

**Chemical-free  
regeneration of macro-  
porous anion-exchange  
adsorbers  
for the removal of Natural  
Organic Matter (NOM)**



**Mathias Ernst  
DVGW Research Centre  
Hamburg University of  
Technology**



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# Chemical-free regeneration of macro-porous anion-exchange adsorbers for the removal of Natural Organic Matter (NOM)

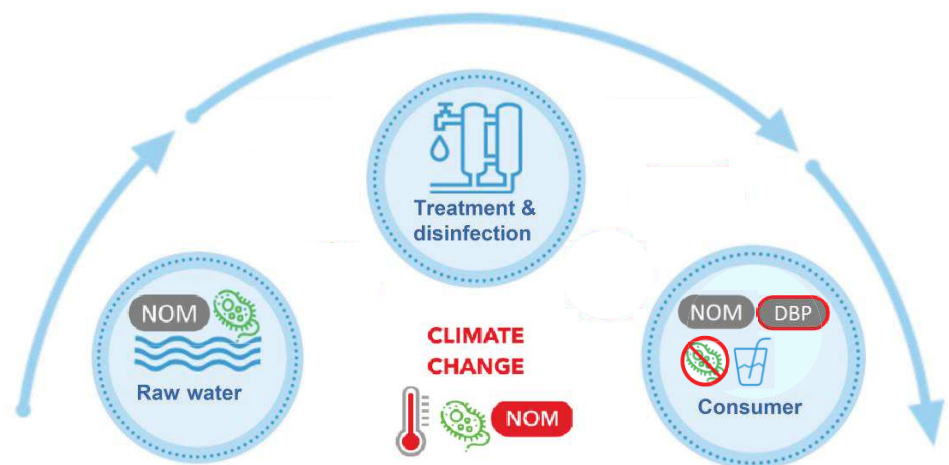
Mathias Ernst, Jon Wullenweber,  
Shahrokh Vahedi, Julia Bennert



**TUHH**  
Technische  
Universität  
Hamburg



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www.safecrew.org

## Natural Organic Matter (NOM):

- ❖ Complex mix of humic substances, proteins, amino acids, hydrocarbons, and polysaccharides
- ❖ Main precursor compounds of DBPs<sup>1</sup>
- ❖ Undesired water characteristics

Humic substances represent up to 90% of DOC<sup>2</sup>

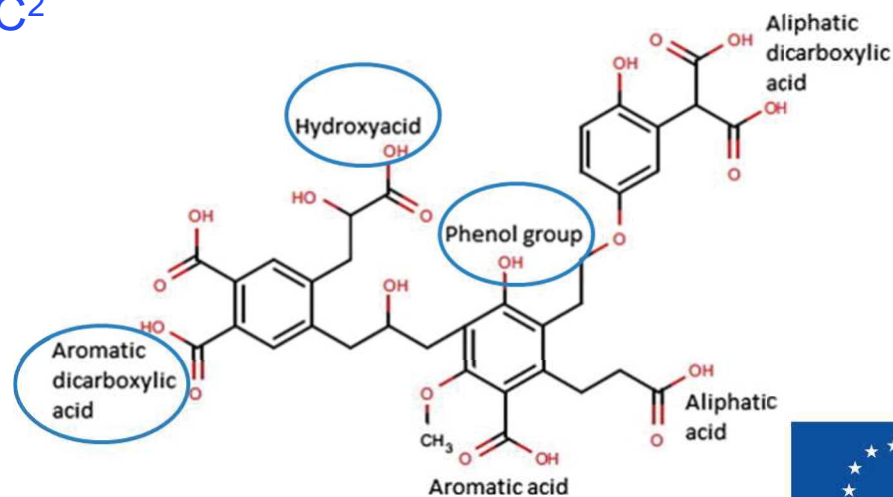
- ❖ HSs are negatively charged at neutral pH<sup>3,4</sup>

Potential for **electrostatic adsorptive** treatment methods:

→ **Ion Exchange Membrane Adsorbers**

Major Drawback: Chemical Regeneration

→ **Electrochemical Regeneration**



Humic acid model compound (Sillanpää, 2015)



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# SafeCREW tested, porous Membranes

| Membrane                          | Manufacturer           | Base material            | Coating         | Permeability<br>(LMH/bar) | z potential<br>at pH 7 (mV) | Pore Size<br>(nm) | E-Sorption &<br>-desorption |
|-----------------------------------|------------------------|--------------------------|-----------------|---------------------------|-----------------------------|-------------------|-----------------------------|
| Microlon 50                       | Membrana               | Polyamide                | Au              | 3000                      | +13.5                       | ~100              | +                           |
| Microlon 05 <sup>2</sup>          | Membrana               | Polyamide                | Au              | 1400                      | +13.5                       | ~40               | +                           |
| Nylon plus                        | Roche                  | Polyamide/Nylon          | Au              | 3900                      | -2                          | 450               | +                           |
| ROTI <sup>®</sup> Nylon (neutral) | Carl Roth              | Polyamide/Nylon          | Au              | ~4000                     | -30                         | 450               | o                           |
| ROTI <sup>®</sup> Nylon plus      | Carl Roth              | Polyamide/Nylon          | Au              | ~4000                     | +2                          | 450               | +                           |
| UP150 <sup>1</sup>                | Microdyn Na.           | Polyethersulfone         | Au              | 280                       | -28                         | 23                | -                           |
| UP150 + Cysteamine                | Microdyn Na.           | Polyethersulfone         | Au              | 280                       | -11                         | 23                | o                           |
| UV150                             | Microdyn Na.           | PVDF                     | Au              | 280                       | -33                         | 23                | -                           |
| DuraPES200                        | Membrana               | Polyethersulfone         | Au              | 25000                     | -42                         | 200               | -                           |
| DuraPES200+<br>Cysteamine         | Membrana               | Polyethersulfone         | Au              | 25000                     | -30                         | 200               | o                           |
| PAN-NH <sub>2</sub> <sup>3</sup>  | HZG <sup>4</sup>       | Polyacrylonitrile        | Au/Pt           | 1700                      | +9                          | 25                | o                           |
| PAN virgin <sup>3</sup>           | HZG <sup>4</sup>       | Polyacrylonitrile        | Au/Pt           | 1870                      | -33                         | 25                | -                           |
| PAN-EDA <sup>3</sup>              | <b>HZG<sup>4</sup></b> | <b>Polyacrylonitrile</b> | <b>Au/Pt/Ag</b> | <b>1770</b>               | <b>+10.5</b>                | <b>25</b>         | <b>++</b>                   |
| PAN-NaOH <sup>3</sup>             | HZG <sup>4</sup>       | Polyacrylonitrile        | Au/Pt           | 1650                      | -17.5                       | 25                | o                           |
| Sartobind Q                       | Sartorius              | Reg. cellulose           | Ni              | 18000                     | +13                         | >3000             | -                           |
| Sartobind STIC                    | Sartorius              | Reg. cellulose           | Ni              | 18000                     | +7                          | >3000             | +                           |
| Sartobind D                       | Sartorius              | Reg. cellulose           | Ni              | 18000                     | +20                         | >3000             | +                           |

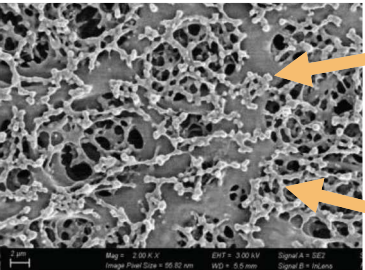
<sup>1</sup>(Mantel et al. 2018), <sup>2</sup>(Mantel et al. 2021b), <sup>3</sup>(Usman et al. 2024), <sup>4</sup>(Glass et al. 2021)

| Membrane    | Manufacturer     | Base material     | External<br>Electrodes <sup>5</sup> | Permeability<br>(LMH/bar) | z potential at<br>pH 7 | Pore Size<br>(nm) | Sorption &<br>E-desorption |
|-------------|------------------|-------------------|-------------------------------------|---------------------------|------------------------|-------------------|----------------------------|
| Sartobind Q | Sartorius        | Reg. cellulose    | SSM, SS, GF                         | 18000                     | +13                    | 3000              | o                          |
| Sartobind D | Sartorius        | Reg. cellulose    | SSM, SS, GF                         | 18000                     | +20                    | 3000              | ++                         |
| PAN-EDA     | HZG <sup>4</sup> | Polyacrylonitrile | SSM, SS, GF                         | 1100                      | +10.5                  | 25                | o                          |

