Pre-processing: A new avenue for coal fly ash circular economy

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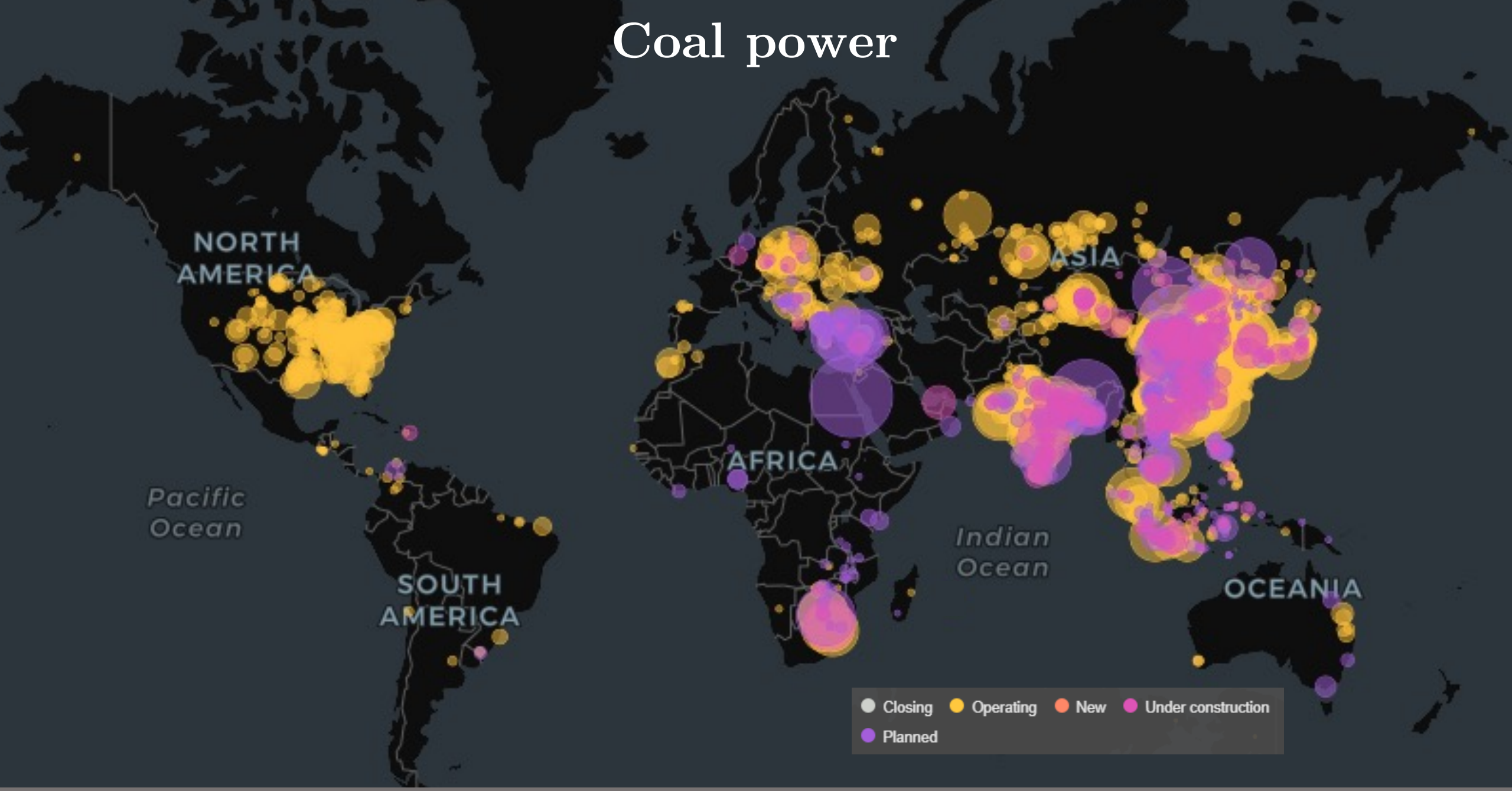
Coal power



Carbon Brief. (2018, June 5). Mapped: World's coal power plants. Carbon Brief. Retrieved March 28, 2023, from https://www.carbonbrief.org/mapped-worlds-coal-power-plants/

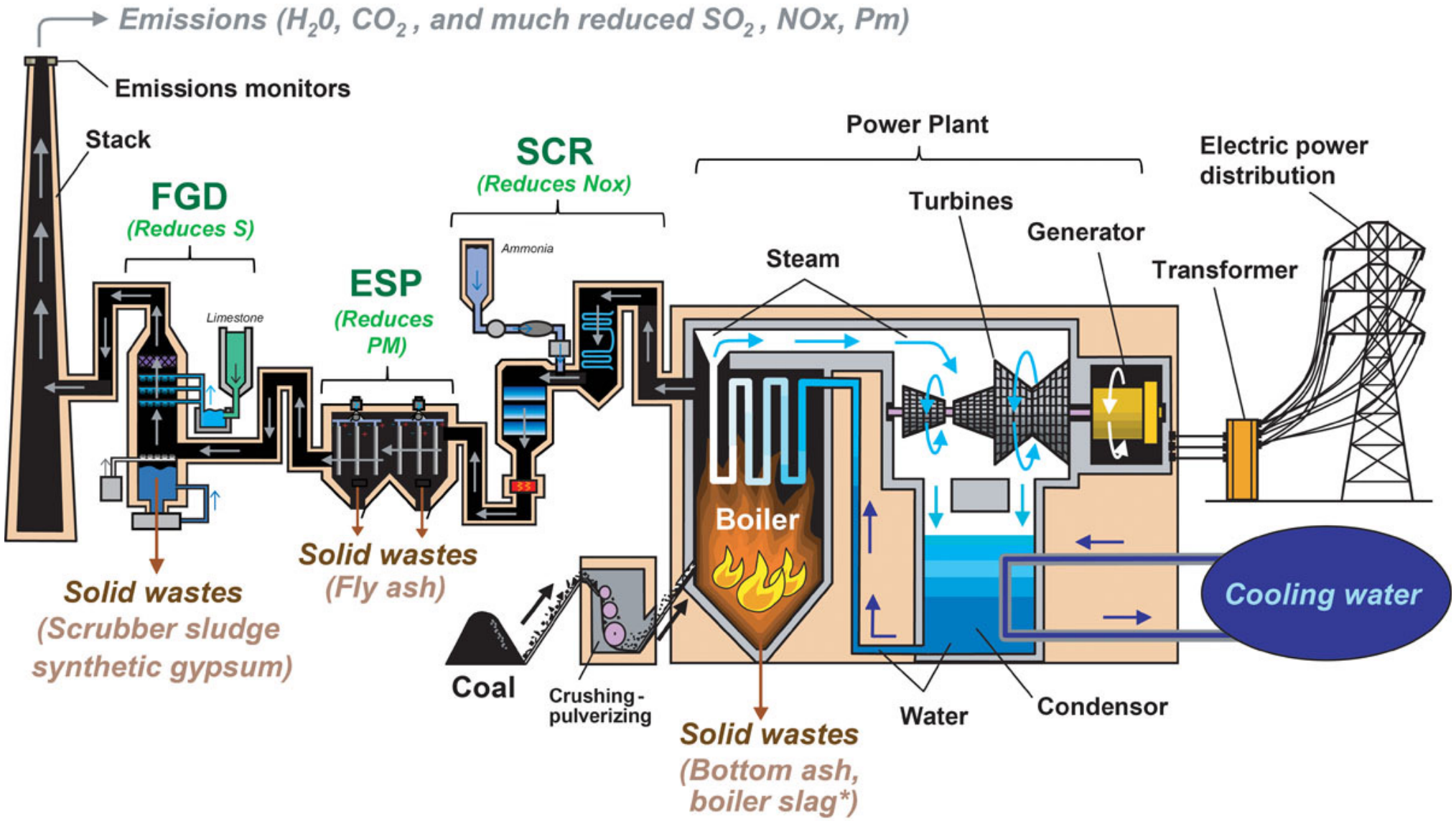
Electricity and coal

Breakdown of electricity sector supply – 2022[1]

- Most abundant fossil fuel
- Demand: 10,325 TWh hour
- Growth rate 2021 – 2022: 1.5%
- Forecast to plateau in 2023 - 2025 [1]

[1] International Energy Agency. (2022). World Energy Outlook 2022. International Energy Agency. Retrieved March 28, 2023, from https://www.iea.org/reports/world-energy-outlook-2022

Coal combustion products



[2] Kentucky Geological Survey. (n.d.). Coal Combustion By-Products. Kentucky Geological Survey. Retrieved March 28, 2023, from http://www.uky.edu/KGS/coal/coal-for-combustionbyproducts.php

Coal fly ash (CFA)

Coal and CFA[3]

- Alkaline component
- 65 – 90% total ash volume [4]
- Over 1 billion metric tonne/annum [5]
- Approximately 316 individual minerals and 188 mineral groups [6]
- Mainly composed of SiO_2 and Al_2O_3
- Size distribution of CFA particles from few nanometers to 500 micrometers [7]

[3] National Precast Concrete Association. (2013, October). The Future of Fly Ash Use in Concrete. Precast.org. https://precast.org/2013/10/future-fly-ash-use-concrete/
[4] F. Mushtaq, M. Zahid, I. A. Bhatti, S. Nasir, T. Hussain, Journal of envi-ronmental management 240, 27 (2019).
[5] D. Valeev, I. Kunilova, A. Alpatov, A. Varnavskaya, D. Ju, Minerals 9(5),320 (2019).
[6] Z. Yao et al., Earth-science reviews 141, 105 (2015).
[7] N. Wang, X. Sun, Q. Zhao, Y. Yang, P. Wang, Journal of hazardous materials 396, 122725 (2020).

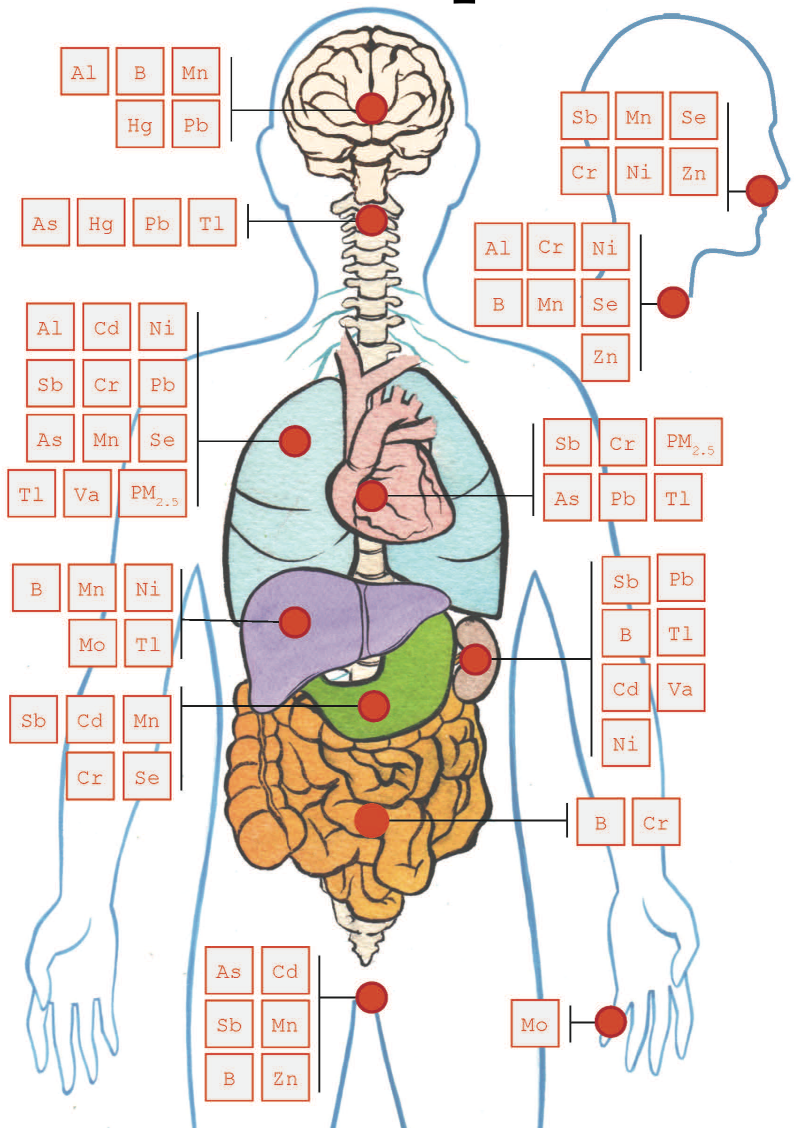
Disposal of CFA and associated environmental concerns

Coal fly ash disposal site[8]

- 40% of total CFA dumped[6]
- Dry storage – Landfills
  - Land exploitation
  - Air contamination
- Wet storage – Ash ponds
  - Usage of immense water
  - Leachability

[6] Z. Yao et al., Earth-science reviews 141, 105 (2015).
[8] DAE Pumps. (n.d.). Overcoming Coal Ash Pumping Challenges. DAE Pumps. https://www.daepumps.com/resources/overcoming-coal-ash-pumping-challenges/

Disposal of CFA and the living



Metal accumulation from breathing and ingesting coal fly ash[9]

Children at a coal fly ash disposal site in India[10]

