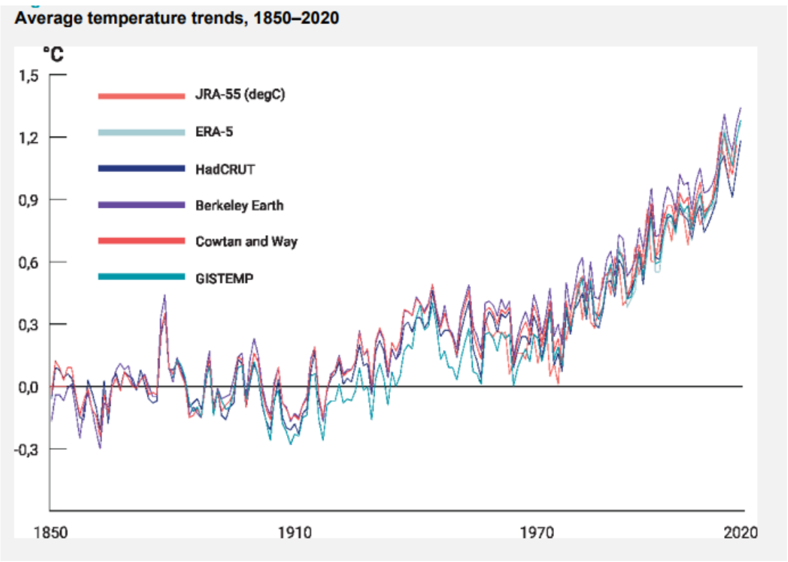
WEI LAB

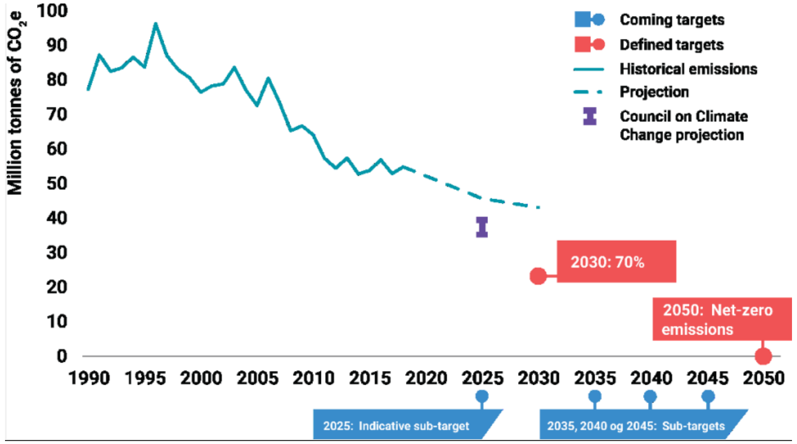
Danish Offshore Technology Conference 2022
R&D for the Offshore Energy Transition

Detection and Monitoring of CO_2 Leakage in Sub-seabed CCS: Current Status and Beyond

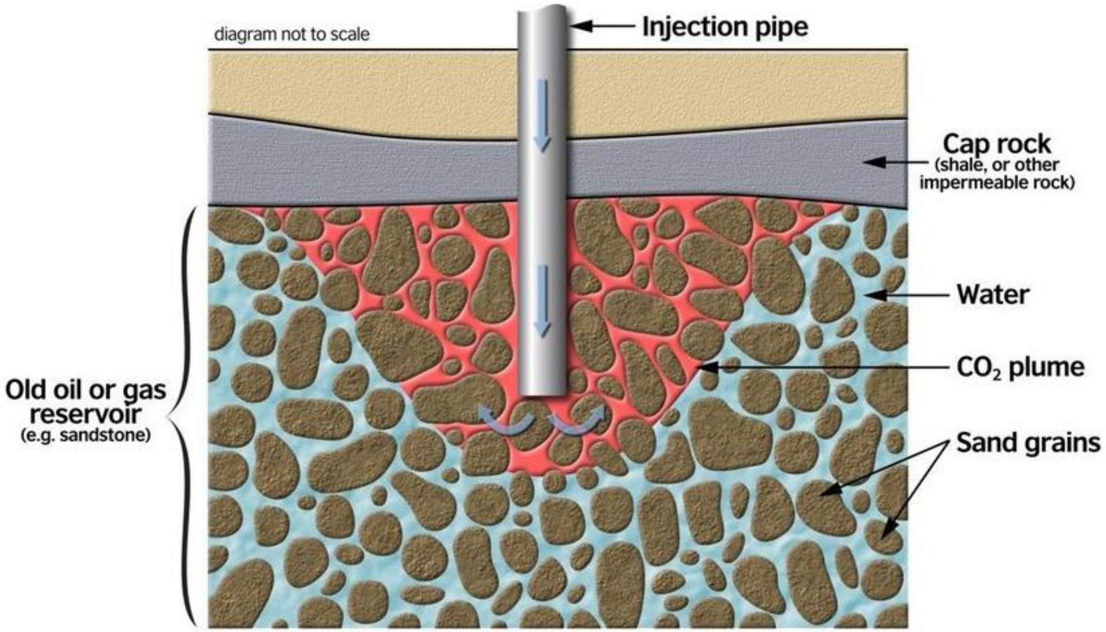
Zongsu Wei, Ph.D., Assistant Professor, Aarhus University
Chizoba Ignatius Ezugwu, Ph.D., Postdoc, Aarhus University
Mikkel Holmen Andersen, Ph.D., CTO, Unisense A/S
Lauge Christensen, Ph.D., Senior Development Physicist, Unisense A/S