## Strong basic vs. weak basic ion-exchange membrane adsorber

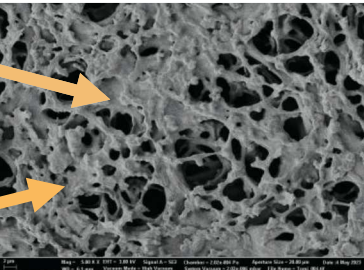
**Sartobind® Q:**  
**strong basic**

Quarternary Amine:  $R-CH_2-N^+(CH_3)_3$   
Approx. pKs: 11



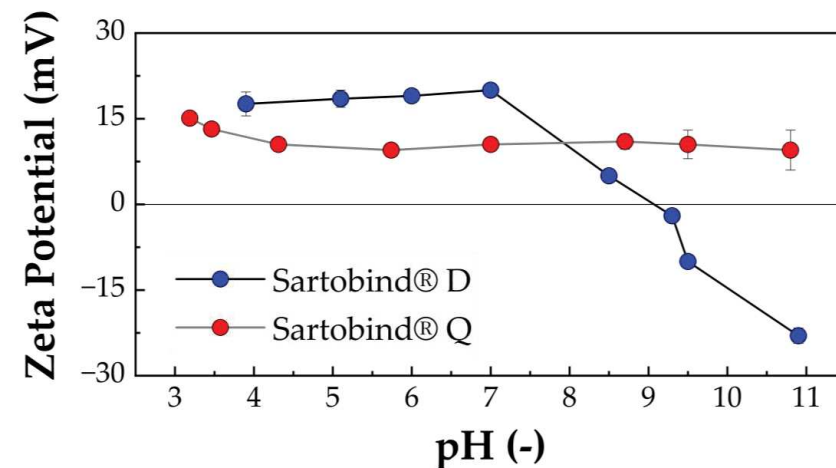
**Sartobind® D:**  
**weak basic**

Diethylamine:  $R-CH_2-N(C_2H_5)_2$   
Approx. pKs: 9.5



Primary Porosity

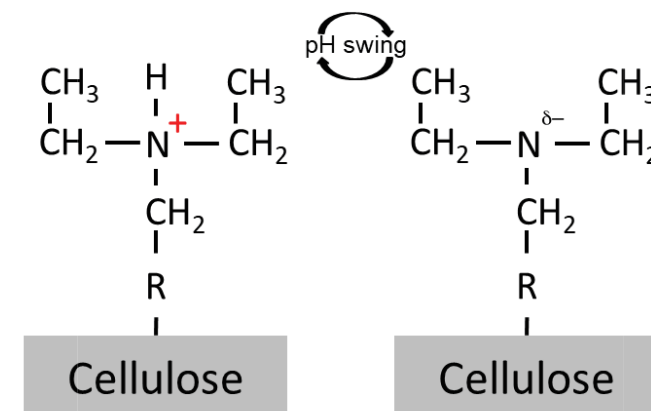
Secondary Porosity

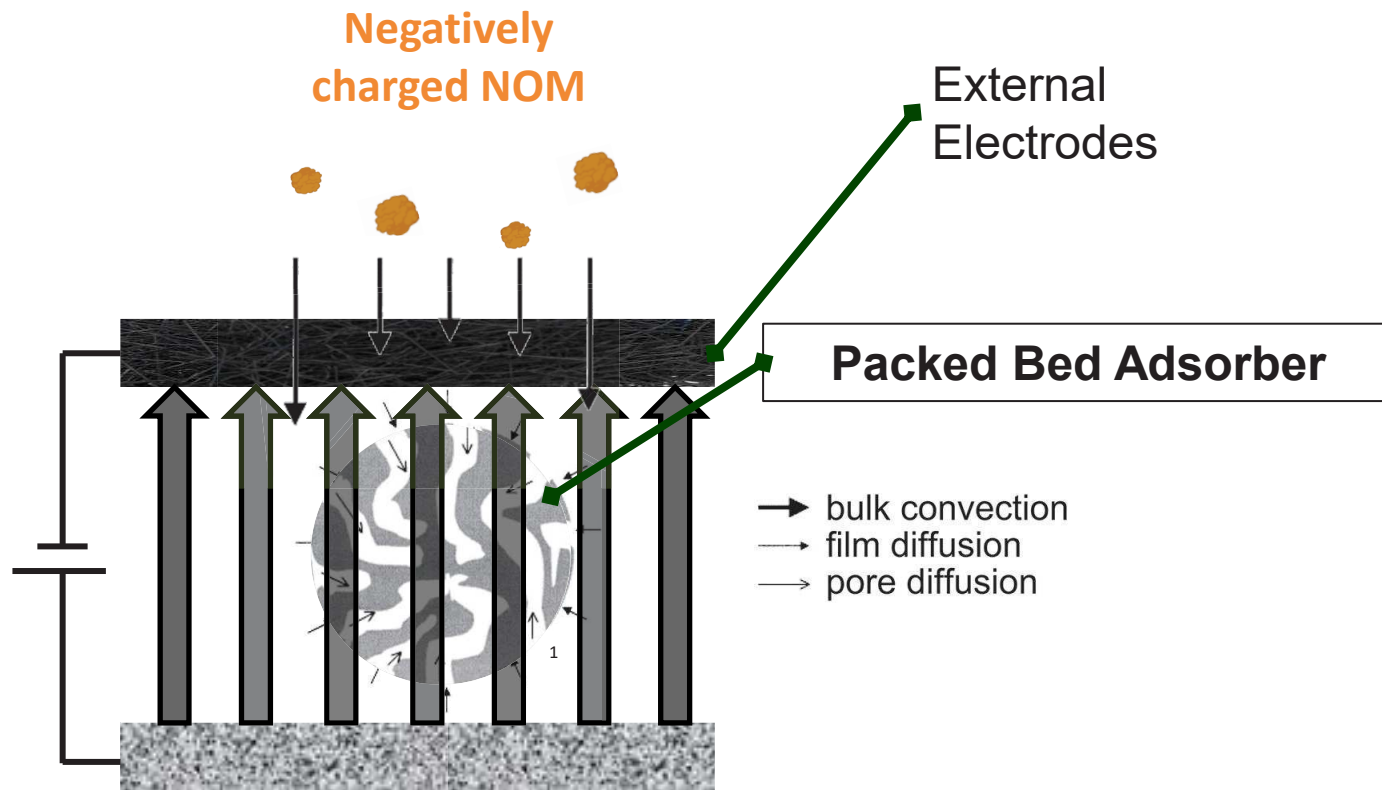


[Adapted from Wullenweber et al. 2024]