Deformed Yellowstone trout[9]

[9] Earthjustice. (n.d.). Coal Ash Contaminated Sites Map. Earthjustice. Retrieved March 28, 2023, from https://earthjustice.org/feature/coal-ash-contaminated-sites-map

[10] Gaon Connection. (2020, June 3). Coal ash, air pollution, and health risks: How lockdown has worsened living conditions in Chhattisgarh and Tamil Nadu. Gaon Connection. Retrieved March 28, 2023, from https://en.gaonconnection.com/coal-ash-air-pollution-chhattisgarh-korba-tamil-nadu-covid19-lockdown-thermal-power-plants-health-risks/

Disposal of CFA and the living

- Cancer, lung and heart ailments, and neurological damage[11]
- DNA damages[12]
- Premature mortality[11]

Skin patches due to fly ash contaminated water, India[13]

Skin allergy, Sri Lanka[14]

[11] Panda, S. (2019, December 10). Coal ash is a serious hazard to our health and the environment. The Third Pole. Retrieved March 28, 2023, from https://www.thethirdpole.net/en/climate/coal-ash-is-a-serious-hazard-to-our-health-and-the-environment/#:~:text=Fly%20ash%20is%20left%20behind,and%20contribute%20to%20premature%20mortality.
[12] A. N. Hagemeyer, C. G. Sears, K. M. Zierold, International Journal of Environmental Research and Public Health 16(19), 3642 (2019)
[13] Earthjustice. (n.d.). Coal Ash Contaminated Sites Map. Earthjustice. Retrieved March 28, 2023, from https://earthjustice.org/feature/coal-ash-contaminated-sites-map
[14] Sunday Observer. (2018, June 17). Ash and Tears of Norochcholai. Sunday Observer. Retrieved March 28, 2023, from https://www.sundayobserver.lk/2018/06/17/news-features/ash-and-tears-norochcholai

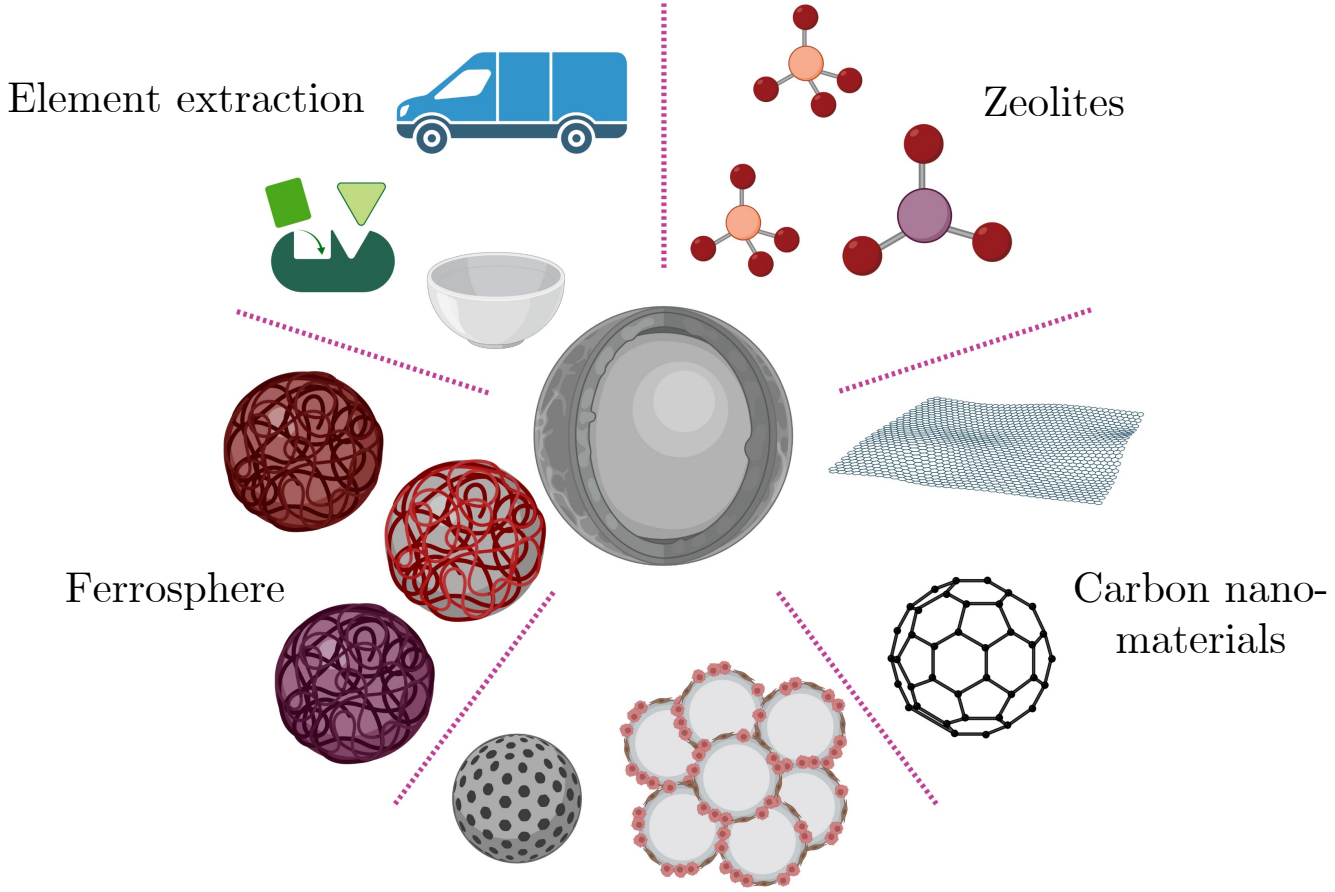
Uses of CFA

First generation uses

CFA cement[15]

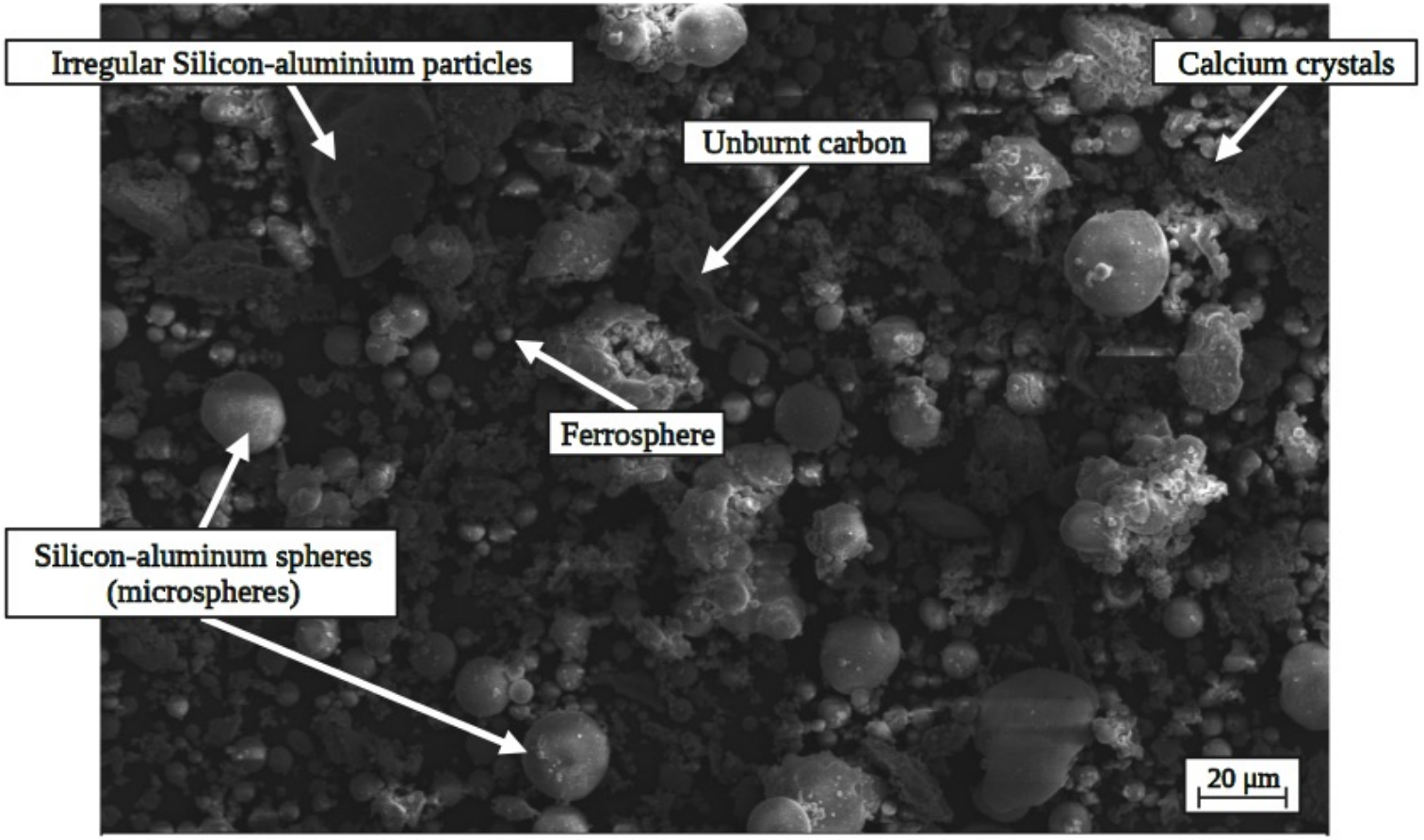
95% of industry related uses are belongs to the construction industry[15]

Second generation uses



[15] OPPD The Wire. (2022, February 15). Reuses for Coal Fly Ash. OPPD The Wire. Retrieved March 28, 2023, from https://oppdthewire.com/reuses-coal-fly-ash/

Problems associated with second generation uses

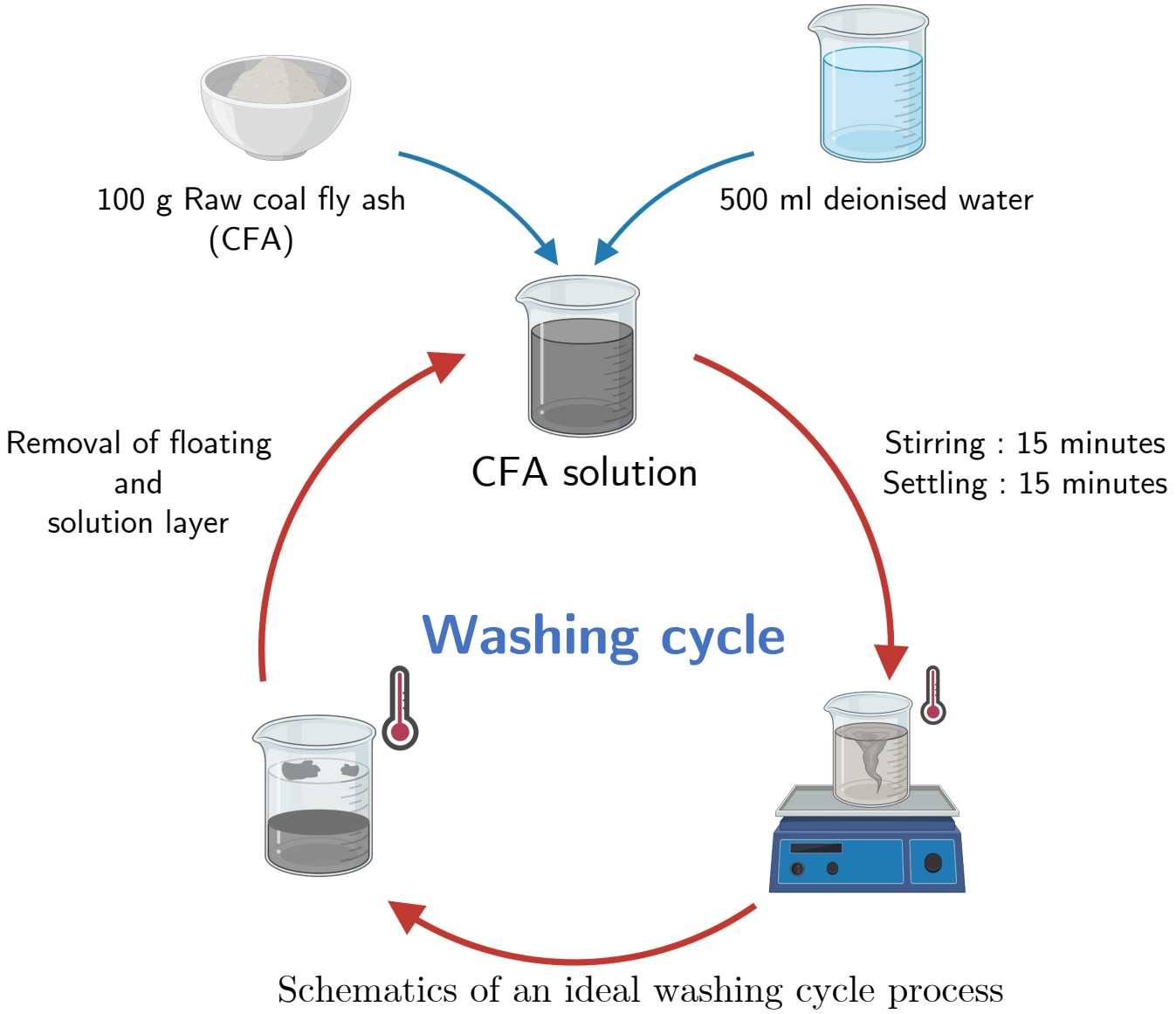


Scanning electron microscope image of CFA particles*

- Most complex material to characterise
- Diverse physical, chemical, and morphological characteristics
- Segregation of usable components

* Brinthan, K., Fernando, W. A. M., Jayawardena, C., Attygalle, D., Amarasinghe, D. A. S., & Panda, S. (under review).Valorising coal fly ash waste via pre-processing to promote circular economy. Resources, Conservation and Recycling.