Global Warming & Danish Climate Law

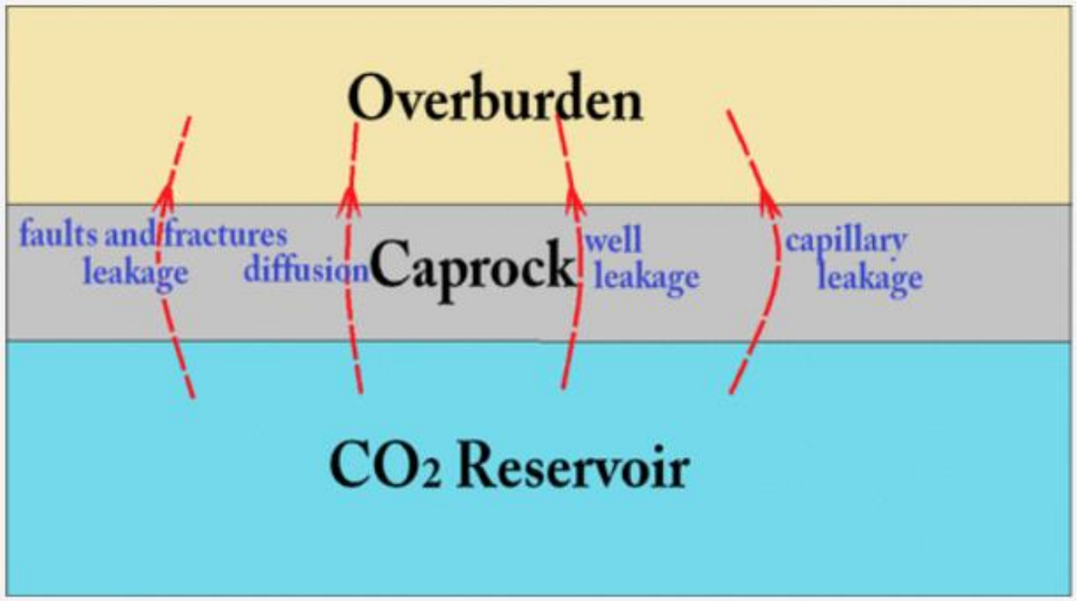




Danish Oil Reservoir & CO_2 Leakage



Injecting CO_2 into depleted oil and gas reservoir



Benefits of re-using depleted oil reservoirs

- Existing infrastructure can be re-used for the injection
- Reduce both the cost of CCS and the environmental impact
- High porosity and permeability
- Traps and seals – easy!

