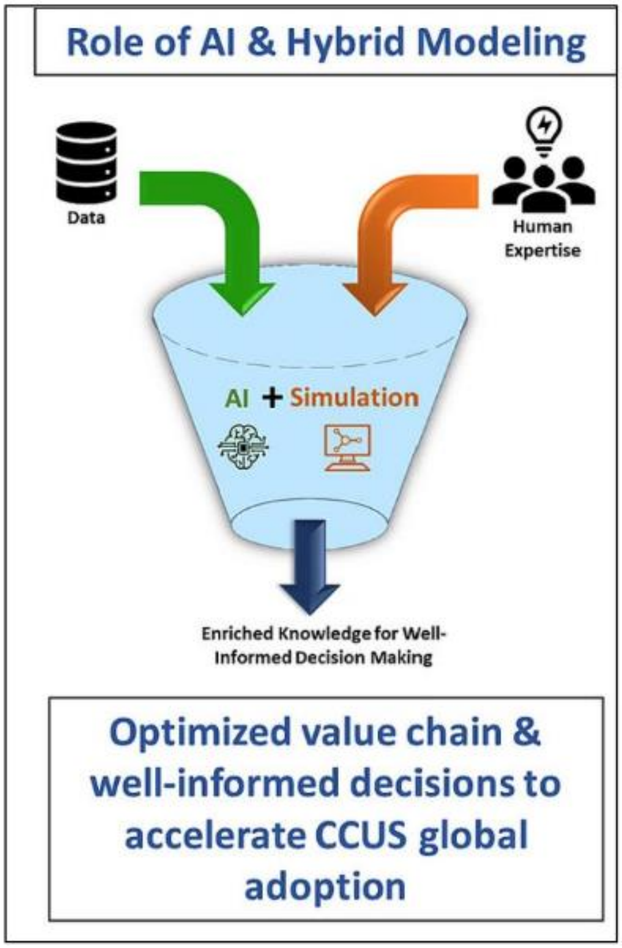
Article #19 Notes: A comprehensive review of enhanced CO_2 capture using activated carbon derived from biomass feedstock

Source Title	A comprehensive review of enhanced CO_2 capture using activated carbon derived from biomass feedstock
Source citation (APA Format)	Kundu, S., Khandaker, T., Anik, M. A. M., Hasan, M. K., Dhar, P. K., Dutta, S. K., Latif, M. A., & Hossain, M. S. (2024). A comprehensive review of enhanced CO_2 capture using activated carbon derived from biomass feedstock. RSC Advances, 14(40), 29693–29736. https://pubs.rsc.org/en/Content/ArticleLanding/2024/RA/D4RA04537H
Original URL	https://pubs.rsc.org/en/Content/ArticleLanding/2024/RA/D4RA04537H
Source type	Review Article
Keywords	Biomass; activated carbon; CO_2 adsorption; sustainability
#Tags	#Biomass #Adsorbents #SustainableCCS
Summary of key points + notes (include methodology)	Surveys biomass-derived activated carbons made from agricultural residues Compares activation methods, porosity, capacity, regeneration energy Highlights sustainability potential and cost advantages, but variability in feedstock and performance remain a challenge
Research Question/Problem/ Need	Can biomass-derived activated carbon deliver cost-effective, sustainable CO_2 sorbents at scale?
Important Figures	

VOCAB: (w/definition)	Activated carbon — porous carbon made (often by pyrolysis + activation) for adsorption Biomass feedstock — organic waste used as raw material
Cited references to follow up on	Sevilla, M., & Fuertes, A. B. (2009). The production of carbon materials by hydrothermal carbonization of cellulose. Carbon, 47(9), 2281–2289. https://doi.org/10.1016/j.carbon.2009.04.035
Follow up Questions	What is the performance variability across carbons from different biomass sources? How does the energy/carbon cost of producing biomass carbon compare to synthetic sorbents? How many cycles (adsorption/desorption) can biomass-based carbon survive before performance drops?