Pre-processing of CFA through washing cycles



Schematics of an ideal washing cycle process

- Neutralises the basicity of CFA
- Reduce the heterogeneity
- Simplify the subsequent processes
- Recovery of value-added products*

* Brinthan, K., Fernando, W. A. M., Jayawardena, C., Attygalle, D., Amarasinghe, D. A. S., & Panda, S. (under review).Valorising coal fly ash waste via pre-processing to promote circular economy. Resources, Conservation and Recycling.

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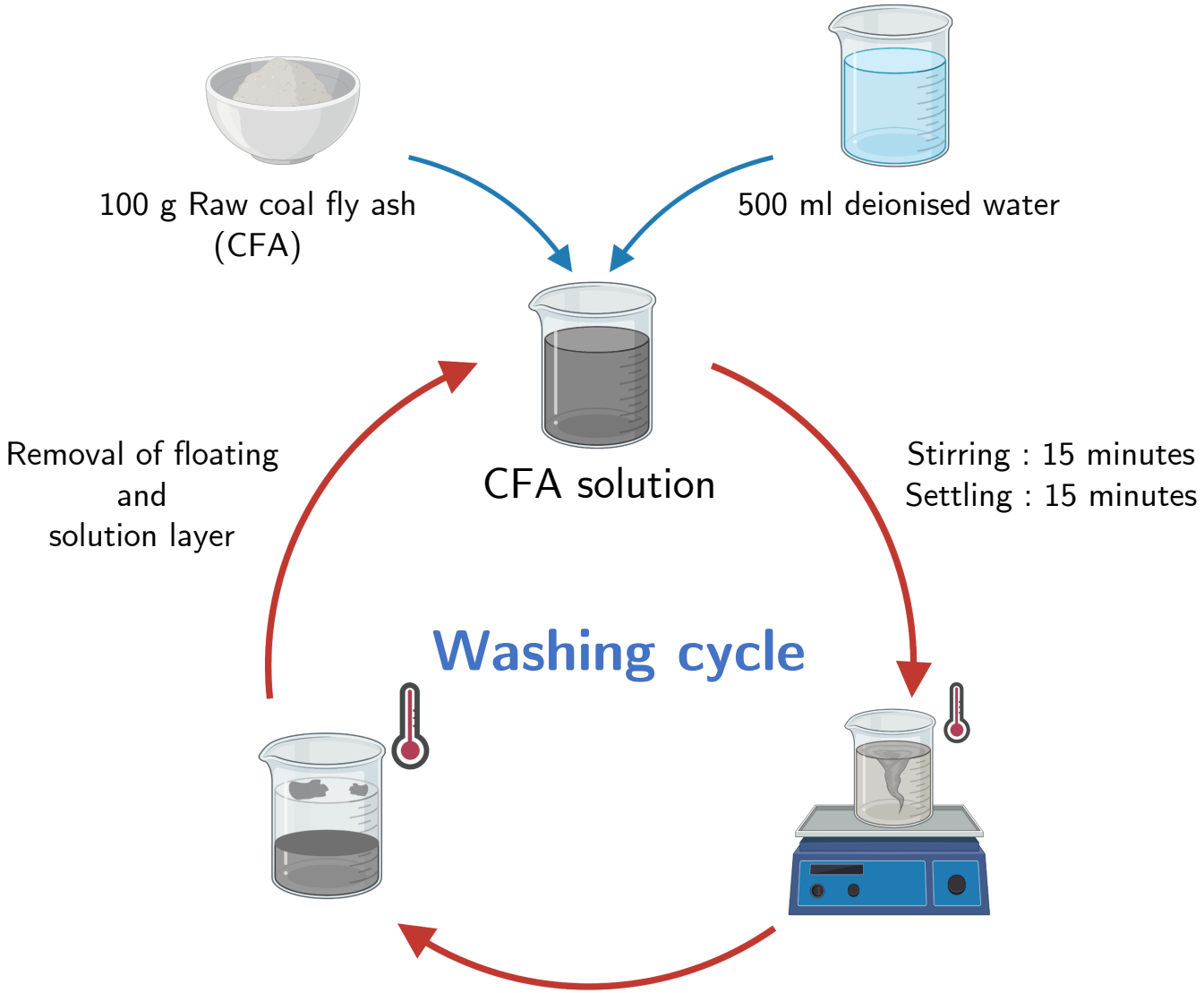
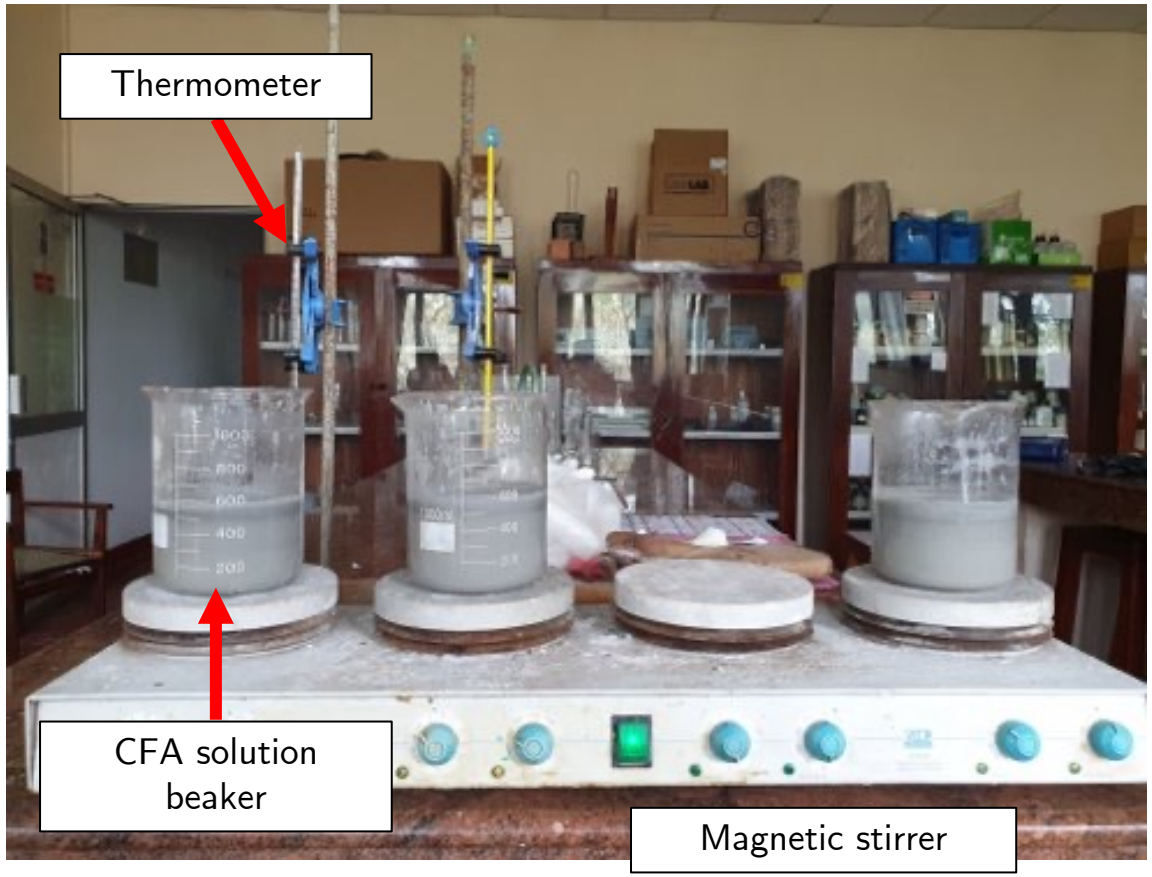
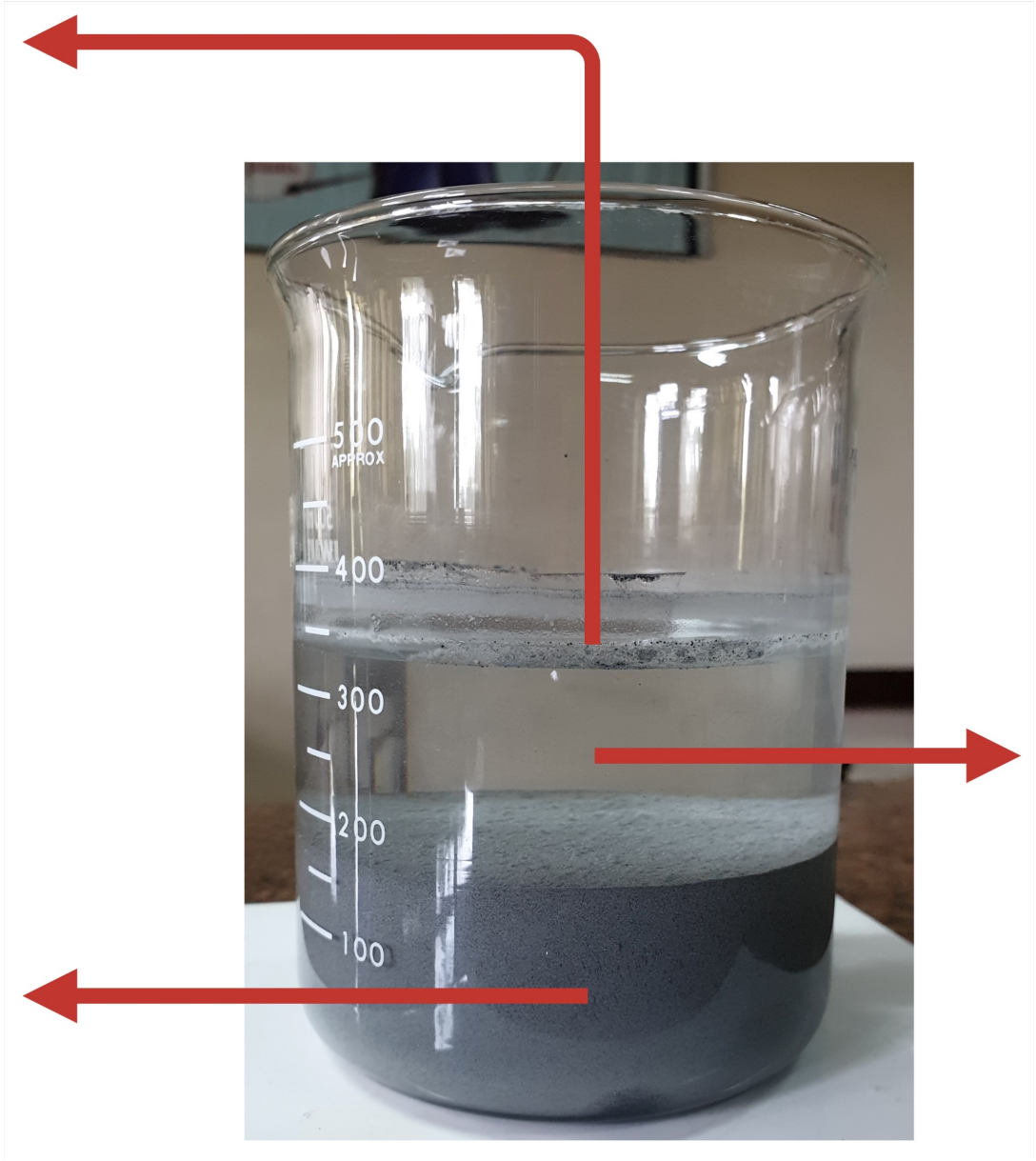