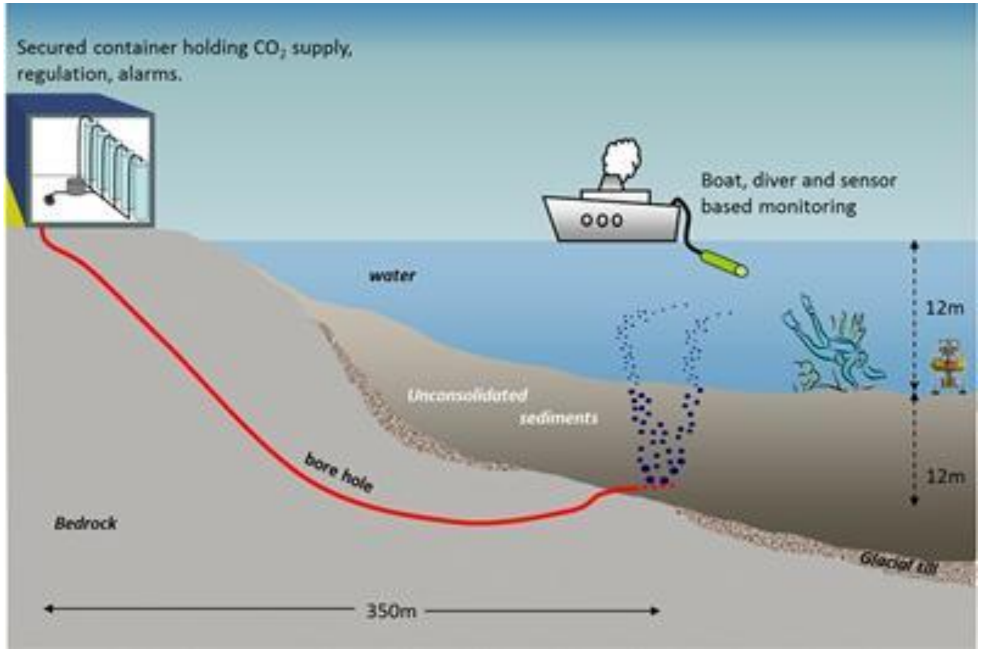
To monitor when injecting CO_2 into the subsurface

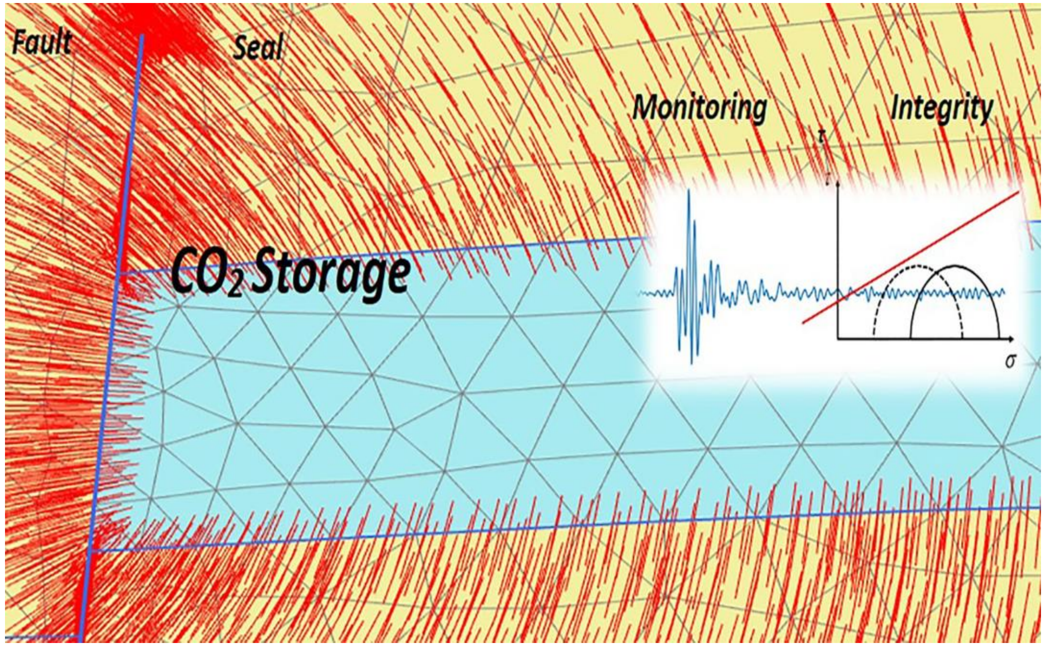
- How does the CO_2 plume move in the subsurface reservoir?
- How are potential leaks at the seabed detected?