Article #20 Notes: Revolutionizing carbon capture efficiency: A comprehensive review of AI-Driven approaches

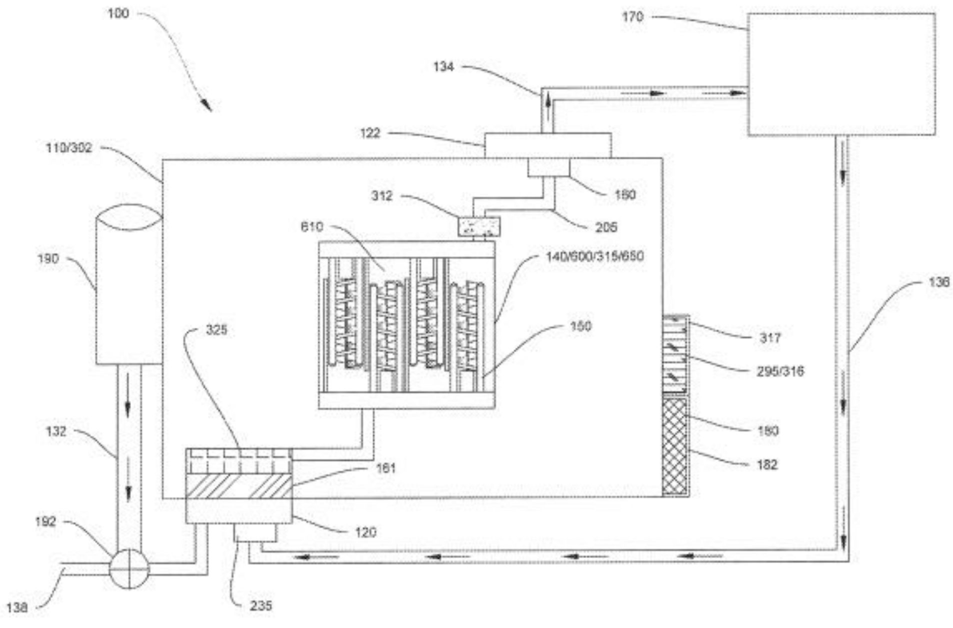
Source Title	Revolutionizing carbon capture efficiency: A comprehensive review of AI-Driven approaches
Source citation (APA Format)	Anonymous authors. (2025). Revolutionizing carbon capture efficiency: A comprehensive review of AI-driven approaches. International Journal of Science, Technology & Research Applications, 9(1), 43–68. https://sciresjournals.com/ijstra/sites/default/files/IJSTRA-2025-0043.pdf
Original URL	https://sciresjournals.com/ijstra/sites/default/files/IJSTRA-2025-0043.pdf
Source type	Review Article
Keywords	Machine learning; process optimization; sorbent discovery; monitoring; CCUS
#Tags	#AI #CCUS #Optimization
Summary of key points + notes (include methodology)	Reviews AI applications in CCUS: ML for materials, DRL for process control, anomaly detection for storage Reports use cases where cost was cut ~10–20% when AI optimized parameters