## Electrochemical in-situ pH control

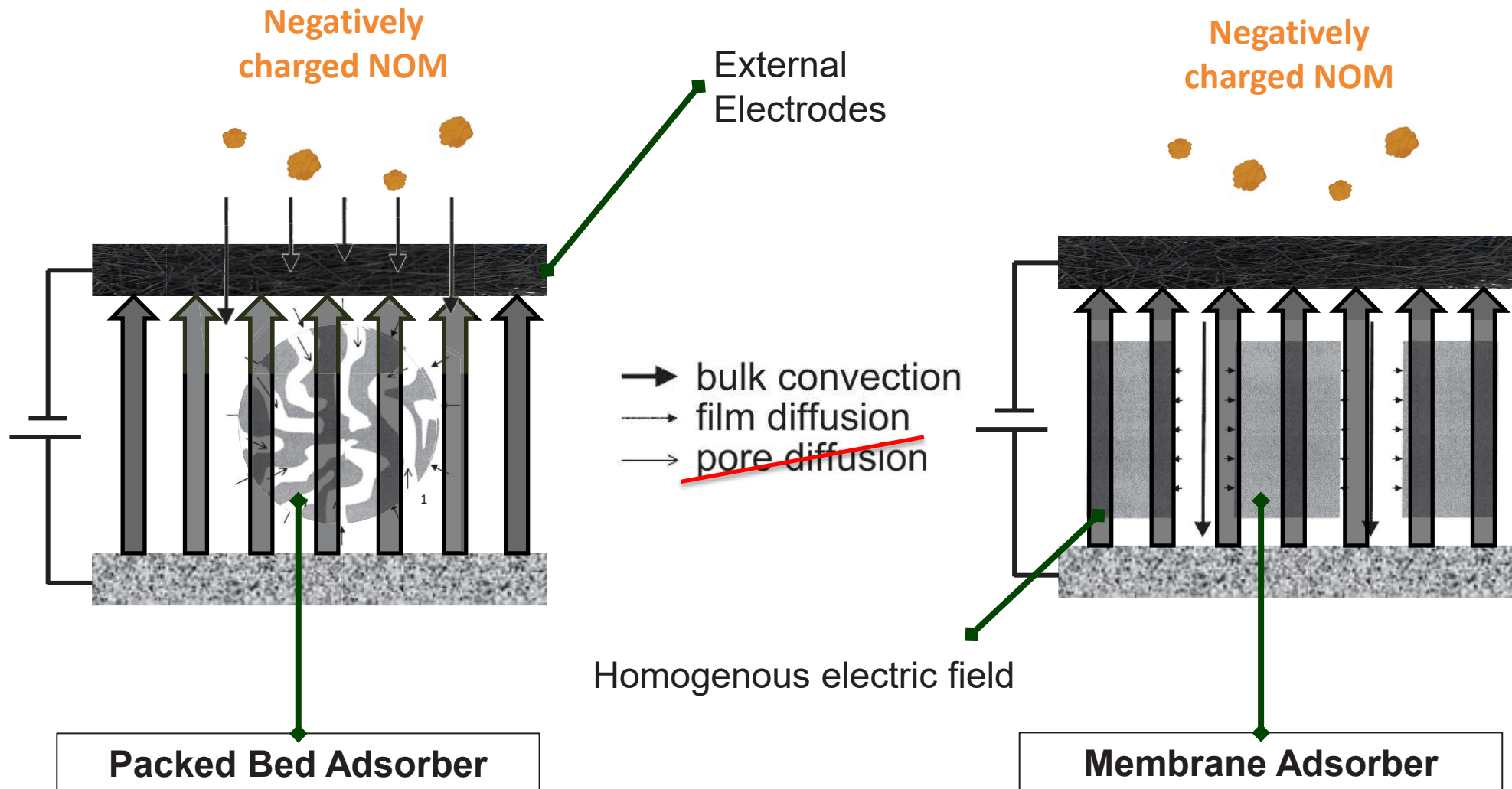
| Alkaline Pathways    | Reactions                                     | $E^0$ vs. RHE  |
|----------------------|---|----------------|
| Direct four-electron | $O_2 + 2 H_2O + 4e^- \rightarrow 4 OH^-$      | <b>1.230 V</b> |
| Two-electron         | $O_2 + H_2O + 2e^- \rightarrow HO_2^- + OH^-$ | <b>0.695 V</b> |
|                      | $HO_2^- + H_2O + 2e^- \rightarrow 3 OH^-$     | <b>1.776 V</b> |