The Danish CO_2 storage capacity

- ✓ 16 Gt CO_2 for 11 saline aquifers
- ✓ 0.8 Gt CO_2 for 17 oil fields

Monitoring of CO_2 Leakage in Sub-seabed





Methods	Limitations
4D seismic and timelapse gravity	• None-engaging • Local CO_2 concentrations not considered

The cost of CO_2 monitoring, especially offshore, are still not affordable

Comparison of CO_2 Sensors

Optical

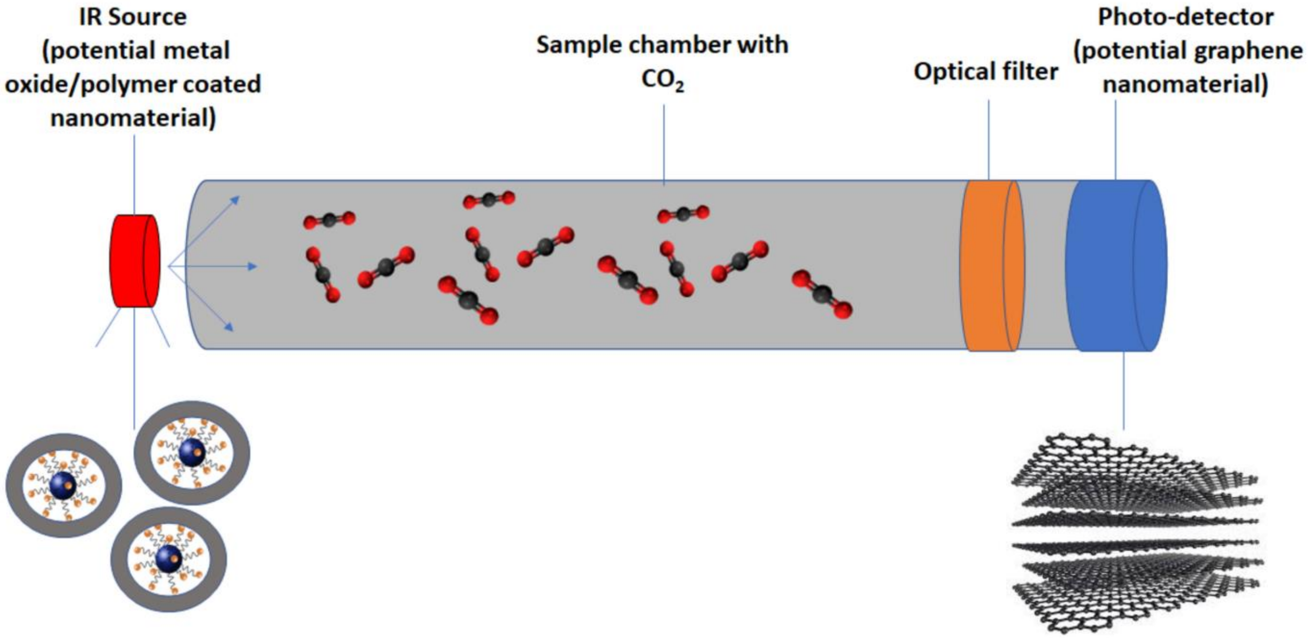
CO_2 Sensors	Working principles	Limitations
NDIR - Nondispersive infrared	**Energy absorption characteristics of CO_2** in the **infrared region**	▪ Interference from particular matter ▪ Bulky and expensive ▪ Changes in the level of infrared energy in the system causes a measurement errors in the NDIR sensors ▪ Regular calibration with zero gas
Fiber Optic - also called **optodes**	Contain a **chemical sensing layer** at the tip of a fiber, which **changes optical properties** in response **to CO_2** Based on **materials** that shows **absorbance** or **reflectance changes** on exposure to CO_2	▪ Requires the use of lenses - dust or soot coating interferes the transmission of light, therefore it need frequent cleaning
Electrochemical/solid-state electrolyte sensors	Uses of MEMS (**microelectro-mechanical systems**) and **nanotechnology** for CO_2 monitoring.	▪ Limited measurement accuracy ▪ Problem of long-time stability

☐ How it works: the chemical reaction produce a change in parameters: ***pH, resistance, conductivity, or capacitance***

☐ **Severinghaus type potentiometric sensors, gas chromatography (GC), mass spectrometers**

Optical CO_2 Sensor

- **Optical CO_2 sensors**
  - **Nondispersive infrared detectors (NDIR), Fiber optic** and **Sol-Gel Optical Sensors**
- CO_2 absorbs IR at wavelengths of **2.7**, **4.3**, and **15 µm**
- Some commercially available CO_2 sensors, like NDIR Model No. GMT220 Carbocap.