Schematics of an ideal washing cycle process



Laboratory scale multiple washing cycle experiments

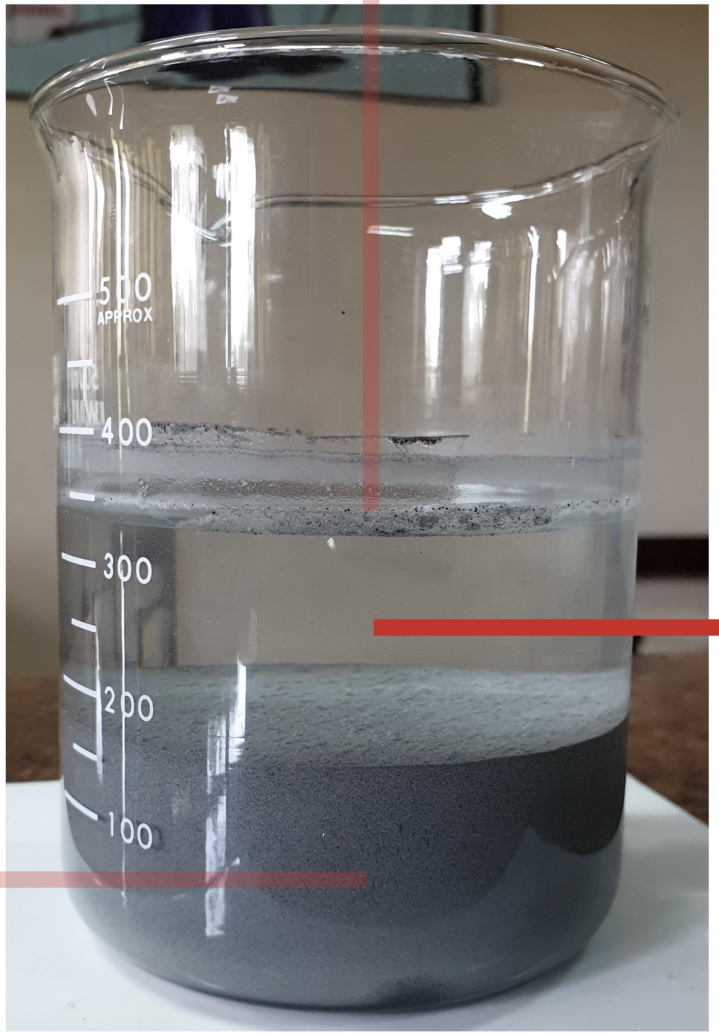
Components after washing cycles



Staked layer of components after settling time

Components after washing cycles

Floating layer



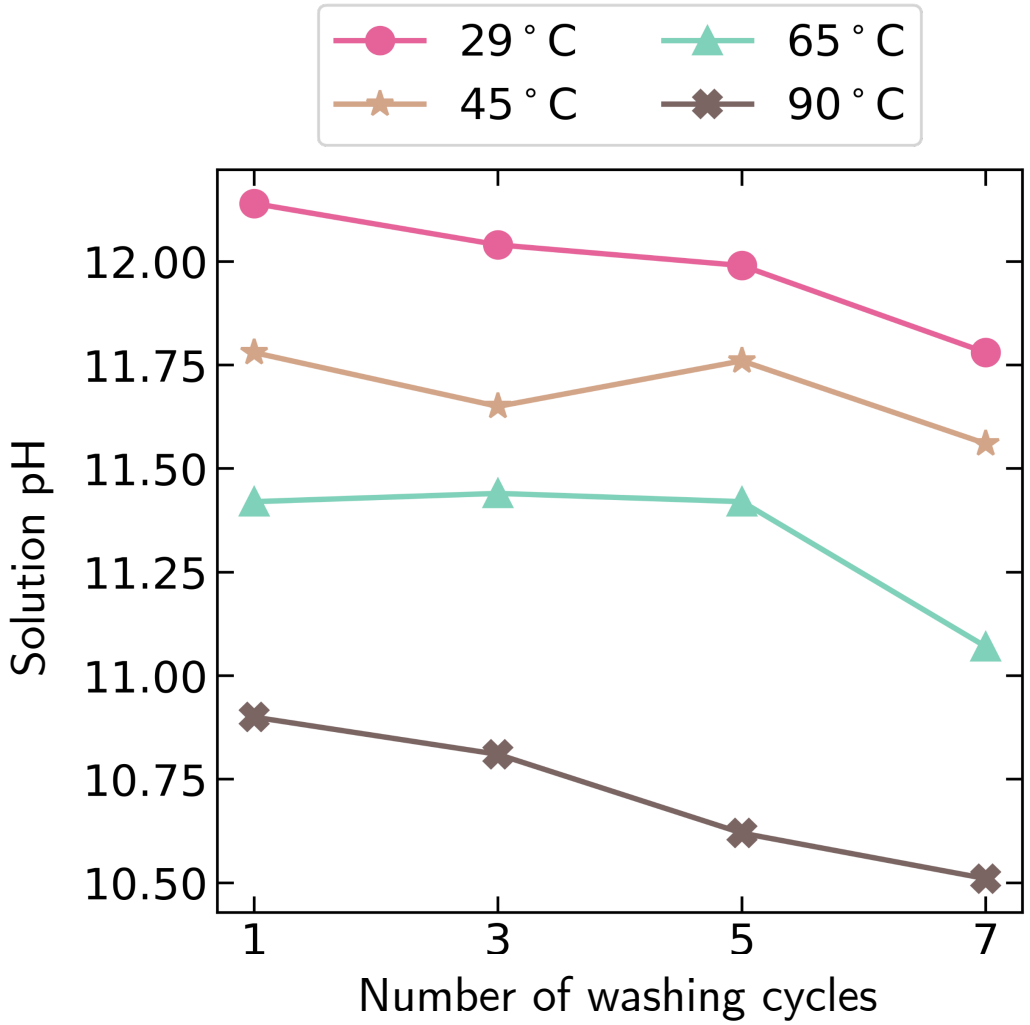
Washed solution

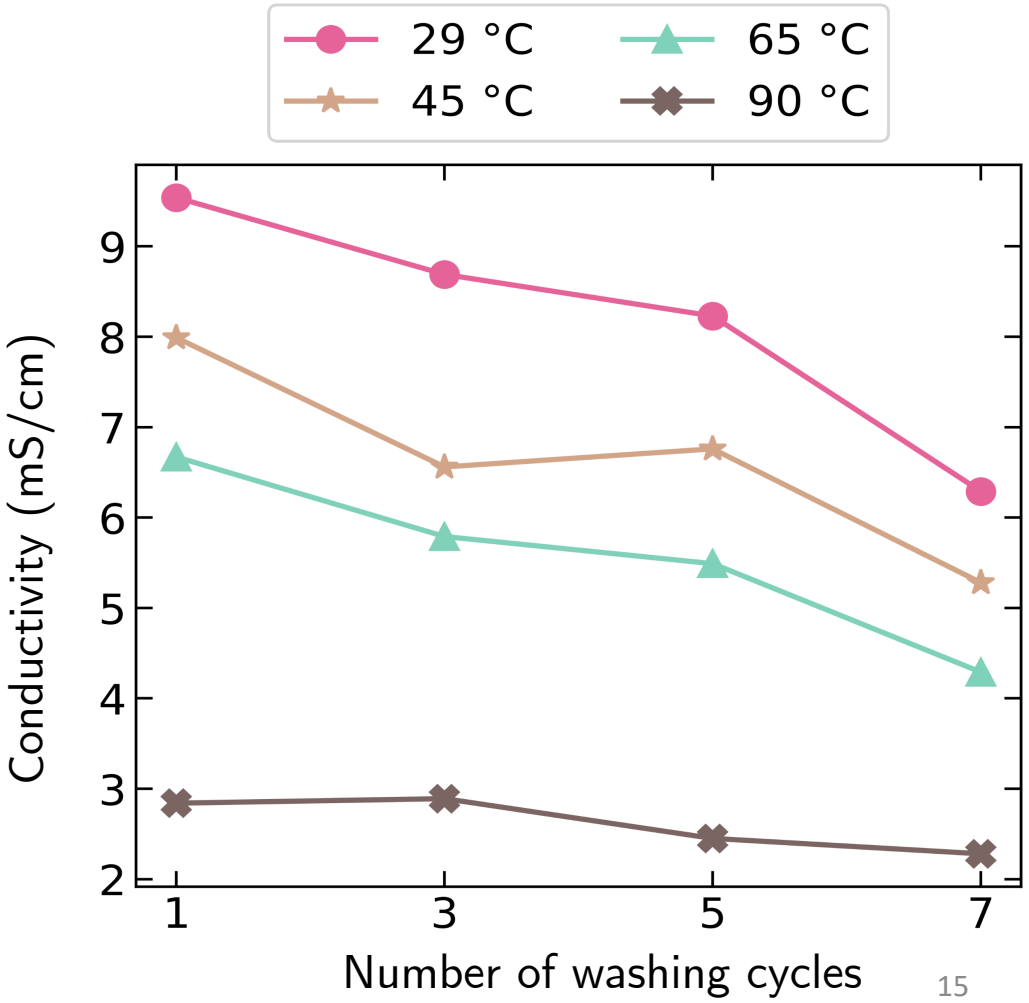
Bottom layer

Staked layer of components after settling time

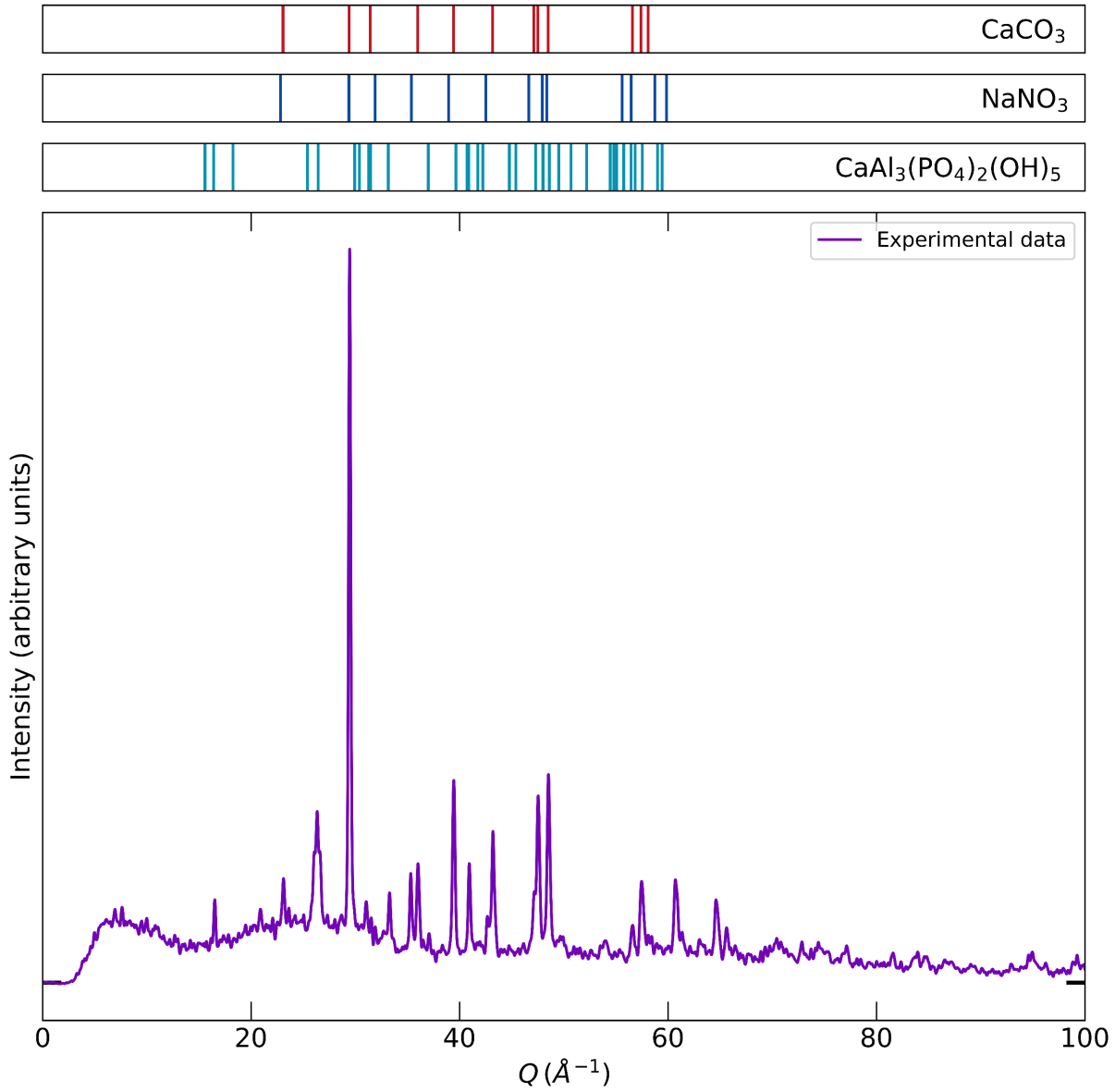
Quantifying the dissolution of ions

- pH and conductivity of the solution indicates the dissolution of ions from the CFA particles