<sup>1</sup>Adapted from Qu et al. 2023

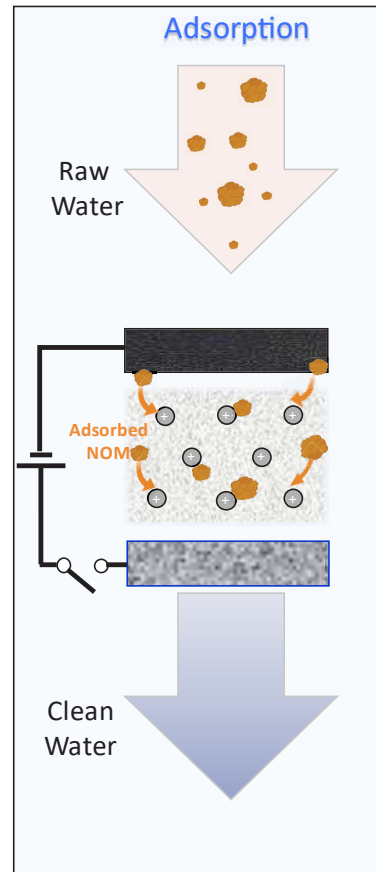




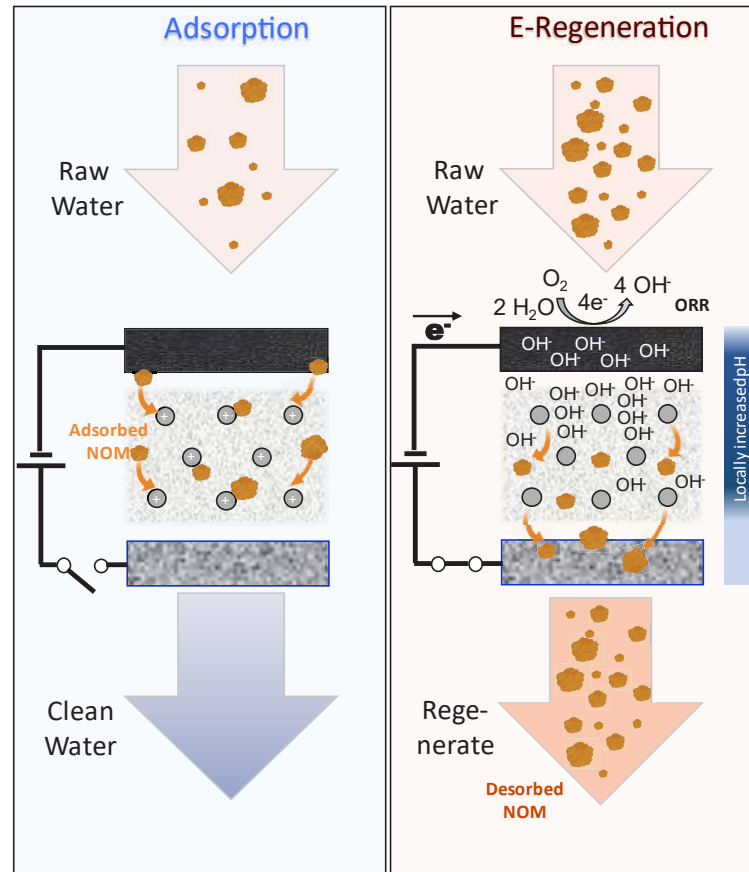
<sup>1</sup>Adapted from Qu et al. 2023

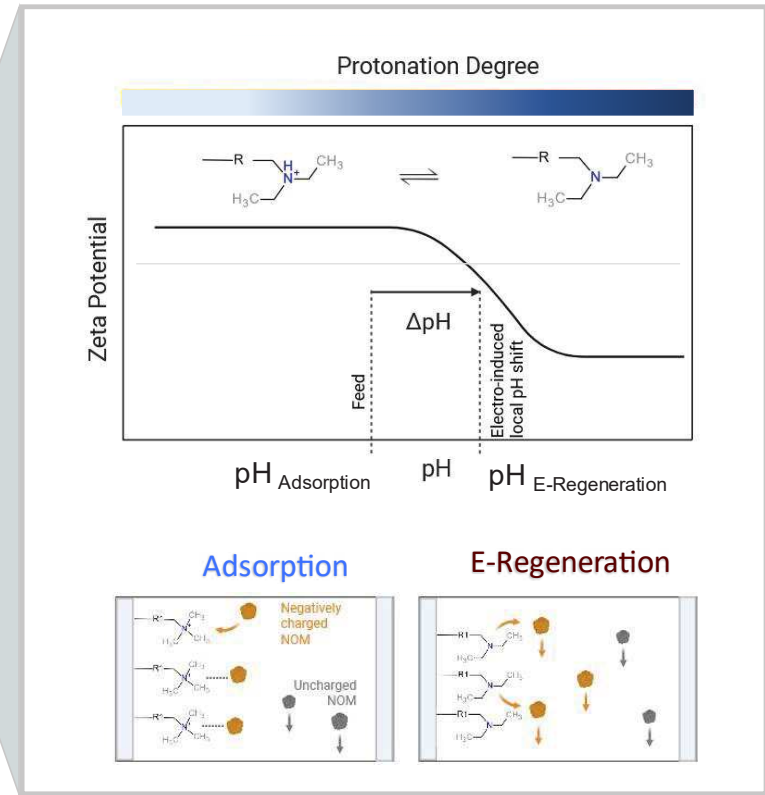
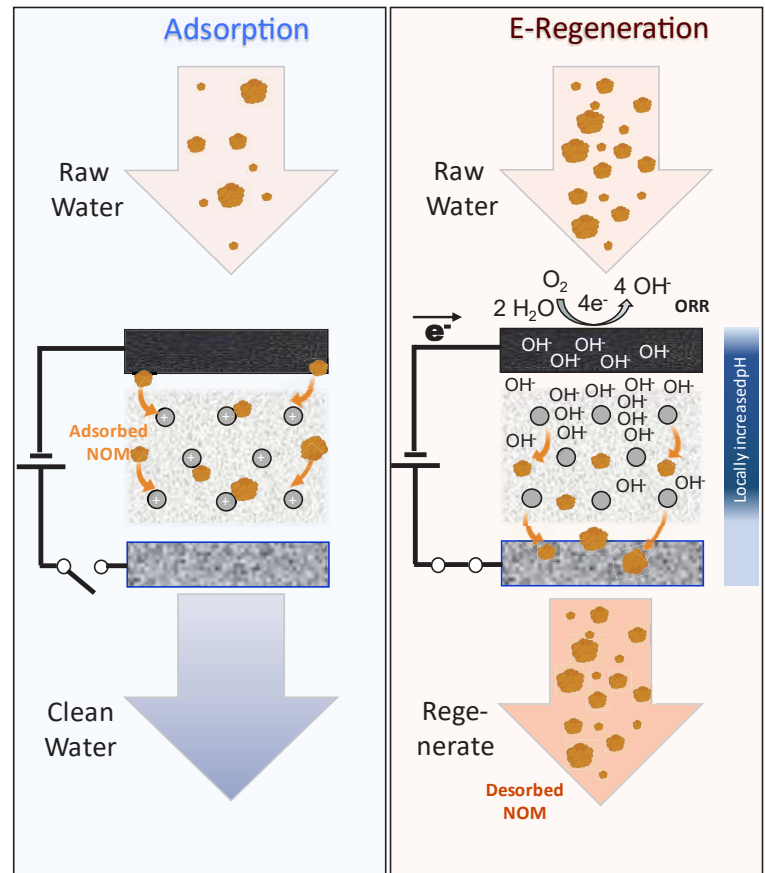