NDIR CO_2 sensing with potential nanomaterial integration

Electrochemical CO_2 Sensors

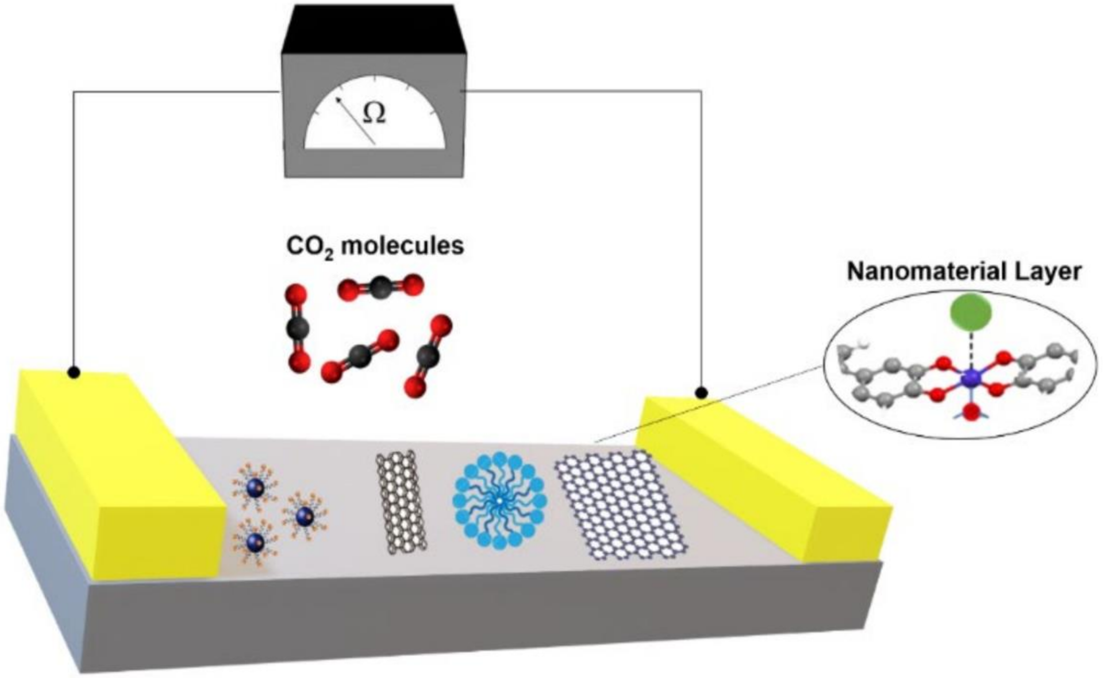
☐ **Classification based on** measurement method:

- **Potentiometric mode** - the measured signal is an electromotive force
- **Amperometric mode** - an electric current is recorded
- **Conductometric sensors** - the current-voltage plot is analyzed

☐ **Metal oxide and polymer materials**

Limitations

- Inappropriate in potentially flammable environments
- Explosive environment
- Limited accuracy of the sensor and the overall measurement range