Characterisation of the oven-dried solution sample

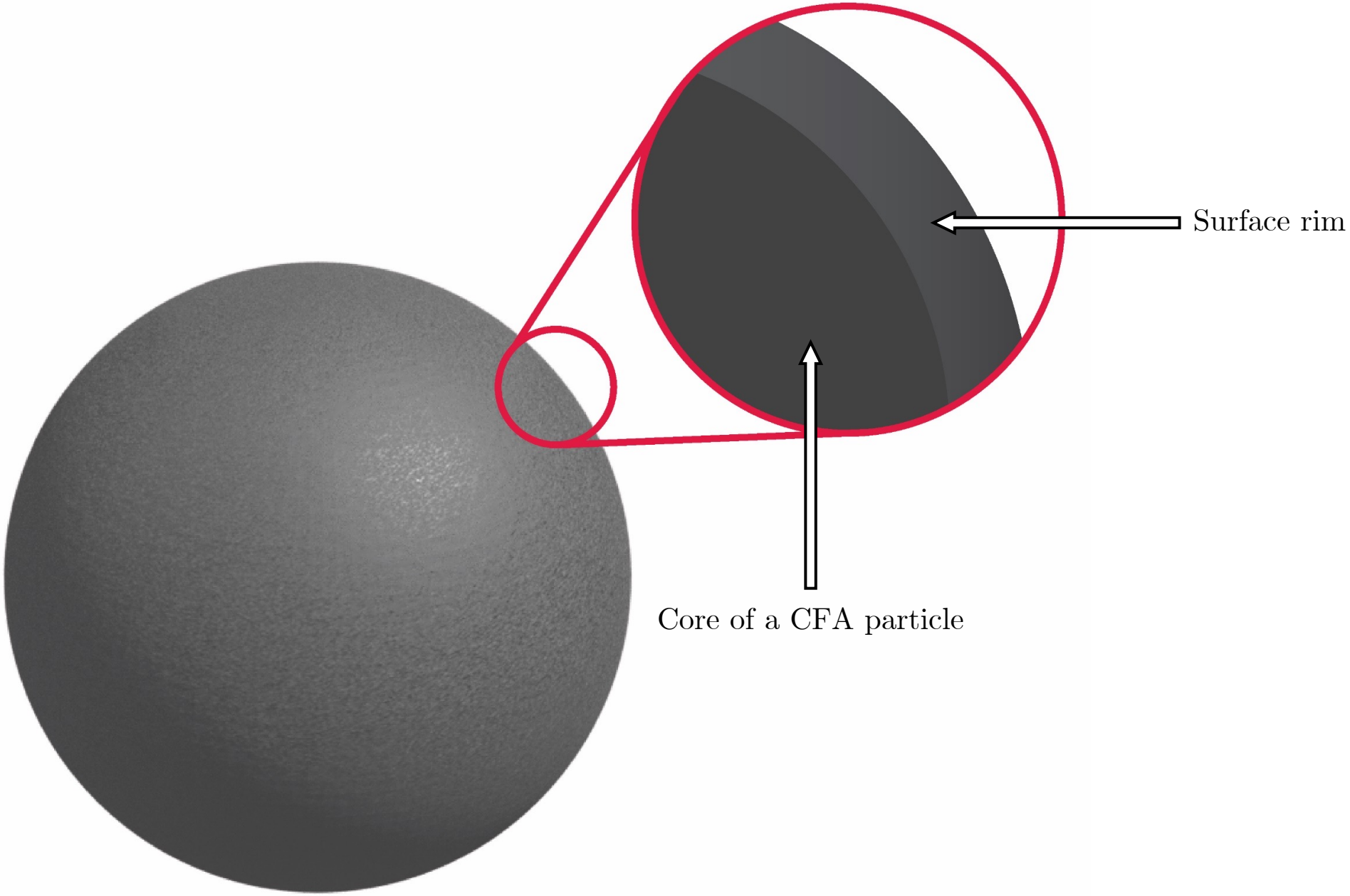


XRD plot of an oven-dried solution sample

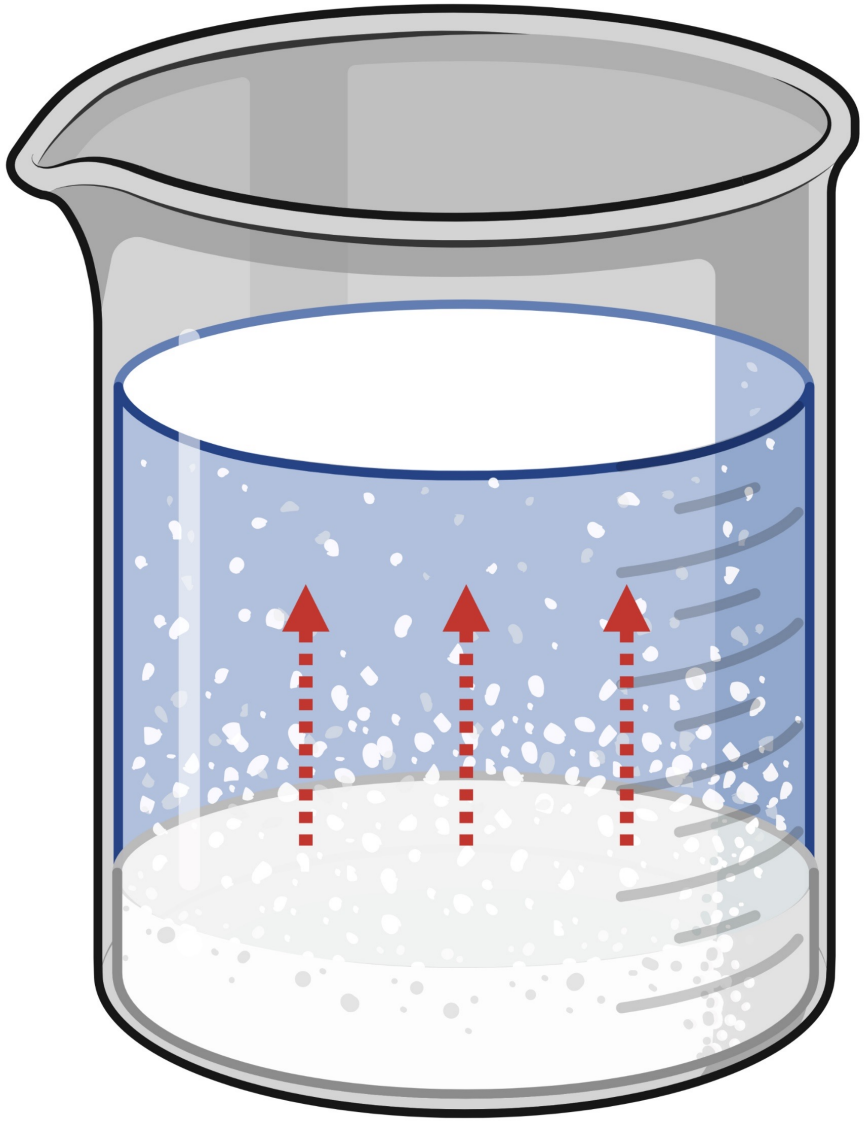
What has been removed during washing cycles?

- Calcite – $CaCO_3$
- Nitratine – $NaNO_3$
- Crandallite – $CaAl_3(PO_4)_2(OH)_5$

Cross-sectional view of a CFA particle



Dissolution of alkaline ions



- Ca^{2+}
- Na^{+}
- K^{+}
- Mg^{2+}
- PO_4^{3-}

$+ H_2O \rightarrow$ **Water soluble alkaline hydroxides**

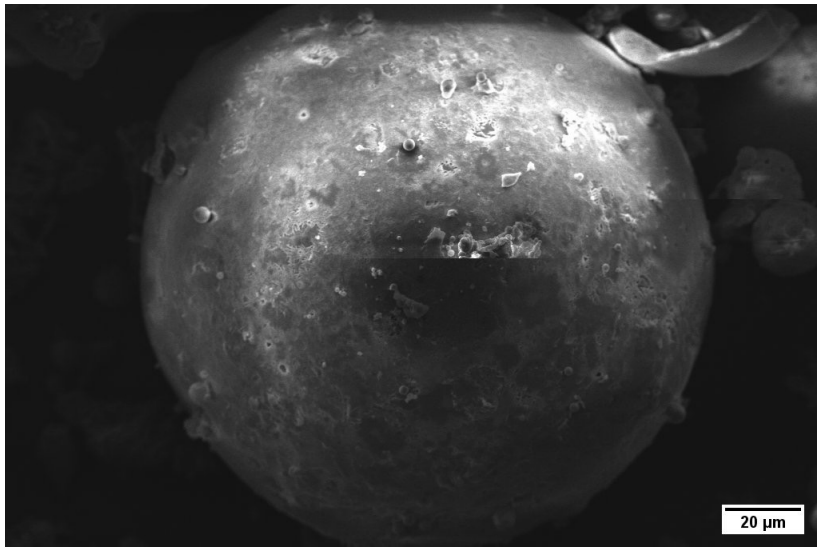
- Reduce Sauter mean diameter
- Expose the core of coal fly ash