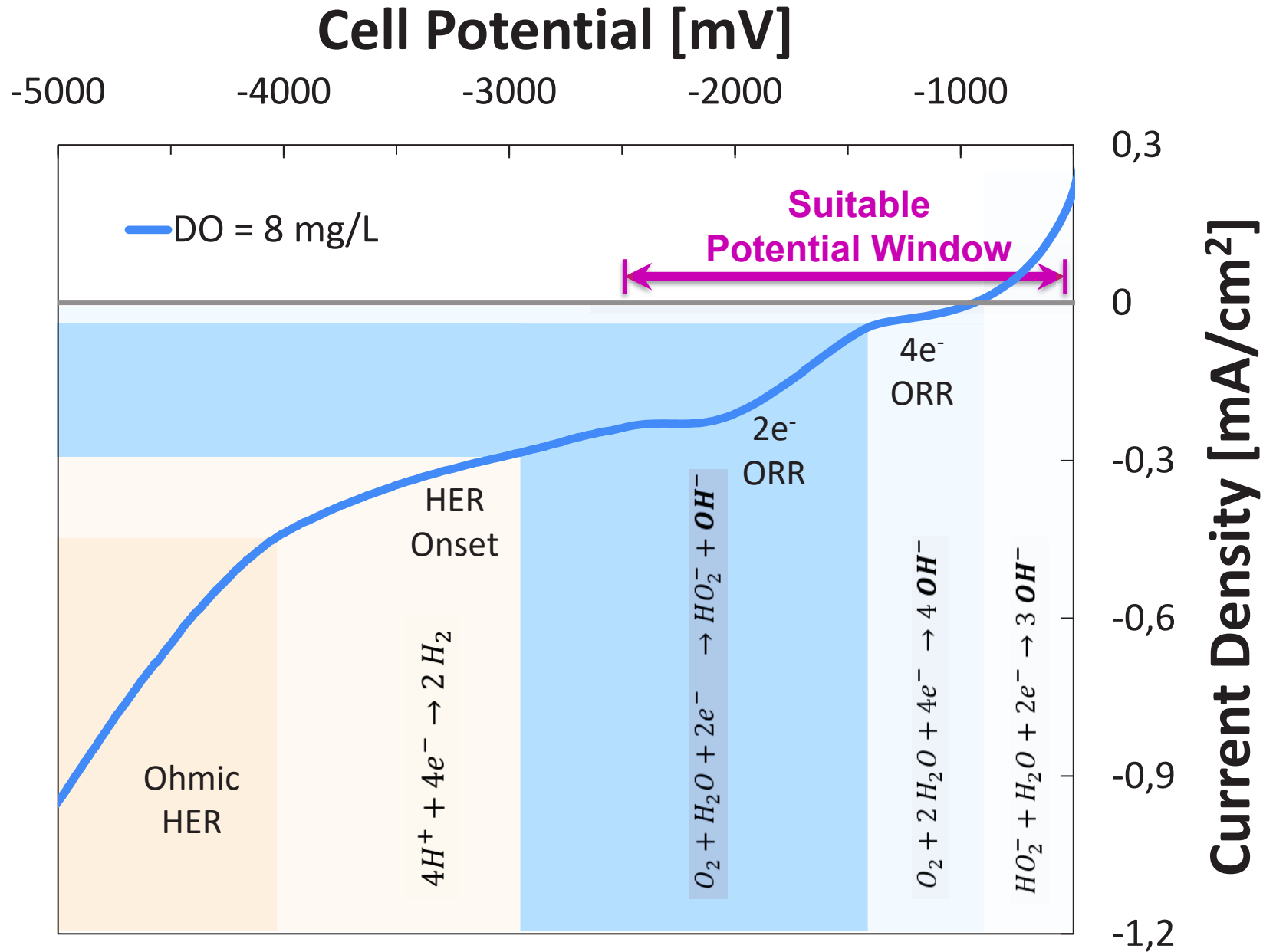
# Adsorptive Membrane for NOM removal



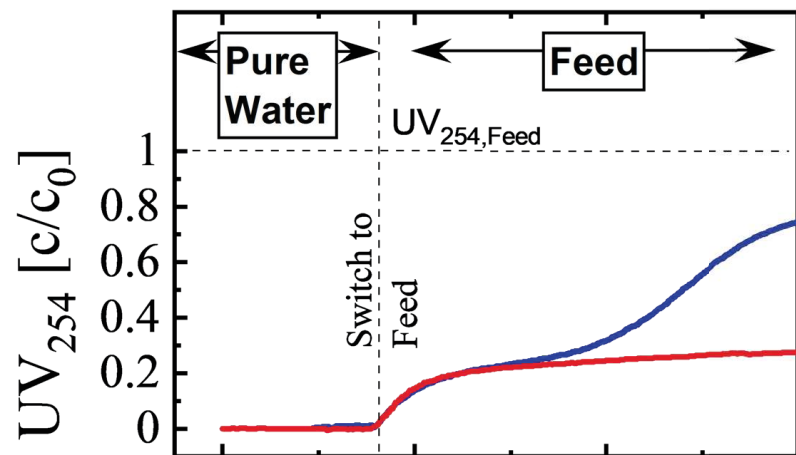
# Electrochemical induced Regeneration







## Adsorption

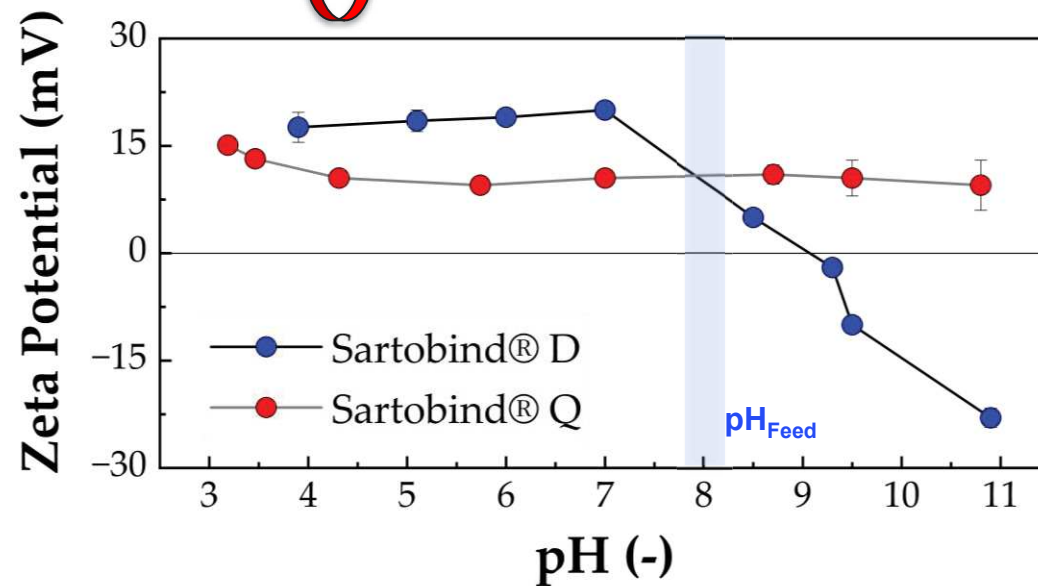
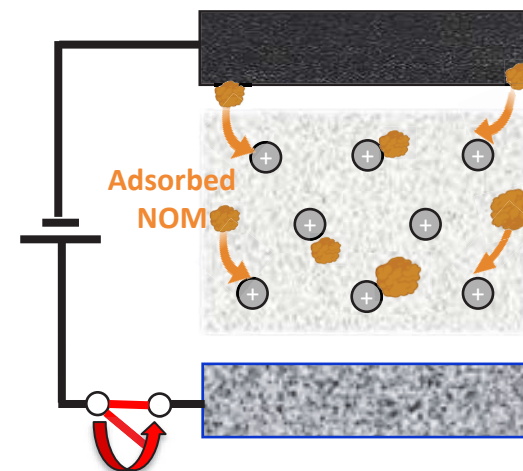


**Sartobind D**  
(weak basic)

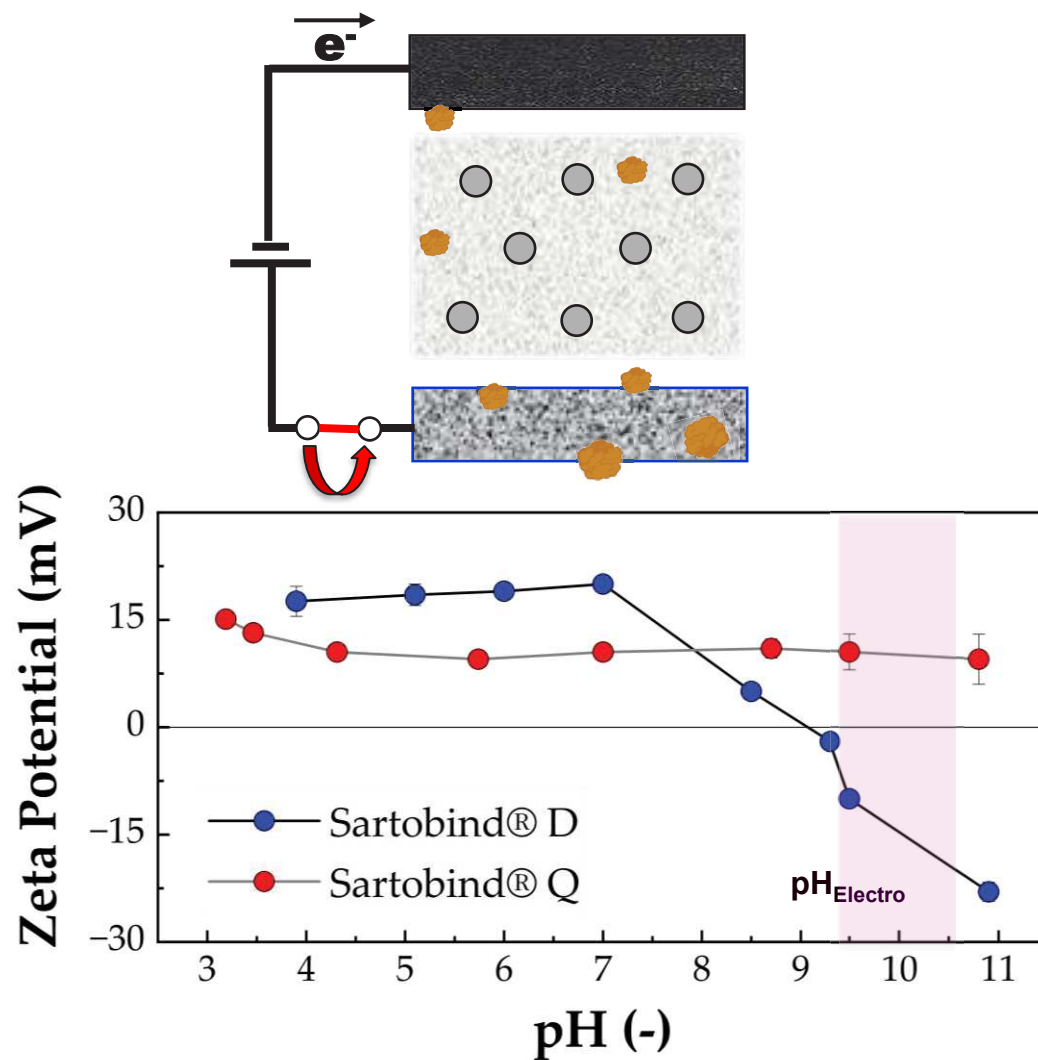
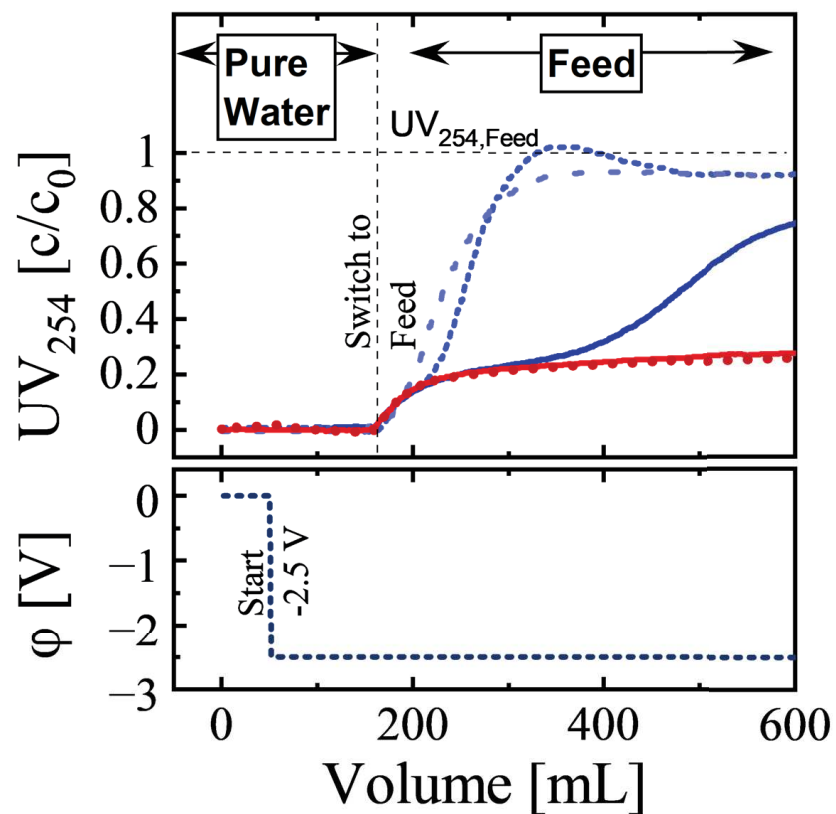
— 0 V