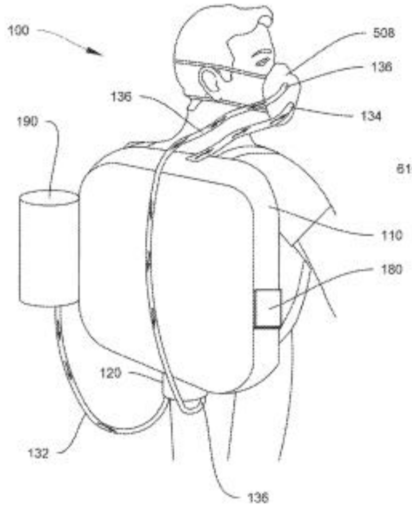
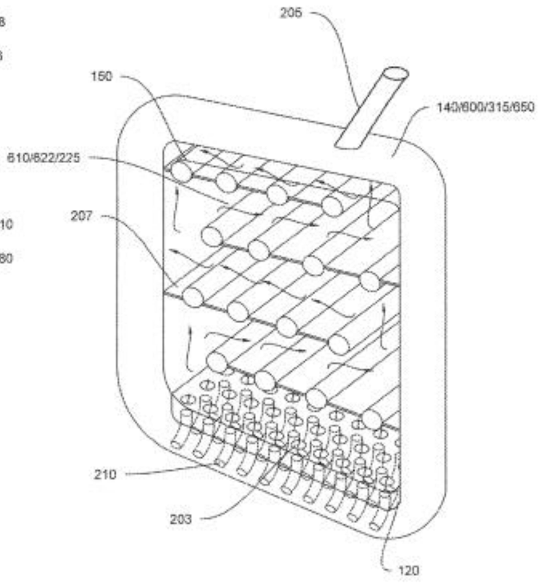
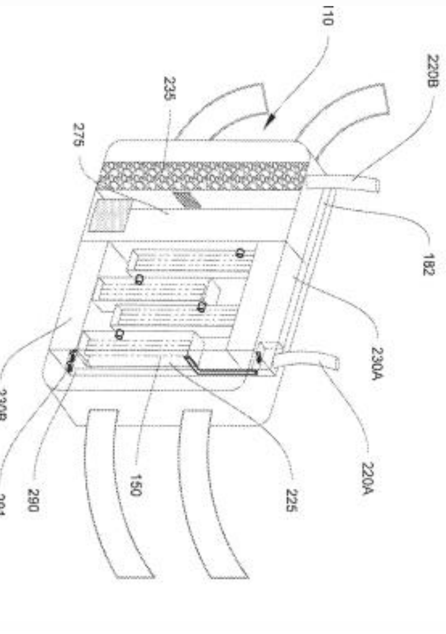
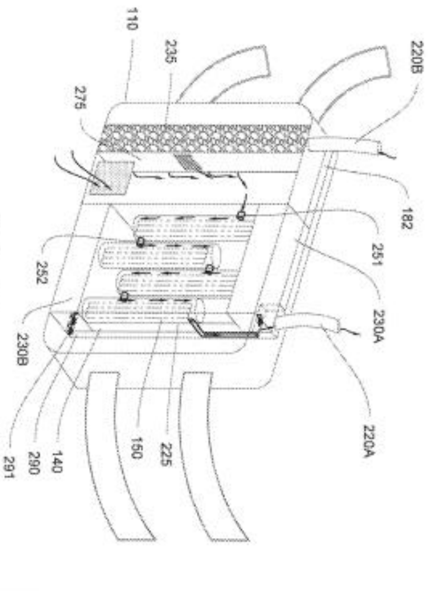
	Suggests that AI can reduce R&D time, improve sorbent lifetime, and support risk monitoring
Research Question/Problem/ Need	How can AI methods accelerate materials discovery and process scale-up for CCUS while reducing costs and risk?
Important Figures	
VOCAB: (w/definition)	Deep Reinforcement Learning — AI technique where learning agents optimize decisions over time Machine Learning — predictive modelling based on patterns in data
Cited references to follow up on	Gómez-Bombarelli, R., et al. (2018). Design of efficient molecular organic light-emitting diodes by a high-throughput virtual screening … Nature, 562(7728), 86–90. https://doi.org/10.1038/s41586-018-0626-6
Follow up Questions	What datasets are most needed to build robust AI models for CCUS? How reliable are AI-predicted lifetimes of sorbents versus real-world cycling data?

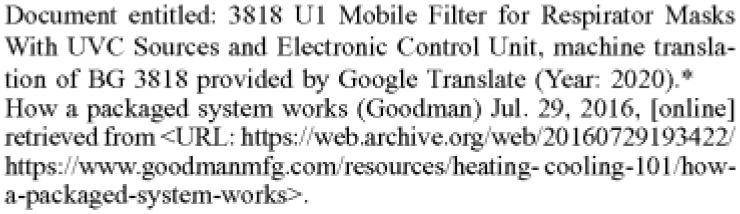
	Can reinforcement learning optimize the full CCUS chain (capture → transport → storage)?

Article #21 Notes (Patent #1): Air purification and disinfection apparatus and methods of use

Source Title	Air purification and disinfection apparatus and methods of use
Source citation (APA Format)	Pisharodi, M. (2022, November 29). *US11511013B2 - air purification and disinfection apparatus and methods of use*. Google Patents. https://patents.google.com/patent/US11511013B2/en q=%28Carbon%2BDioxide%2BFilter%29&oq=Carbon%2BDioxide%2BFilter
Original URL	https://patents.google.com/patent/US11511013B2/en?q=(Carbon+Dioxide+Filter)&oq=Carbon+Dioxide+Filter
Source type	Patent
Keywords	Carbon Dioxide Purification Portable Contaminants Airborne
#Tags	
Summary of key points + notes (include methodology)	Personal Air Purification & Disinfection: The invention focuses on a portable system that purifies and disinfects ambient air for an individual user, e.g., a healthcare worker or person in a confined space. Multi-Stage Air Treatment: Air enters a housing where it may pass through HEPA filtration, activated carbon filters, and UV-C disinfection chambers to remove particulates, microorganisms, chemical vapors, and other contaminants. Ultraviolet Disinfection: UV-C and Far-UV light sources within multiple chambers kill/neutralize airborne microorganisms by exposing them to ultraviolet radiation with extended residence times through serpentine/helical air paths. Carbon Dioxide & Gas Absorption: The apparatus can include replaceable carbon dioxide absorption units to reduce CO_2 in the breathed air when required (e.g., in closed circuits).