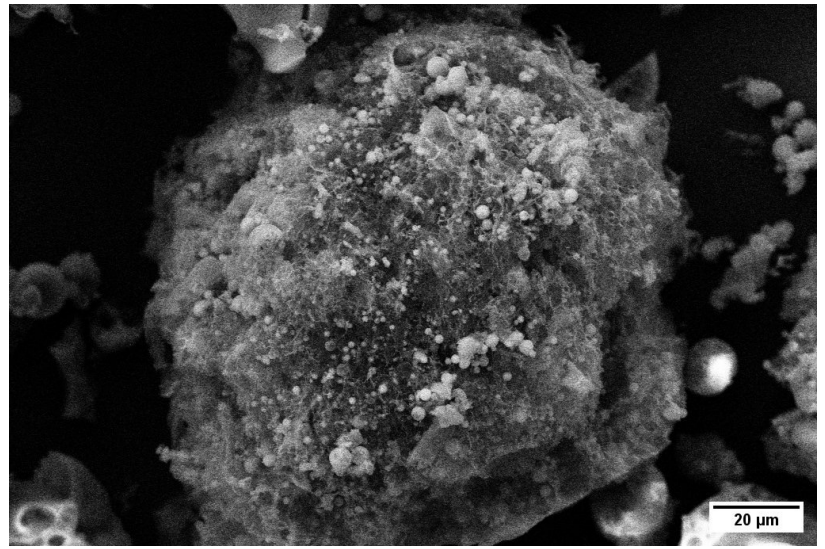
Dissolution of alkaline ions

Raw coal fly ash particle

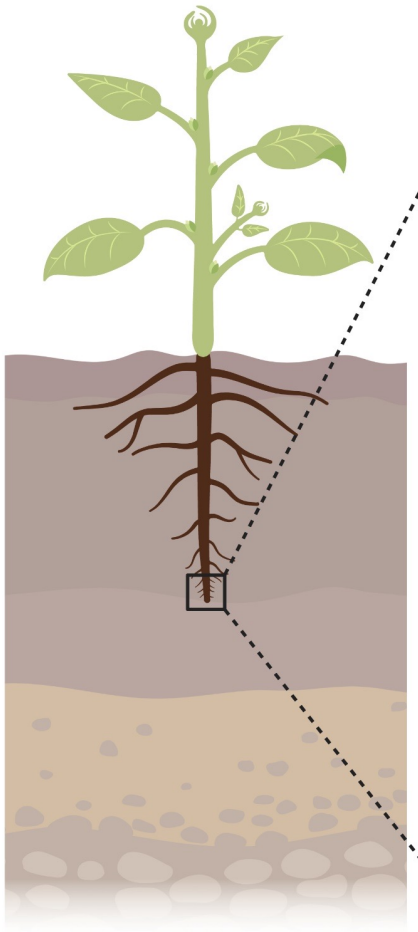
Dissolution of surface rim

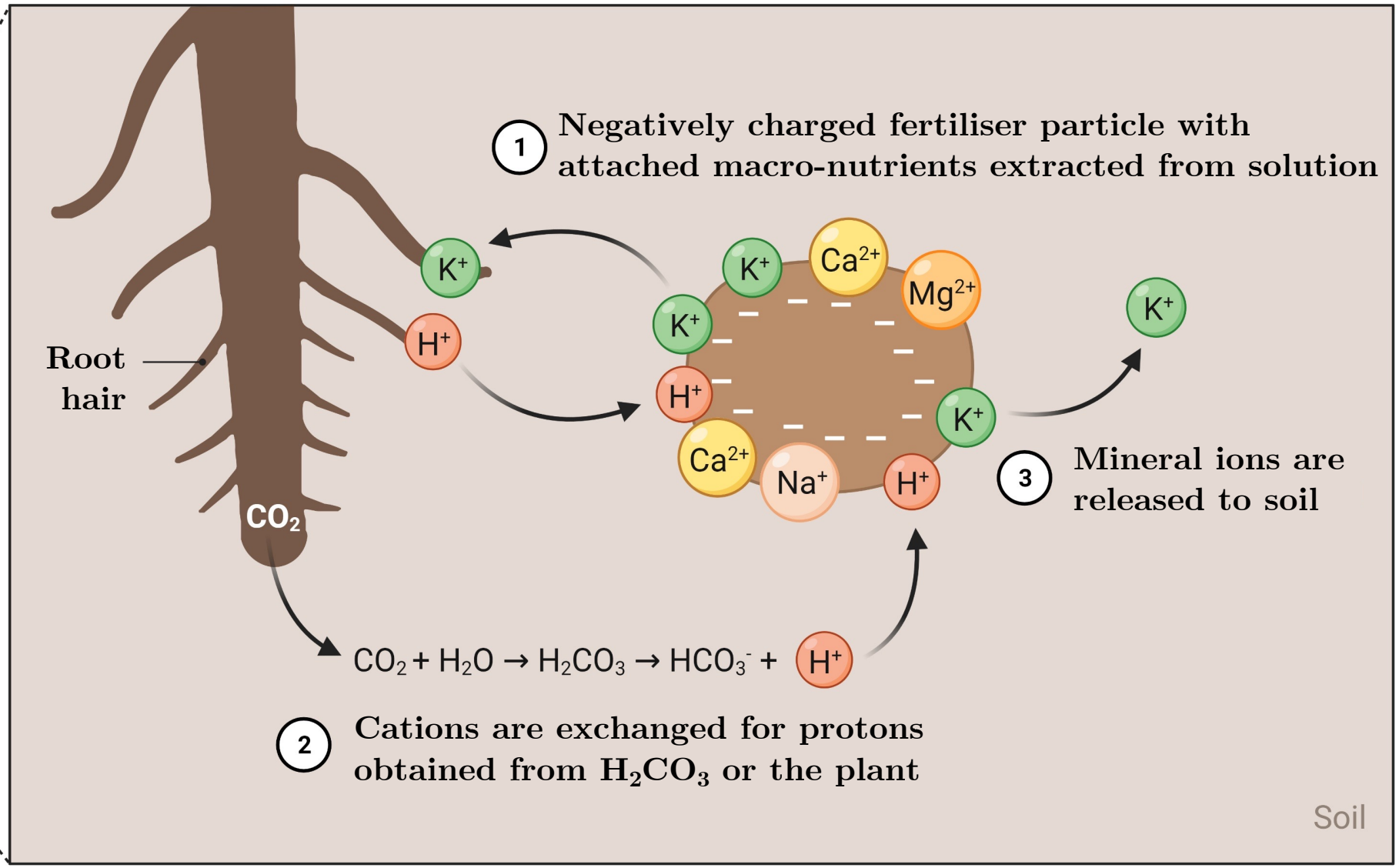
Washed coal fly ash





Alkaline ions as fertilisers





Components after washing cycles

Floating layer

Washed solution

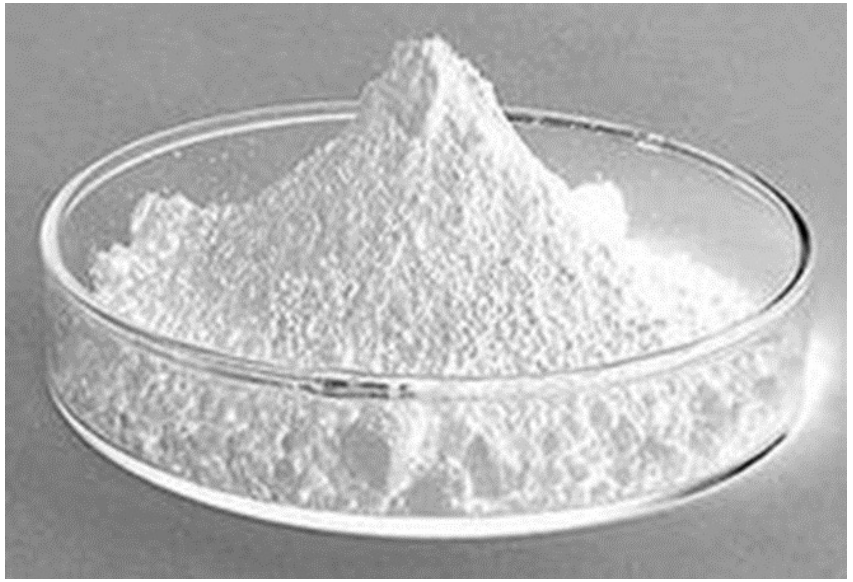
Bottom layer

Staked layer of components after settling time

A substrate to zeolites

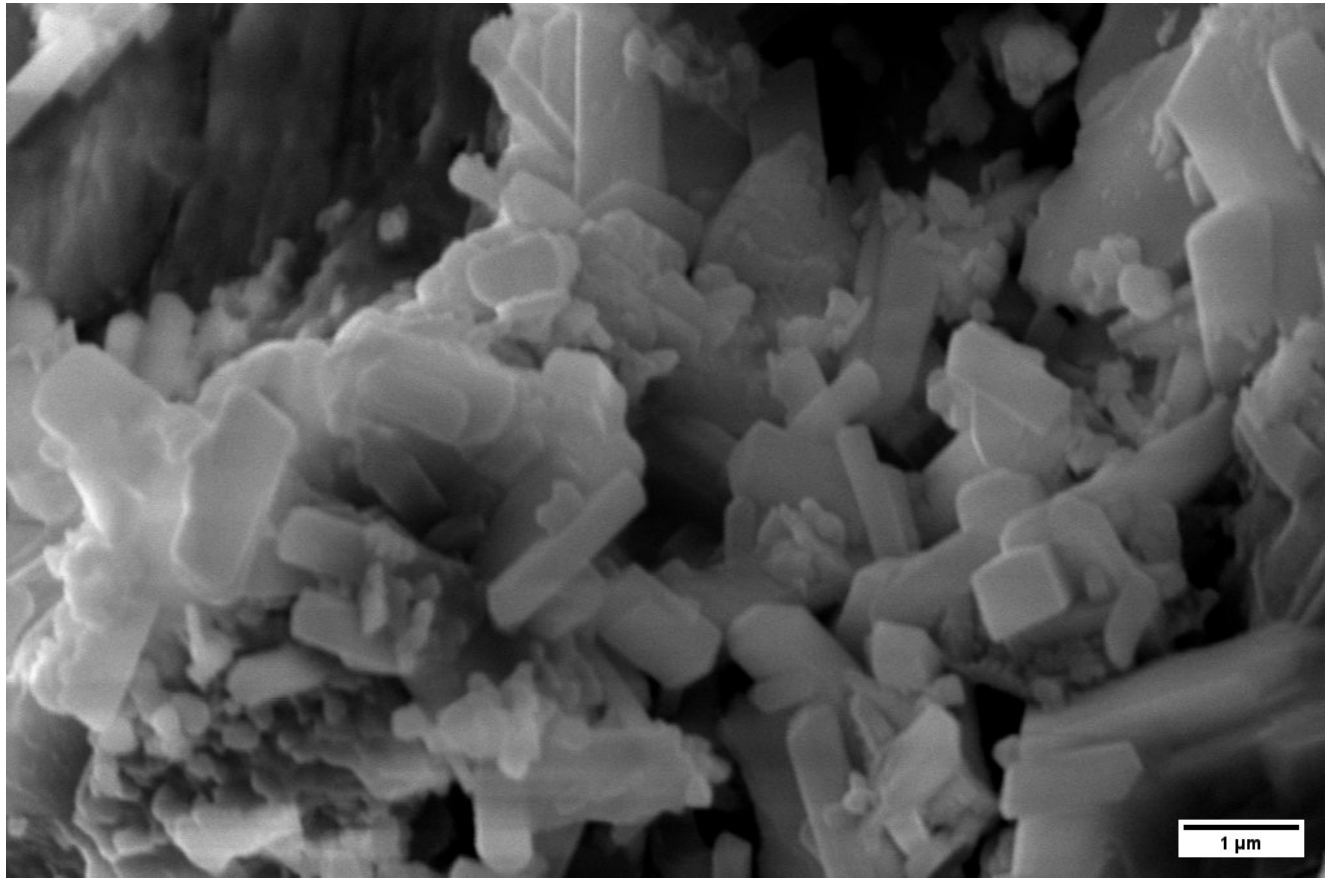
Oven-dried bottom sample

Alkaline-activated
hydrothermal treatment

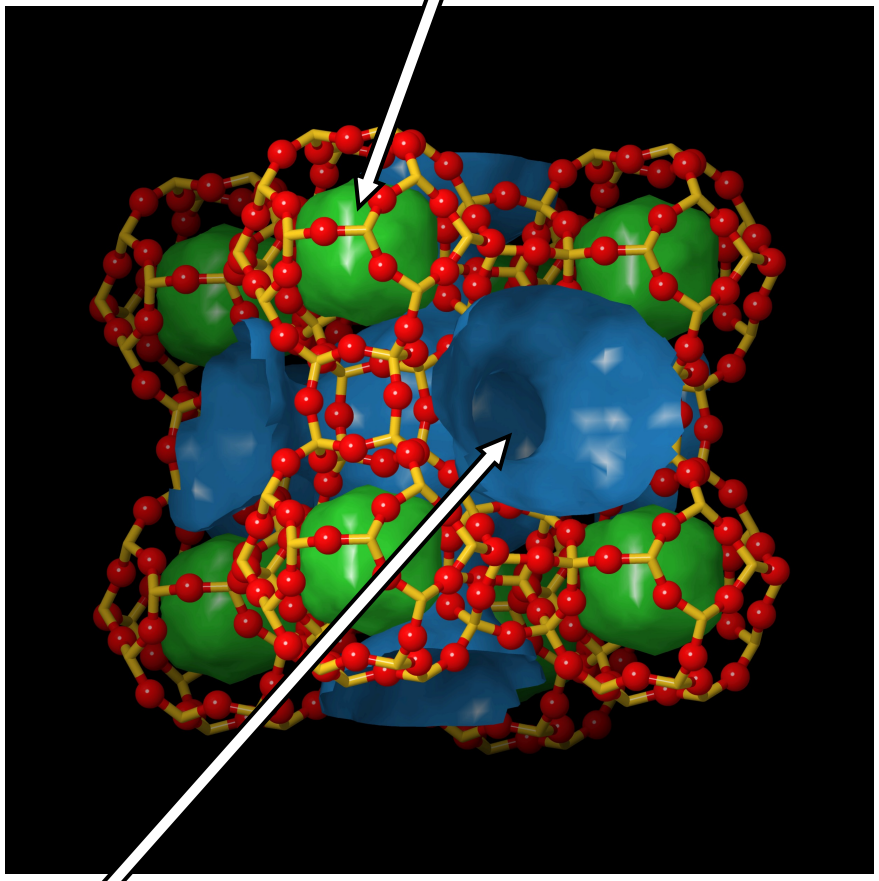


Zeolite powder

A substrate to zeolites



Scanning electron microscope image of a zeolite-LTA



Framework of zeolite-LTA

Applications of zeolites

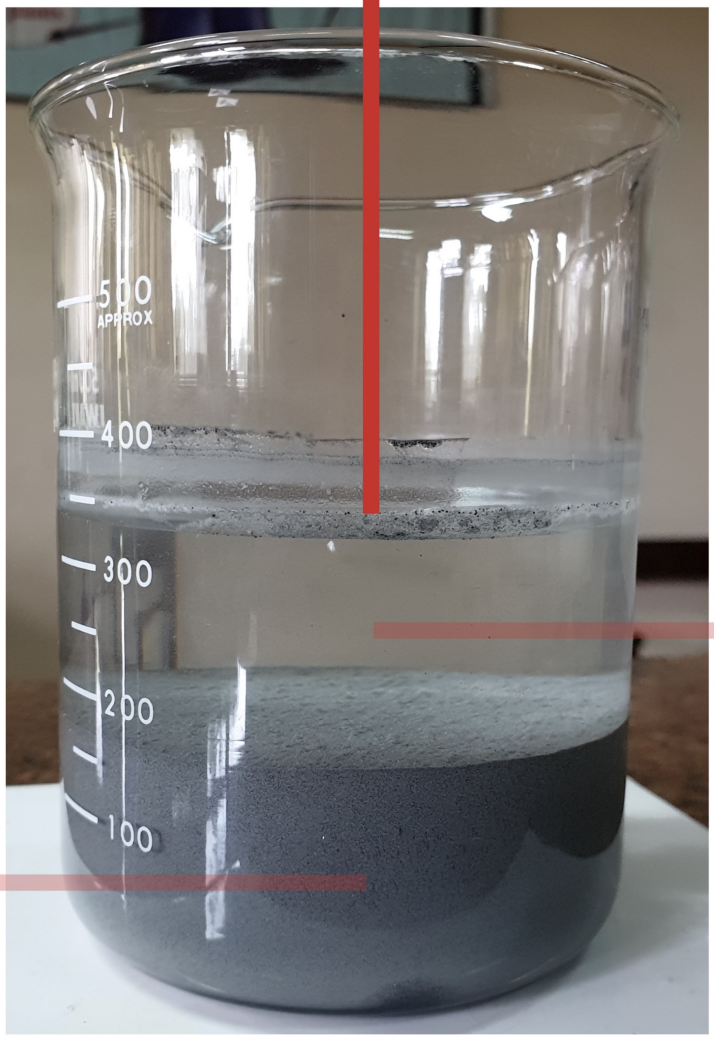
Zeolite as a molecular sieve[16]

- Adsorbents
  - Wastewater treatment
  - Gas-purification
- Molecular sieves
- Catalysts
  - Petrochemical industry
- Soil ameliorants

[16] MolsivCN. (n.d.). Zeolite Molecular Sieve. MolsivCN. Retrieved March 28, 2023, from https://www.molsivcn.com/molecular-sieve/zeolite/