**Sartobind Q**  
(strong basic)

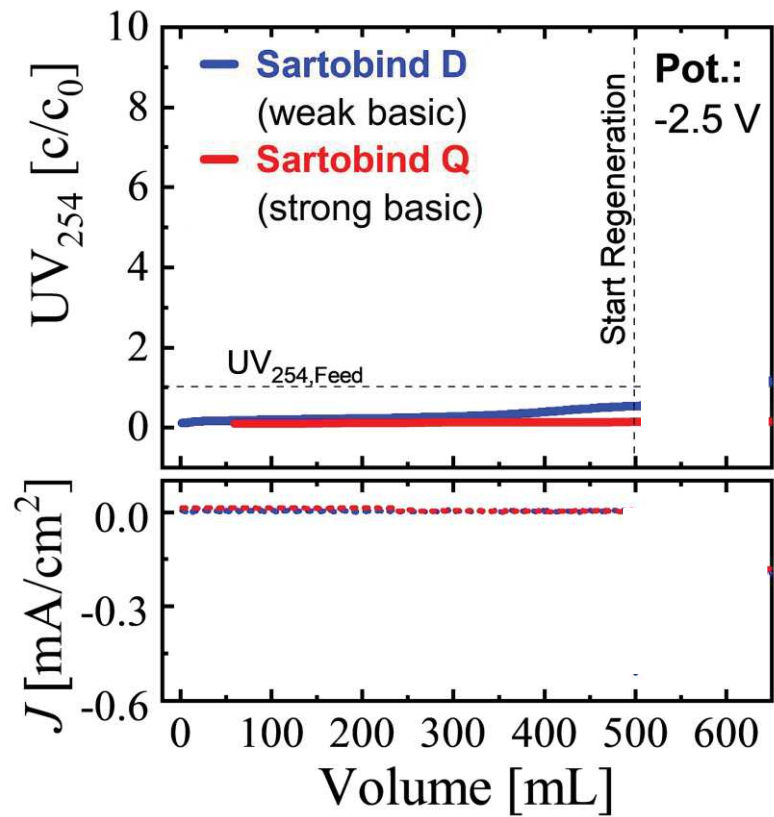
— 0 V



## Electro Selective Adsorption

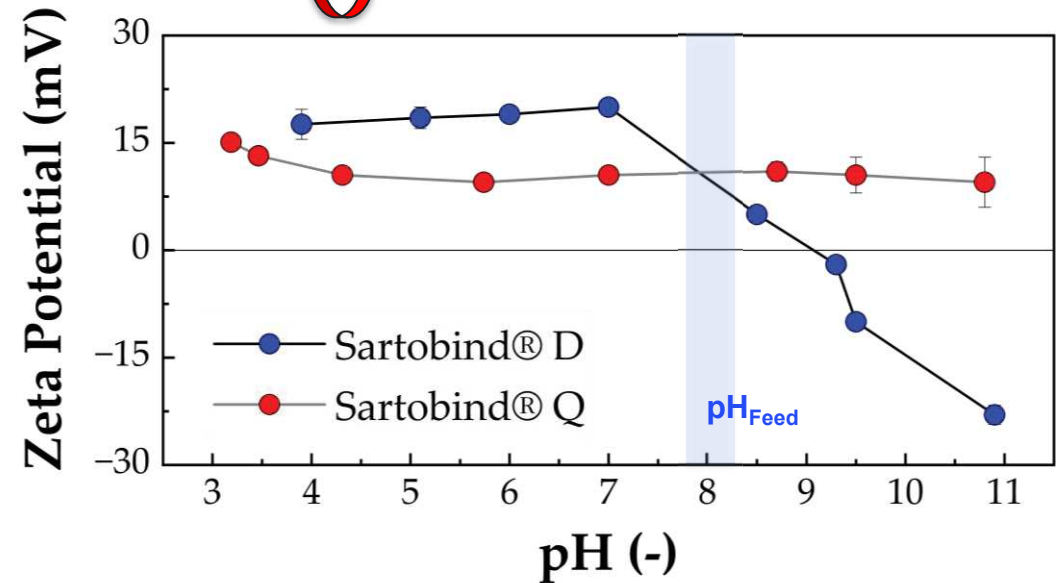
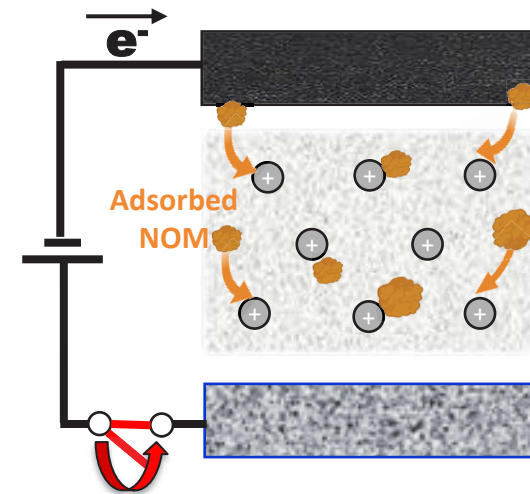