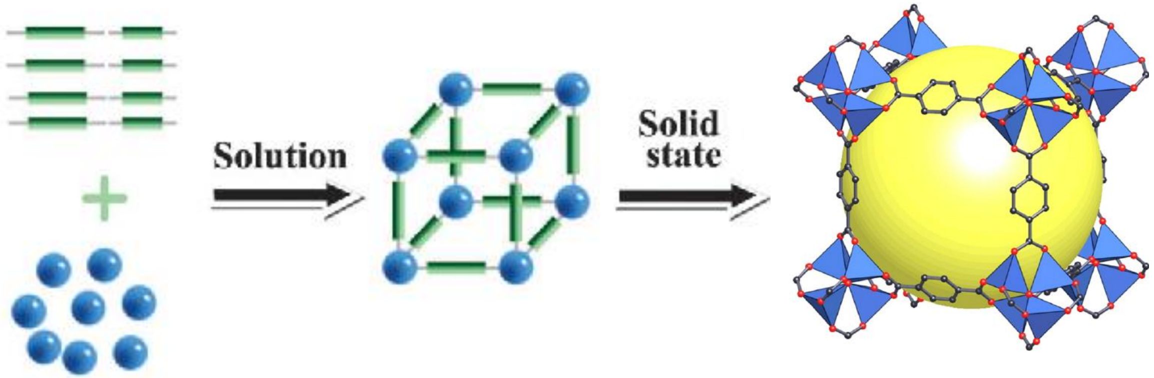


Sensing mechanism of electrochemical CO_2 sensors via different nanomaterials

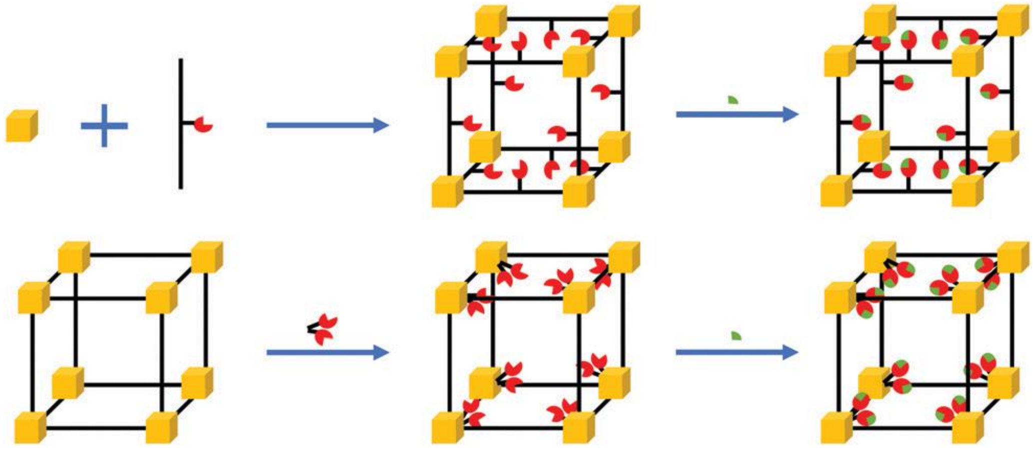
Research Gap & Limitations

- ☐ Lack of cost-effective, simple, and reliable monitoring methods
- ☐ How to quantify the likelihood for a potential leak to surface through well penetrations
- ☐ Difficulty with micro measurements
- ☐ Lack of cheap and reliable deploying method for sensors in deep sea
- ☐ Excluding the background interferences from seabed, *e.g.*, bioactivities producing CO_2, H_2S, *etc*.