Components after washing cycles

Floating layer

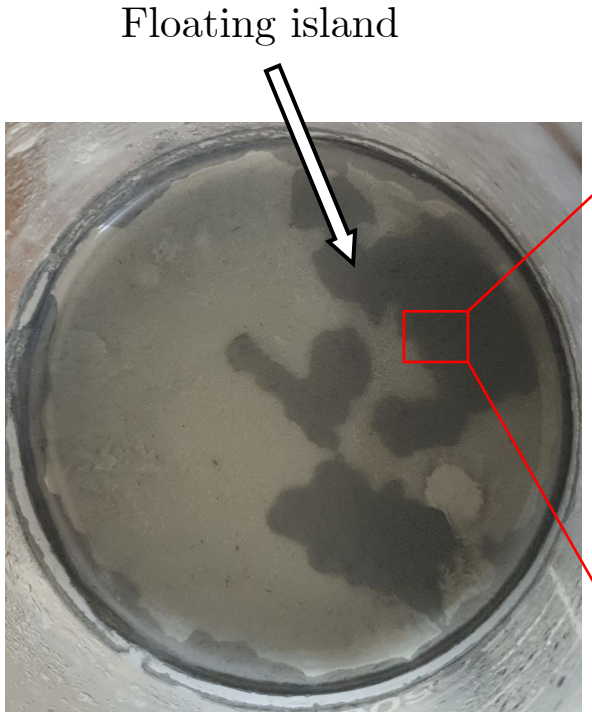


Washed solution

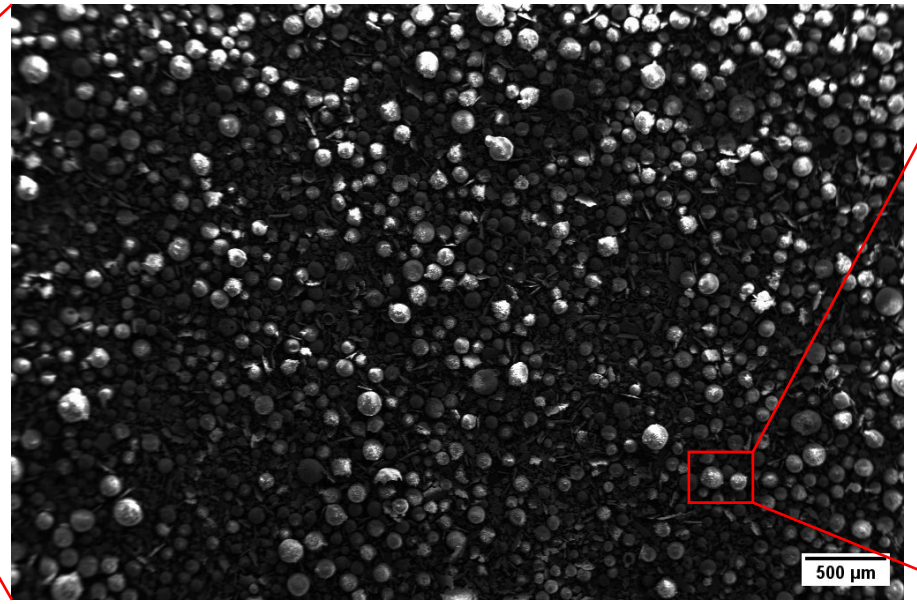
Bottom layer

Staked layer of components after settling time

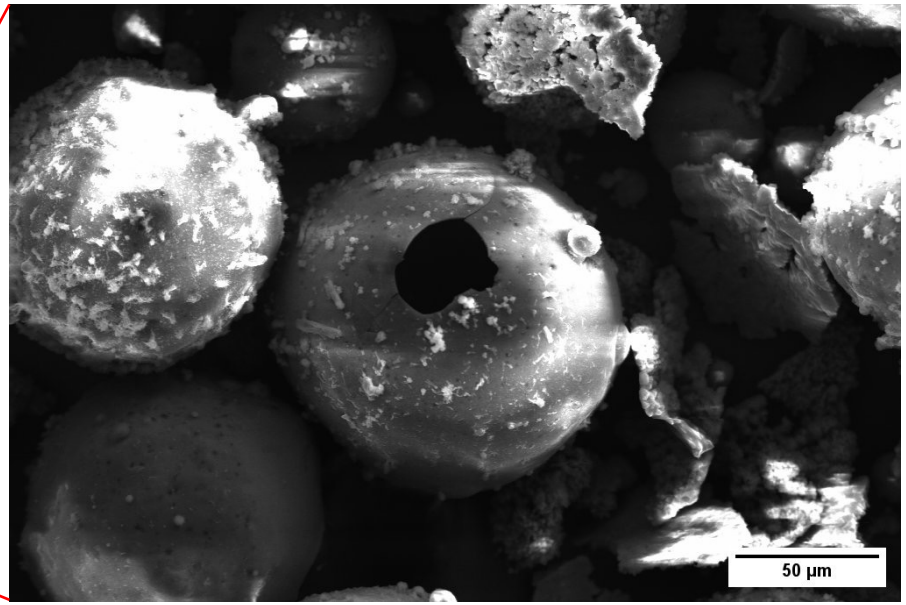
Floating layer



Plan view of the
settled experimental setup

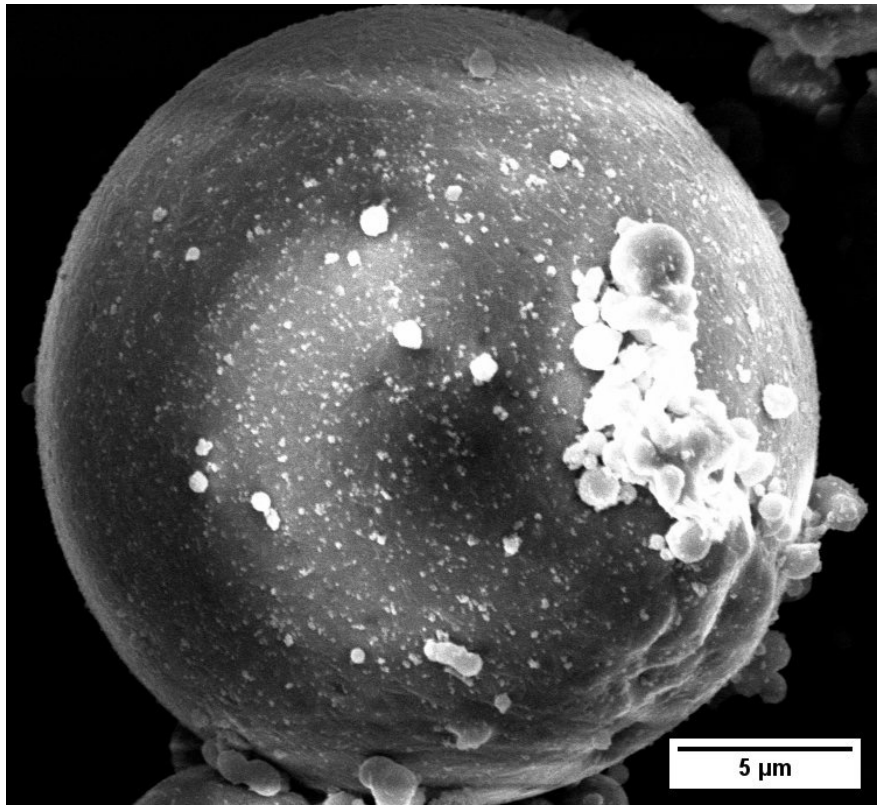


Scanning electron microscope image of
selected region at 5x magnification

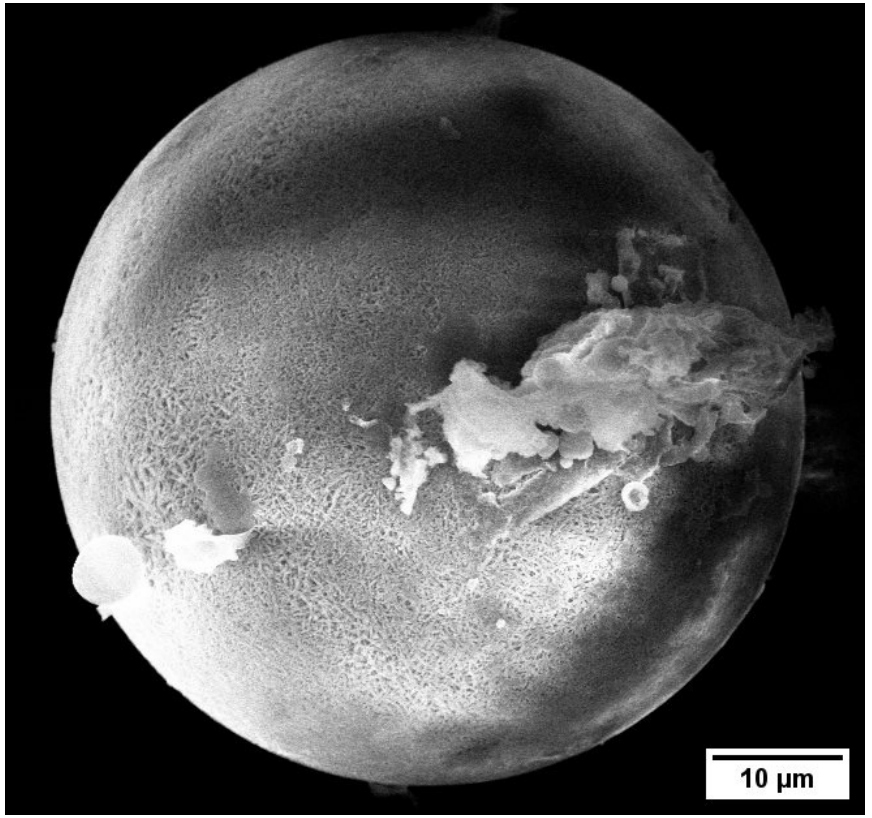


Scanning electron microscope image of
selected region at 900x magnification

Components of cenosphere island



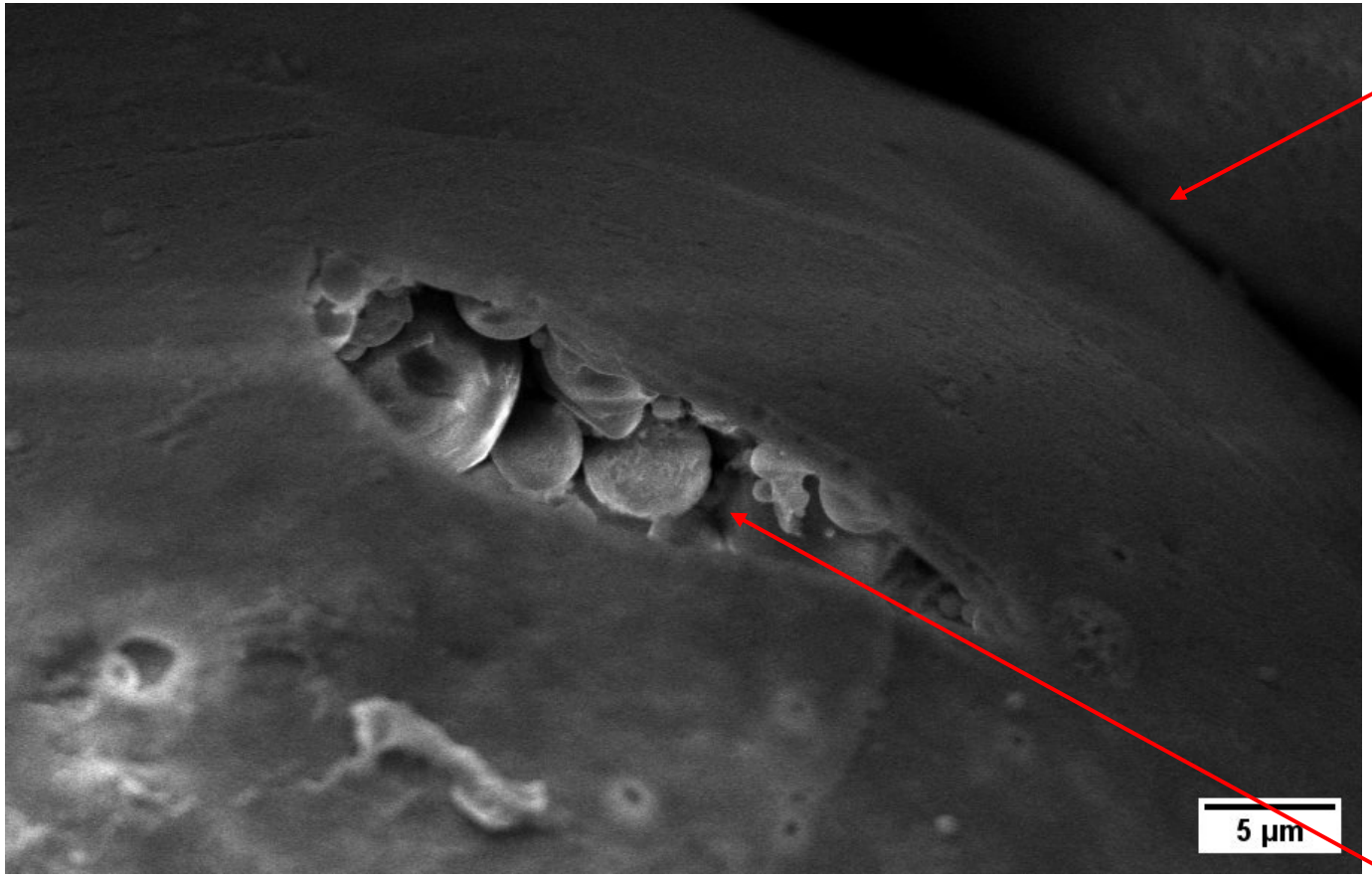
Scanning electron microscope image of a solidsphere*