	Active Airflow Control: The system uses an air mover (pump or fan) and a pump speed controller (PCB) to regulate airflow through filters, UV chambers, and to the user's distribution unit (mask/ventilator). Modular / Wearable Configurations: The device can take many physical forms: backpack, briefcase, wearable cervical collar, or integrated respirator-style unit. This accommodates diverse use-case scenarios. Closed and Open Circuit Modes: Embodiments include systems that either release exhaled air back into the unit for purification (closed-circuit) or discharge it externally (open-circuit), providing flexibility depending on application needs
Research Question/Problem/ Need	How can a portable air purification and disinfection apparatus be designed to effectively remove airborne particulates, pathogens and other contaminants to deliver purified air directly to a user?
Important Figures	 FIG. 1A

	 FIG. 1B  FIG. 2A  FIG. 2C  FIG. 2B
VOCAB: (w/definition)	HEPA – A type of air filter that removes at least 99.97% of airborne particles that are 0.3 microns in size, such as dust, pollen, mold, and bacteria. PCB - A flat board that holds and connects electronic components and allows electricity to flow between them in a controlled way. Apparatus - A device or system of connected parts designed to perform a specific function or task, often used in technical or scientific contexts.

Cited references to follow up on	 Document entitled: 3818 U1 Mobile Filter for Respirator Masks With UVC Sources and Electronic Control Unit, machine translation of BG 3818 provided by Google Translate (Year: 2020).* How a packaged system works (Goodman) Jul. 29, 2016, [online] retrieved from <URL: https://web.archive.org/web/20160729193422/ https://www.goodmanmfg.com/resources/heating-cooling-101/how-a-packaged-system-works>.
Follow up Questions	What are the specific performance benefits and limitations of including a carbon dioxide absorption unit within this system? How does the system balance airflow rate, UV exposure time, and filter/absorbent media durability to ensure both effective microbial kill rates and user comfort? What are the design trade-offs for integrating multiple treatment technologies in a single portable housing?

Article #22 Notes (Patent #2): Purifying carbon dioxide using activated carbon

Source Title	Purifying carbon dioxide using activated carbon
Source citation (APA Format)	Degenstein, N., Shah, M., & Neu, B. (2012, October 9). *US8282715B1 - purifying carbon dioxide using activated carbon*. Google Patents. https://patents.google.com/patent/US8282715B1/en?q=%28Carbon%2BDioxide%2BFilter%29&oq=Carbon%2BDioxide%2BFilter
Original URL	https://patents.google.com/patent/US8282715B1/en?q=(Carbon+Dioxide+Filter)&oq=Carbon+Dioxide+Filter
Source type	Patent
Keywords	Adsorption/Adsorbent Flue Gas Carbon Amines
#Tags	
Summary of key points + notes (include methodology	Activated carbon adsorption is used to purify CO_2-rich gas streams by selectively removing contaminants such as SO_x, NO_x, and trace impurities. The invention targets industrial exhaust and flue gas, enabling cleaner carbon dioxide suitable for sequestration, reuse, or further processing.

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Chemical interactions on the carbon surface convert sulfur and nitrogen oxides into adsorbed species, improving removal efficiency beyond simple physical filtration.

The system includes regenerable adsorbent beds, allowing activated carbon to be reused rather than replaced after saturation.

Washing or regeneration steps (often using water) remove adsorbed acidic compounds from the carbon, restoring adsorption capacity.

The process may operate using pressure-swing adsorption (PSA) or vacuum PSA, improving control over adsorption and desorption cycles.

Overall, the patent claims a cost-effective, scalable alternative to solvent-based CO_2 purification methods (such as amines), with lower corrosion and operational complexity.

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<tr>
<td>Research Question/Problem/ Need</td>
<td>How can an impure carbon dioxide-rich gas stream be effectively purified using regenerable activated carbon adsorption techniques to produce higher-purity CO_2 for reuse, sequestration, or industrial applications?</td>
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<td>Important Figures</td>
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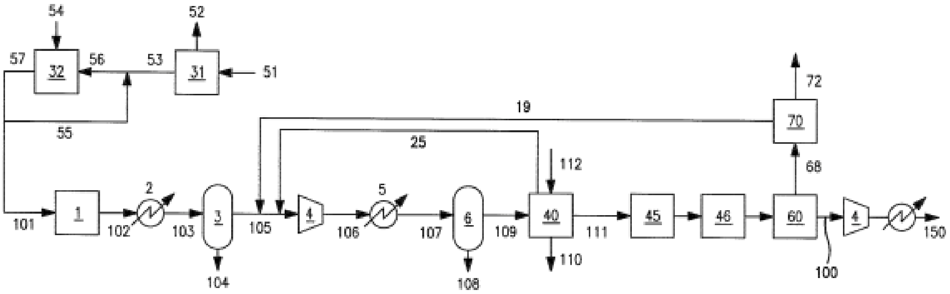