## Adsorption

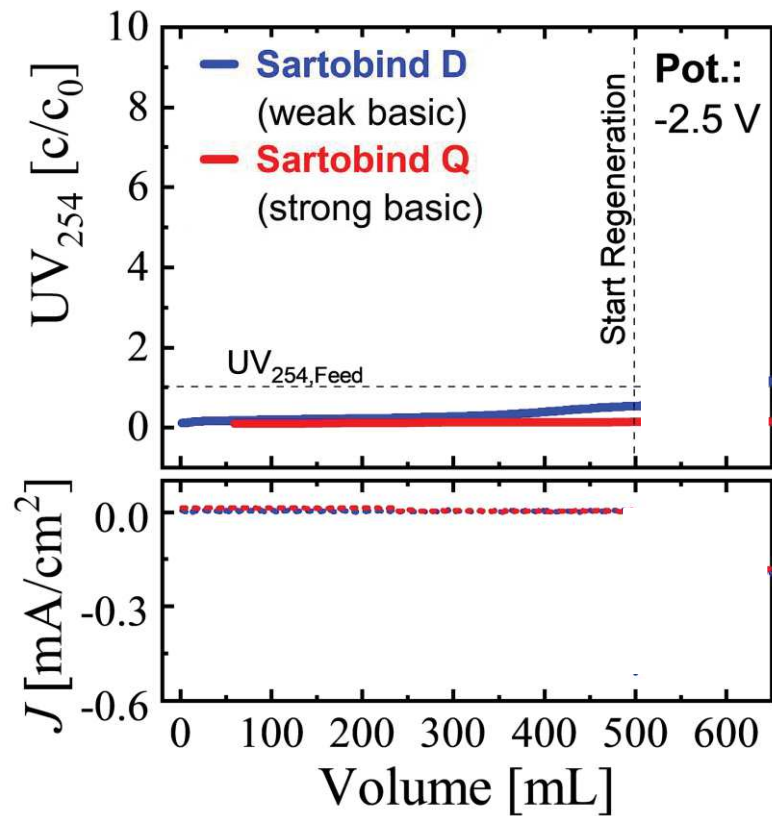


**Sartobind D**  
(weak basic)

**Sartobind Q**  
(strong basic)

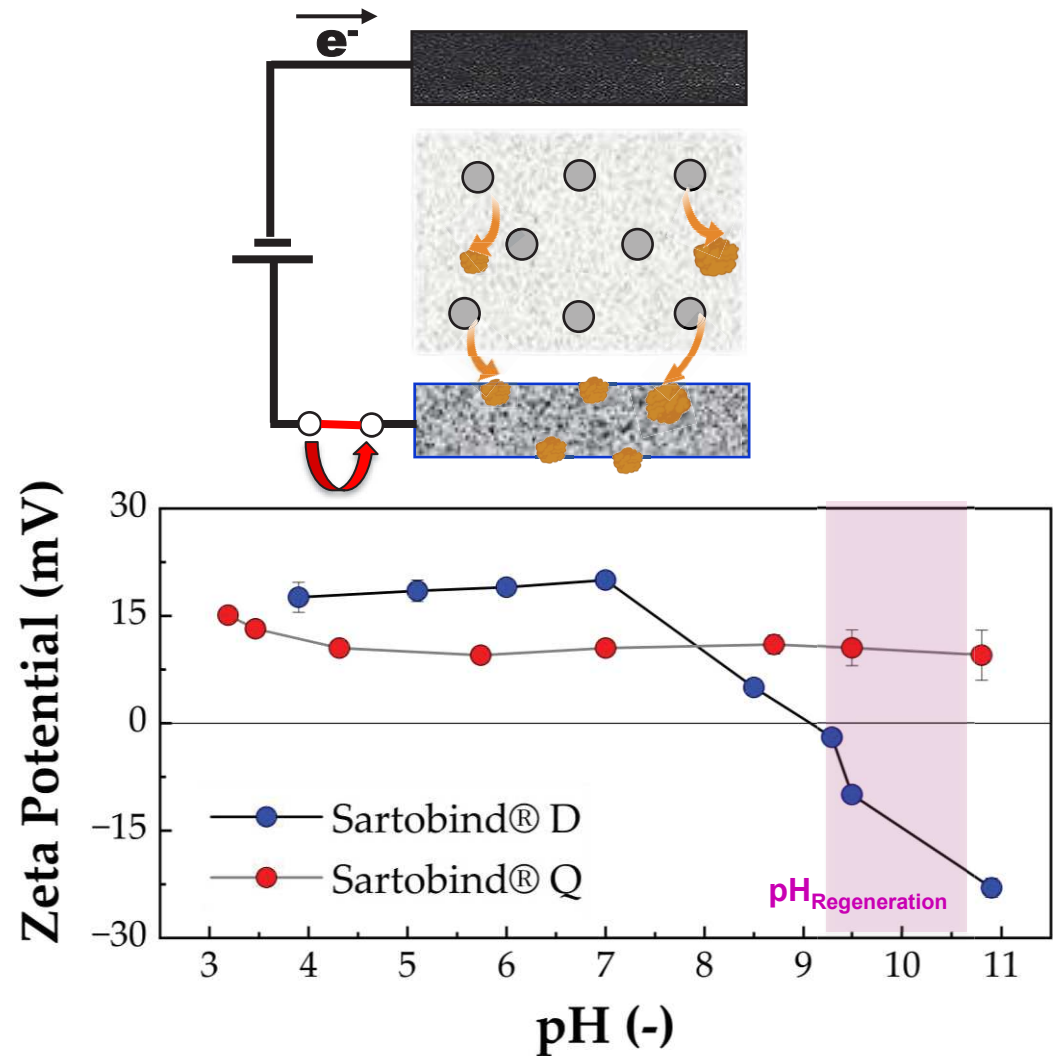


## E-Regeneration

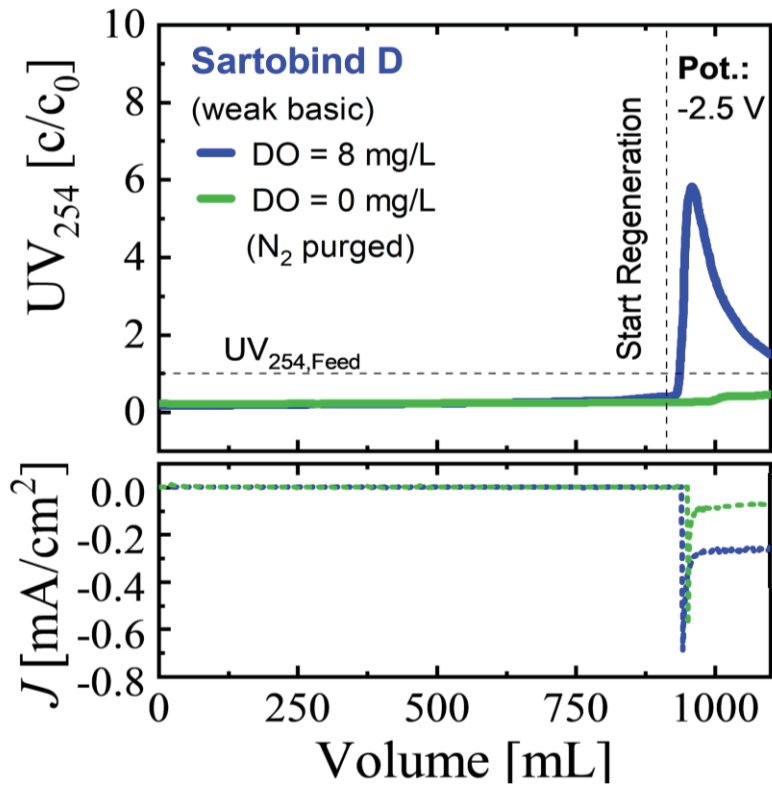


**Sartobind D**  
(weak basic)

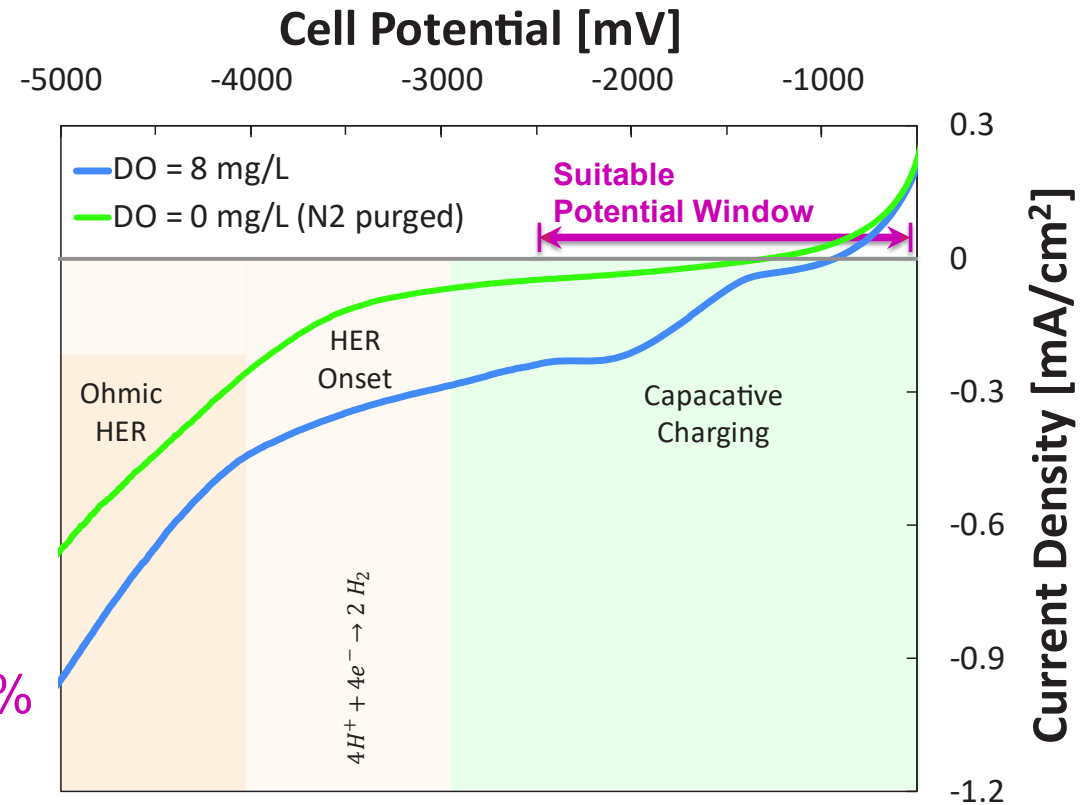
**Sartobind Q**  
(strong basic)