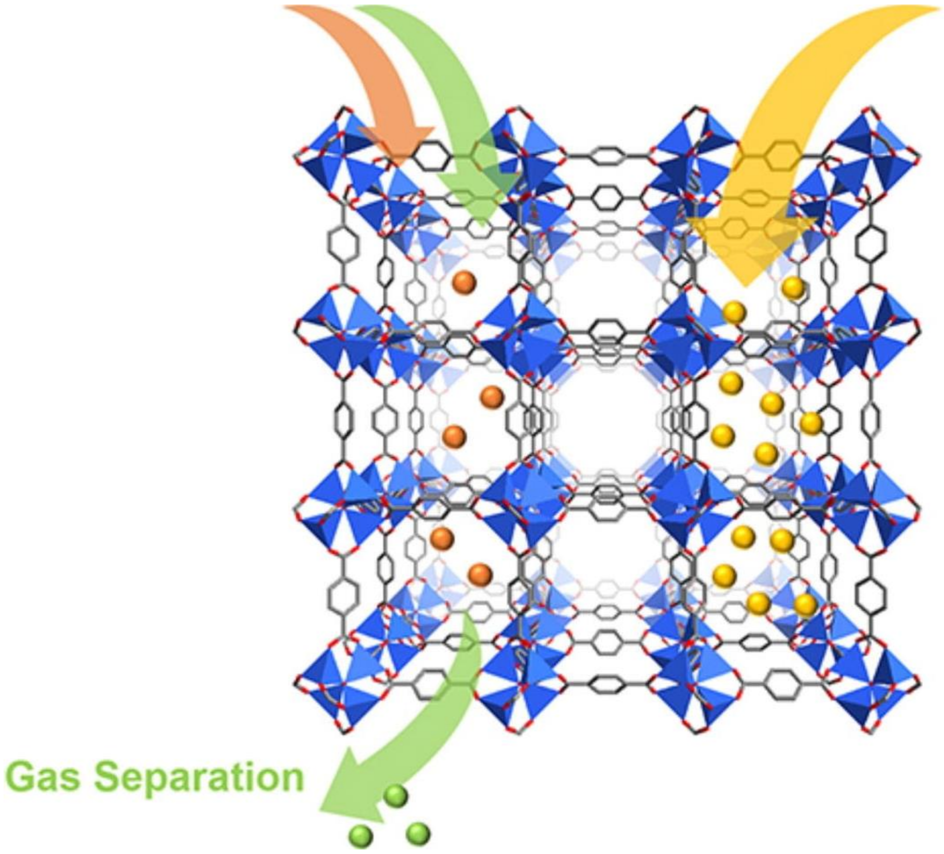
MOFs for Selective CO_2/H_2S Separation



Combination of ligand and metal ion for MOFs synthesis



Modifications of MOFs to promote selective CO_2 adsorption



MOFs for H_2S Removal

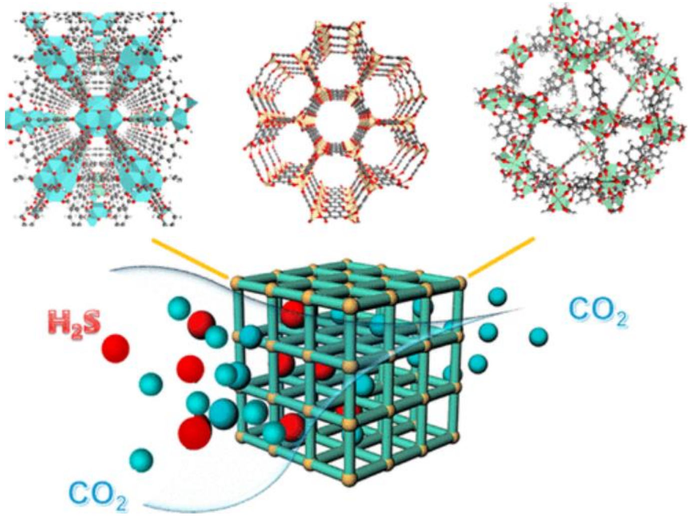
☐ Tip of the optical sensor will be composed of silicone membrane blended with MOFs

☐ The MOFs will selectively absorb H_2S, allowing only CO_2 to penetrate the sensor

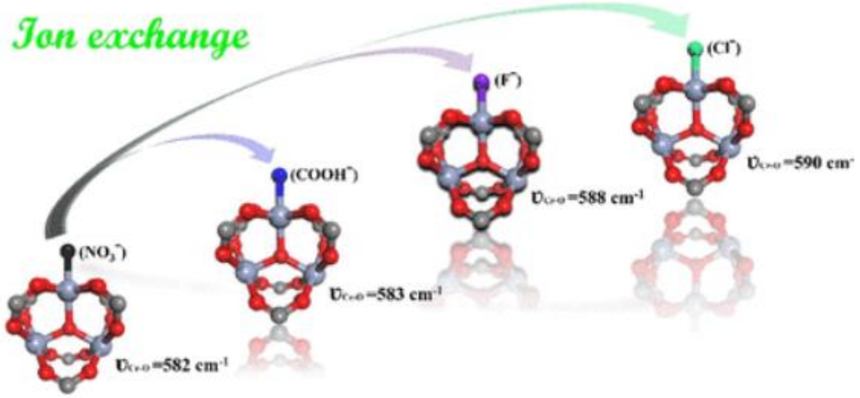
☐ Also, the MOFs can repel H_2S and allow CO_2 to pass

How to achieve these?

- Modulating the pore size of the MOFs for selective H_2S/CO_2 separation
- Ligand functionalization
- Tuning the metal clusters