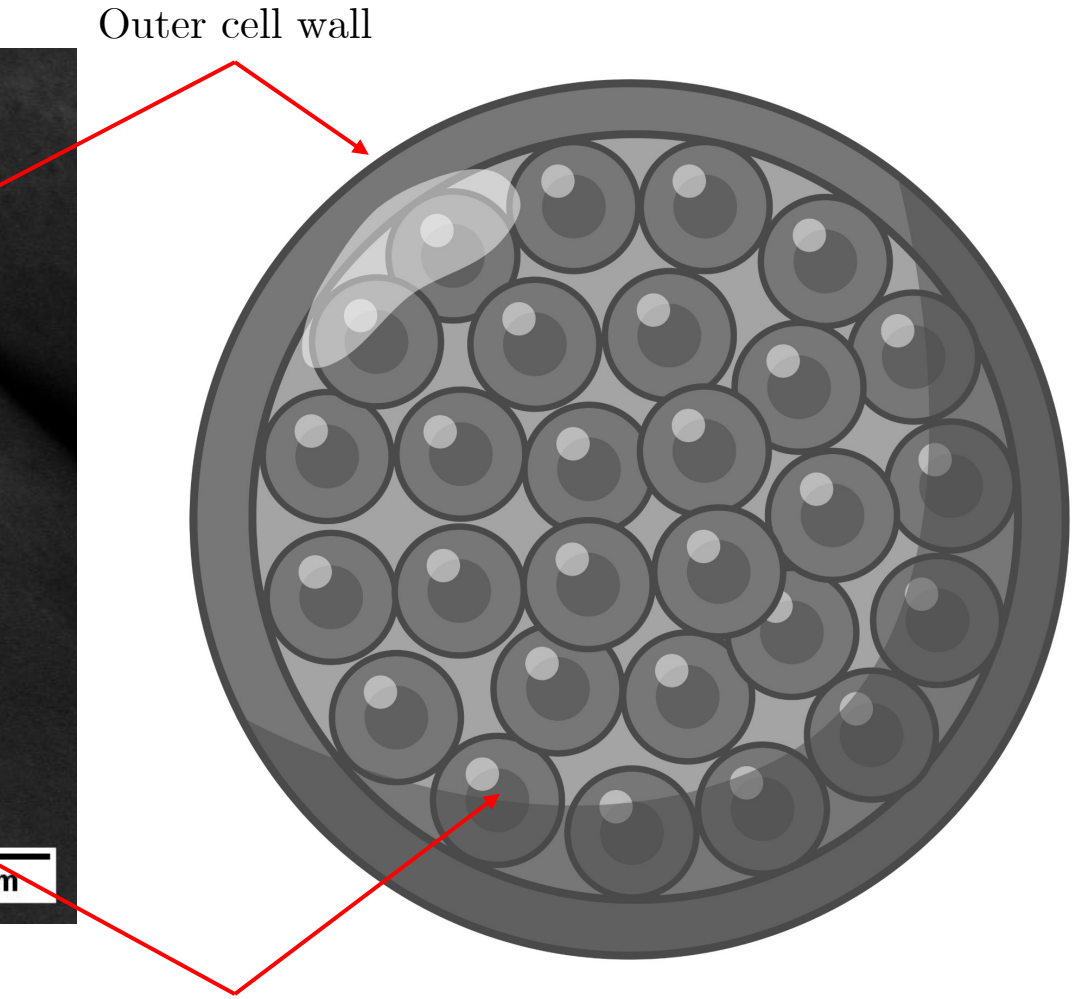
Scanning electron microscope image of a cenosphere*

* Brinthan, K., Fernando, W. A. M., Jayawardena, C., Attygalle, D., Amarasinghe, D. A. S., & Panda, S. (under review).Valorising coal fly ash waste via pre-processing to promote circular economy. Resources, Conservation and Recycling.

Components of cenosphere island



Scanning electron microscope image of a plerosphere*



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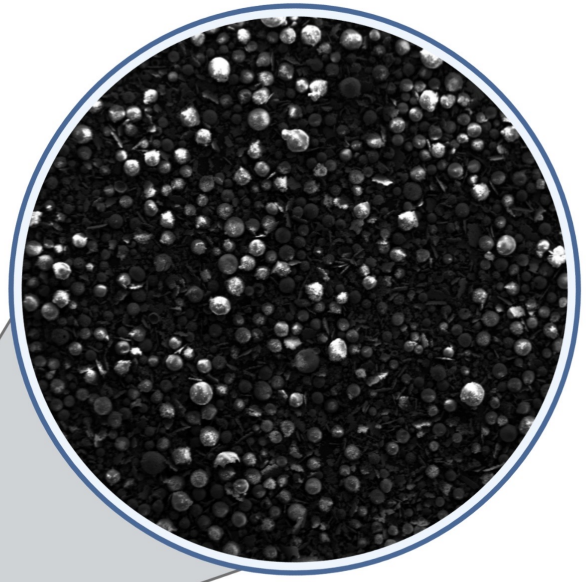
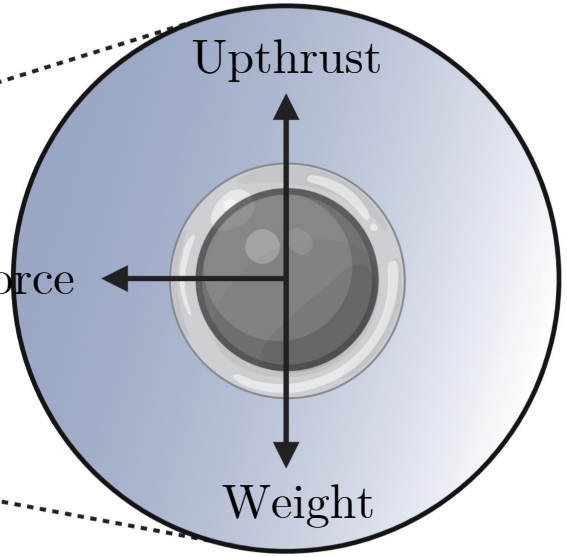
Cenosphere island



Scanning electron microscope image of cenosphere island

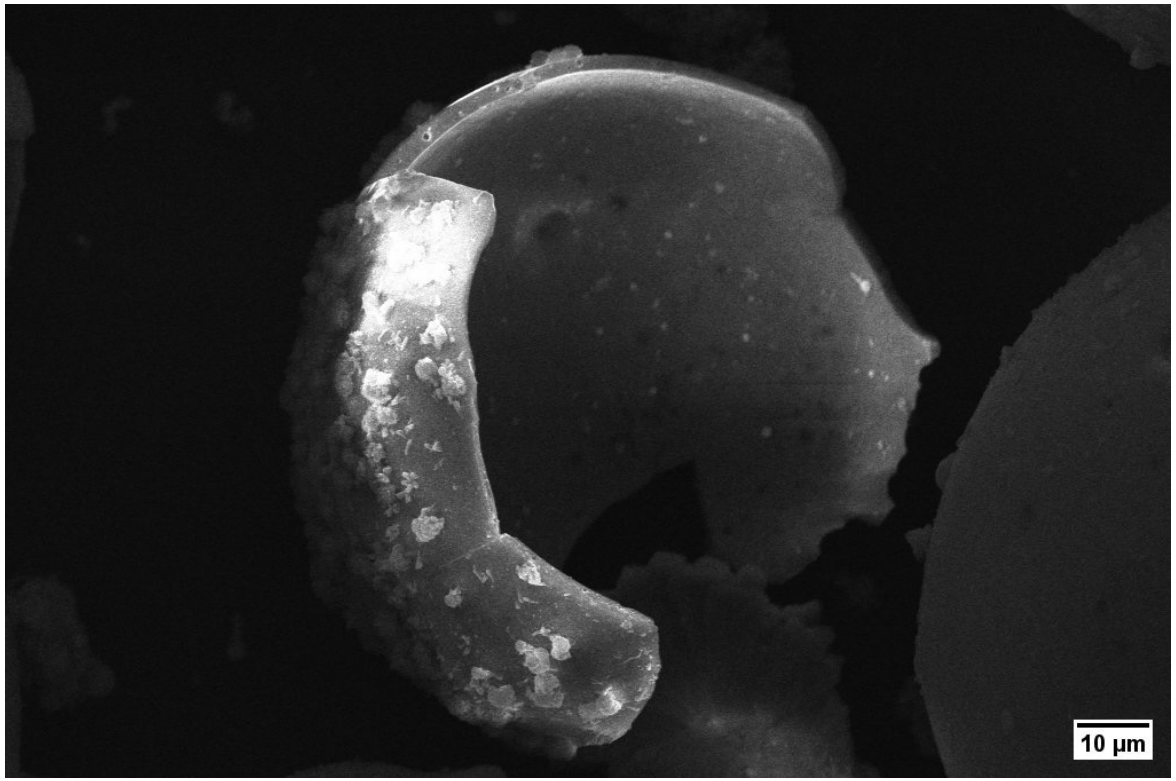
Floating layer

Cenosphere



Force field map

Cenospheres

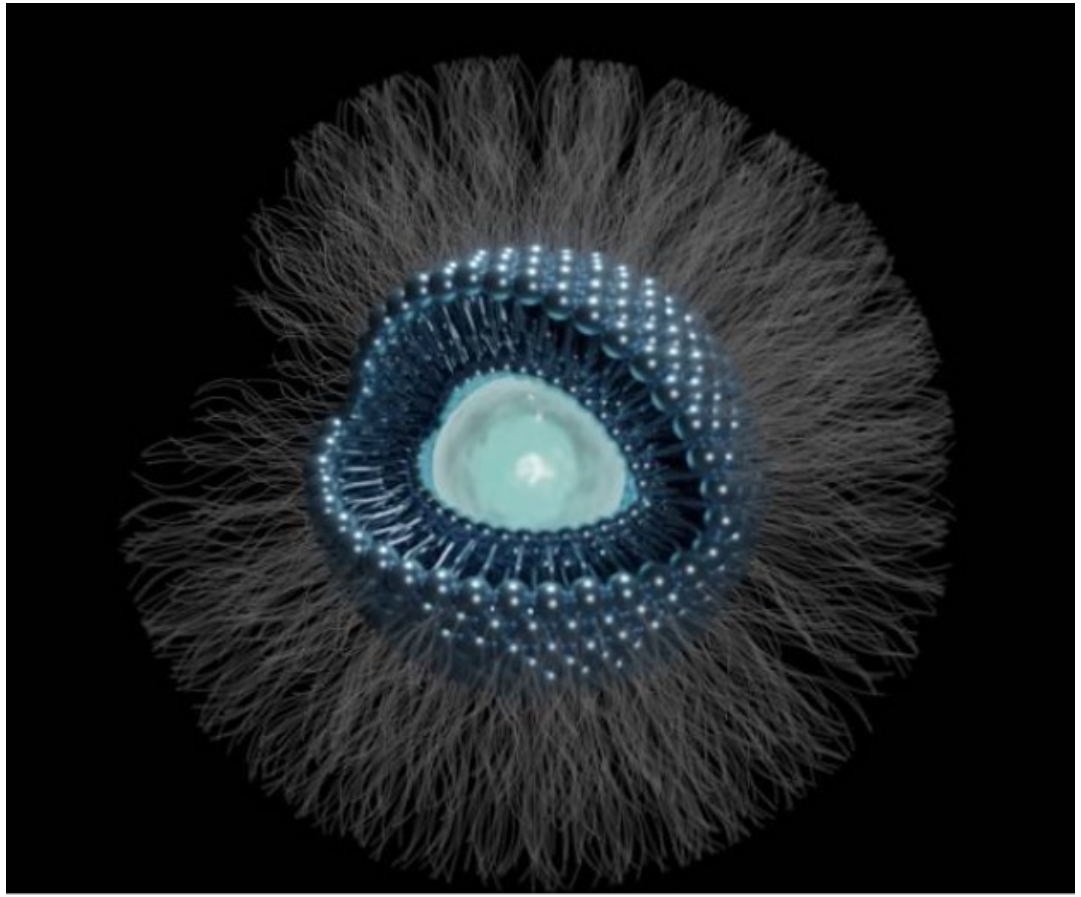


Scanning electron microscope image of a broken cenosphere

- Spherical-shaped hollow particles[16]
- 0.01 to 4.80 wt% of coal fly ash[16]
- Varies from few nanometers to 500 micrometers
- Mainly of Si and Al
- Density: 0.2 - 2.6 g/cc [17]
- Most valuable product from CFA[16]

[16] N. Ranjbar and C. Kuenzel, Fuel 207, 1 (2017).
[17] S. Yoriya, T. Intana, P. Tepsri, Applied Sciences 9(18), 3792 (2019).1

Applications of cenospheres



Isolated nano-drug [18]

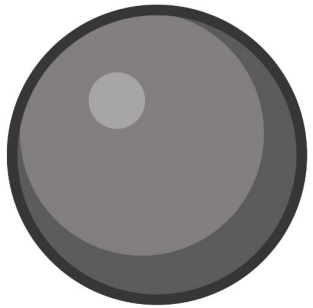
- Electromagnetic shielding
- Lightweight metal alloy
- Emulsion explosive sanitiser
- Insulation and thermal resistant material
- Low dielectric constant substrate
- Transporting agent for drugs and photocatalysis[16]

[16] N. Ranjbar and C. Kuenzel, Fuel 207, 1 (2017).
[18] iStockphoto. (n.d.). Nanoparticles for Drug Delivery. iStockphoto. Retrieved March 28, 2023, from https://www.istockphoto.com/photos/nanoparticles-for-drug-delivery

Circular economy of CFA

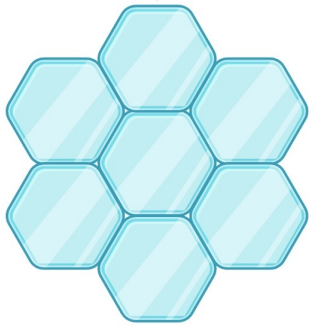
Coal fly ash

Washing cycle



Cenospheres

Fertilisers



Zeolites

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