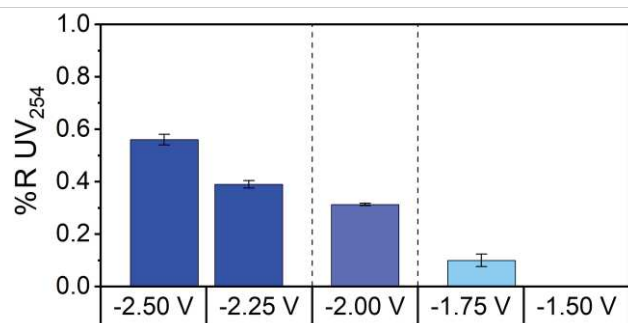
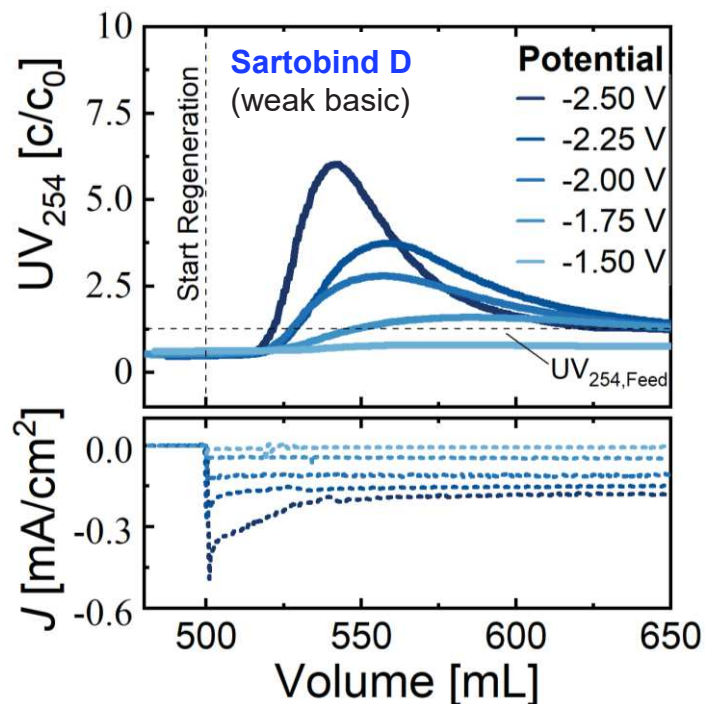
## O<sub>2</sub> vs N<sub>2</sub>



Farradaic Efficiency  
 $\eta_{\text{ORR}} = 75\%$



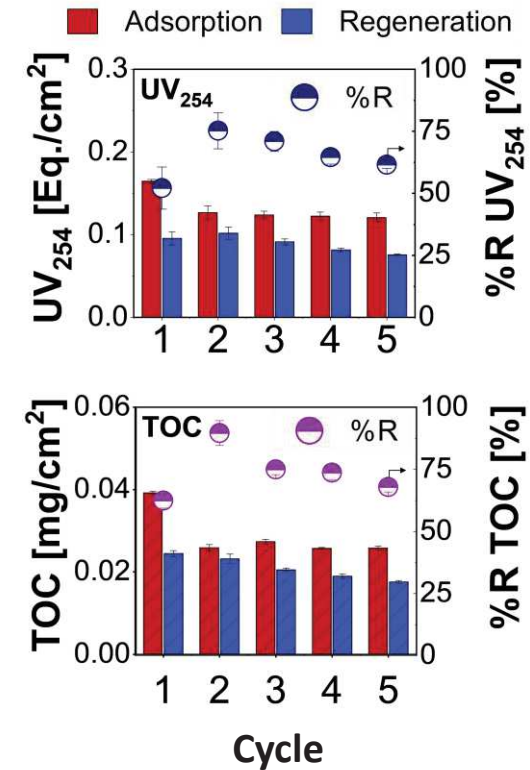
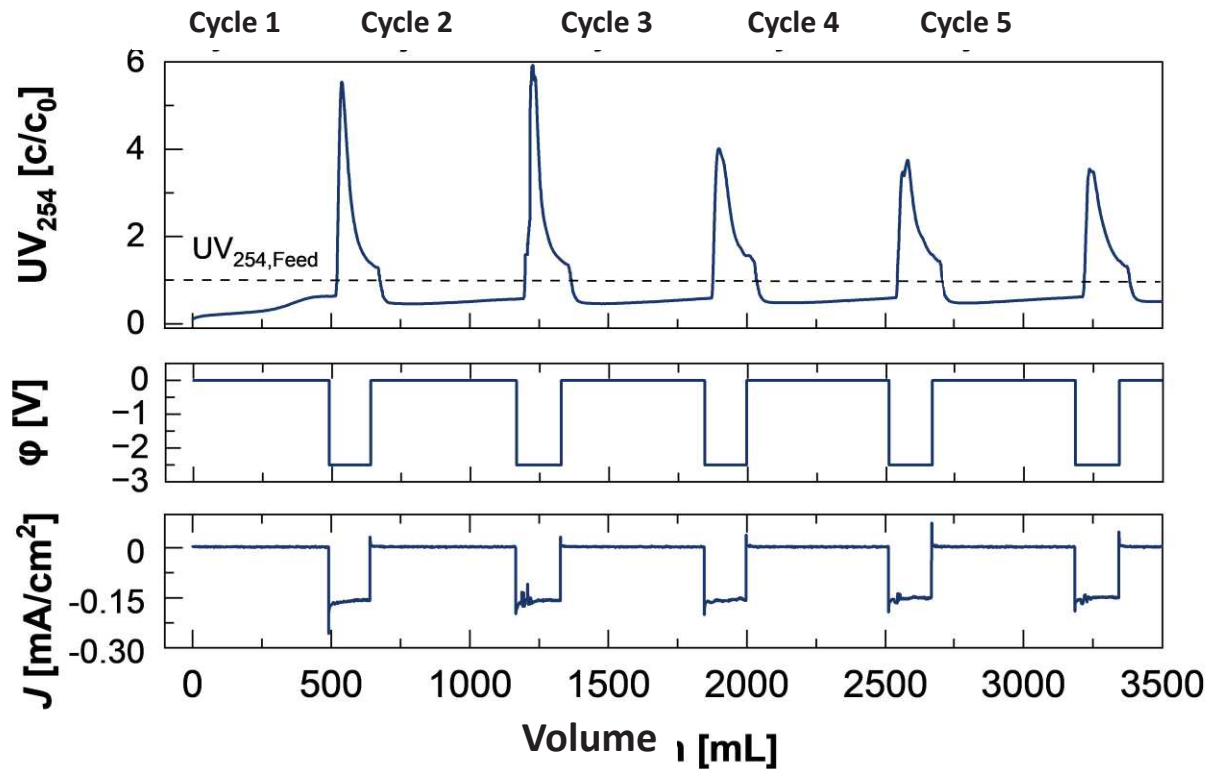
## Variation of Potential



- %R UV<sub>254</sub> increases with applied potential
- Significant increase in regeneration efficiency occurs between -1.75 V & -2.00 V
- Half-wave potential observed at -2.00 V C.P.
- Maximum %R UV<sub>254</sub> at -2.50 V vs. C.P



# Cyclic Process: electro-sorption/-desorption



- Highest adsorption capacity in 1st cycle.
- %Regeneration peaks in 2nd cycle.
- "Weaker adsorbing" sites dominate after 1<sup>st</sup> cycle, enabling better regeneration.
- Almost no energy required (appr. 10 W/m<sup>3</sup>)

- Adsorber sites are electrochemically tunable, electro-induced regeneration enables chemical-free membrane cleaning
- Oxygen reduction causes localized in-situ pH
- Regeneration efficiency improves with higher applied electric potential
- Optimal operation at ~100 LMH balances mass transfer limitations
- Microfiltration energy use is low (~0.1 kWh/m<sup>3</sup>) with NOM removal comparable to energy-intensive nanofiltration.
- Electro-regeneration adds minimal energy demand (~0.01 kWh/m<sup>3</sup>).



# Thank you for your attention!



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Website: [www.safecrew.org](http://www.safecrew.org)

LinkedIn: <https://www.linkedin.com/showcase/safecrew-org/>

X: @safeCREW\_org

E-Mail: [mathias.ernst@tuhh.de](mailto:mathias.ernst@tuhh.de)

## Disclaimer

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