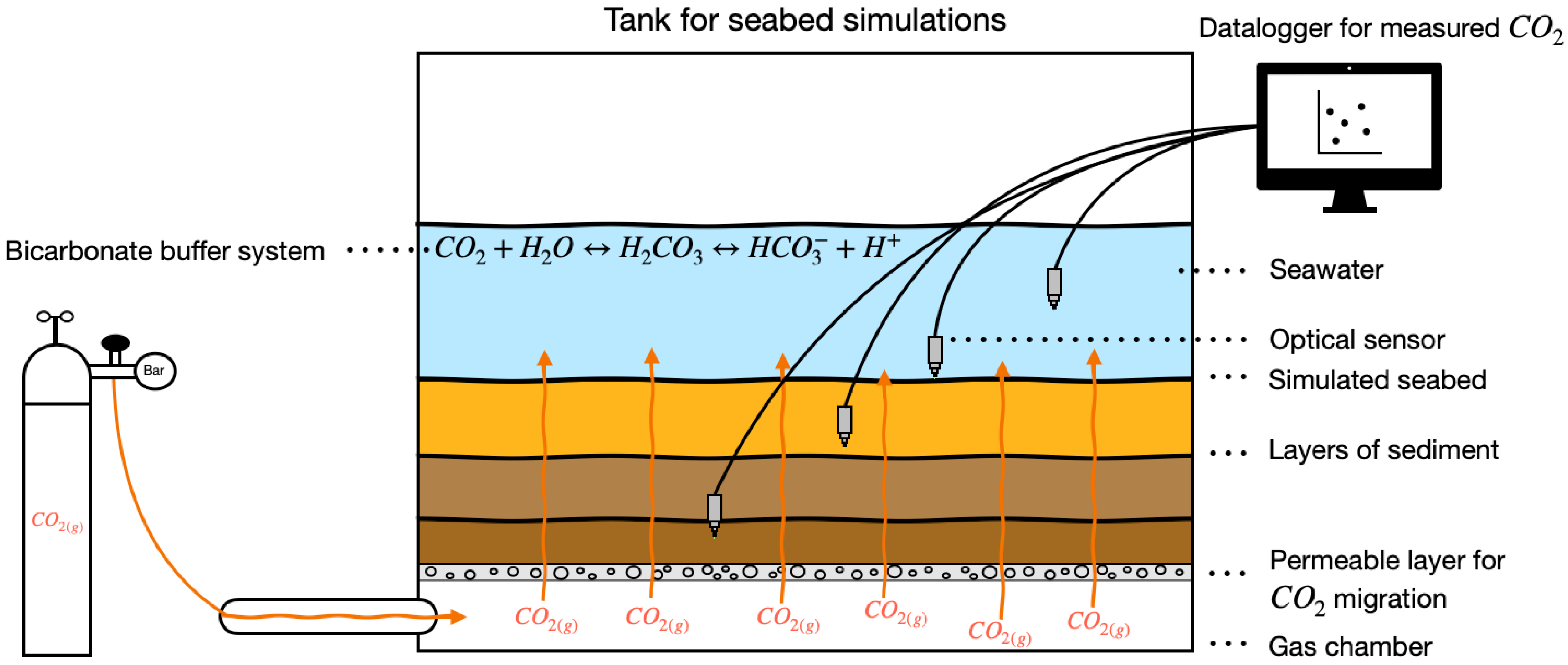
Size selective separation of molecules



Why CROSS - Fiber Optic CO_2 Sensor?

- ✓ **Cheap** fabrication due to the few components used
- ✓ No interference from **salty water and H_2S**
- ✓ **Easy to scale up** with no electrical interference generated by the sensors
- ✓ **Ease of use**
- ✓ **Self-developed digital control platform**
- ✓ **Online control**
- ✓ **DLR approach** more accurate readings and a long-life span for the sensor
- ✓ **Seamless solution** for CO_2 monitoring at CCS
- ✓ Applicable to **onshore CCS** where CO_2 leakage monitoring is of importance
- ✓ Can be used to monitor CO_2 emission **in wastewater treatment**, animal farm, industrial manufacturing sites, *etc*.

Online CO_2 monitoring in a mimic underwater environment



Unisense and WEI lab

Unisense

- Established in 1998 for developing, constructing, and applying microsensors
- The **world-leading** manufacturer of microsensors with over 20 years track record in Denmark
- Manufacture high-performance microsensors for a full range of applications in environmental and medical research

UNISENSE

WEI Lab

- **Many years of experience** in developing different physicochemical methods fit for the challenge of green transition in water and energy production
- Track records on many scientific publications (high IF) and US patent relating to water technology and sensor
- Experienced in design, preparation and modifications of **MOFs** for adsorption and catalytic removal of gaseous pollutants, such as CO_2, H_2S, HCHO, *etc*.

DTU Offshore

Danish Offshore Technology Centre

Danish Offshore Technology Conference 2022

R&D for the Offshore Energy Transition

AARHUS
UNIVERSITY