FIG. 1

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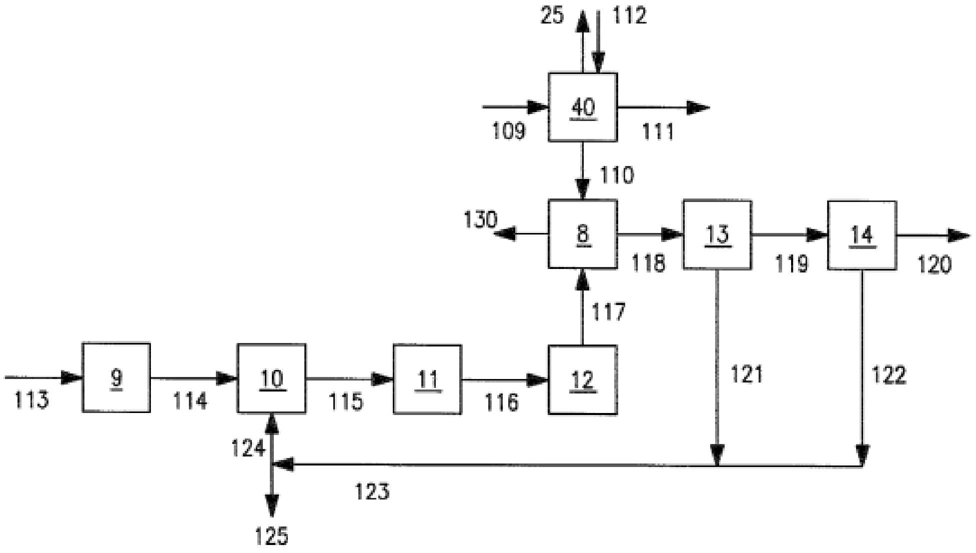
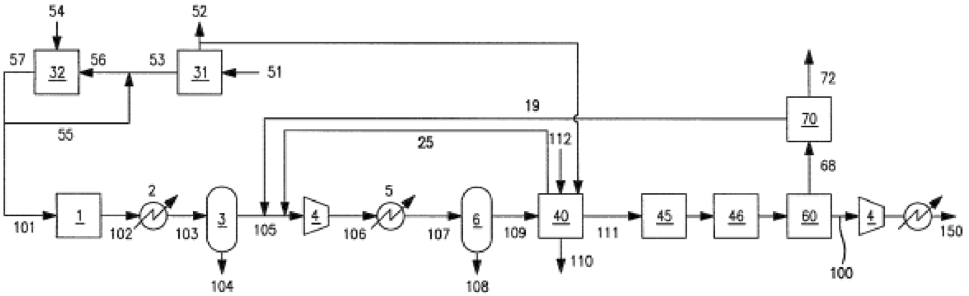
	 FIG. 2  FIG. 3
VOCAB: (w/definition)	Activated Carbon Adsorption – method to purify CO_2-rich gas streams by selectively removing contaminants Pressure Swing Adsorption - improves control over adsorption and desorption cycles
Cited references to follow up on	Metzinger J, et al., “Application of a Periodically Operated Trickle Bed to Sulfur Removal from Stack Gas.” Chemical Engineering Science, (47) 3723-3727, 1992. Metzinger J, et al., “A Novel Periodic Reactor for Scrubbing SO2 from Industrial Stack Gas.” Chemical Engineering Science, (49) 4533-4546, 1994.

	Vladea R, et al., “High-Efficiency Structured-Packing Catalysts with Activated Carbon for SO2 Oxidation from Flue Gas” Energy & Fuels, (11) 277-283, 1997.
Follow up Questions	What are the specific performance advantages of using the patented activated carbon system compared with traditional solvent-based CO_2 purification methods like amine scrubbing? How does the regeneration process for the activated carbon beds affect operational downtime and energy consumption? What types and concentrations of contaminants can the system tolerate before performance degrades, and how does that influence the choice of carbon material?