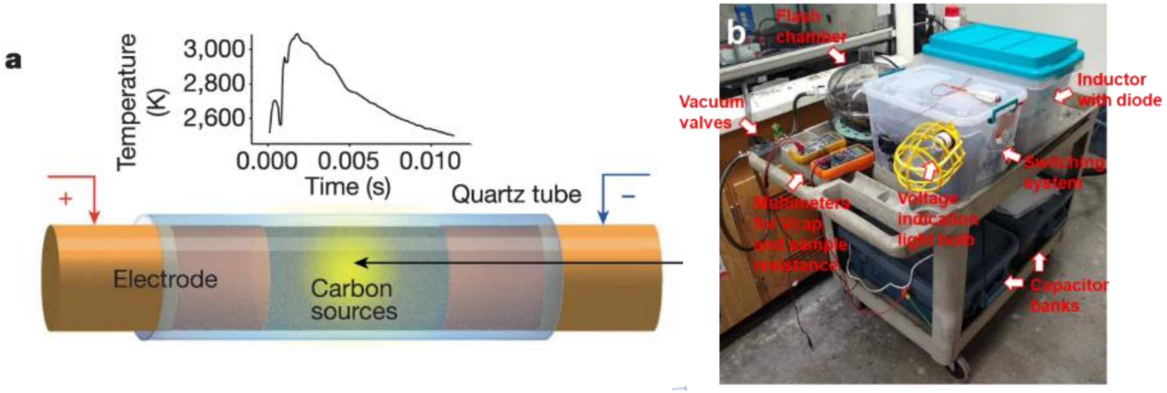
High-Temperature Electrothermal Remediation of Multiple Pollutants in Soil

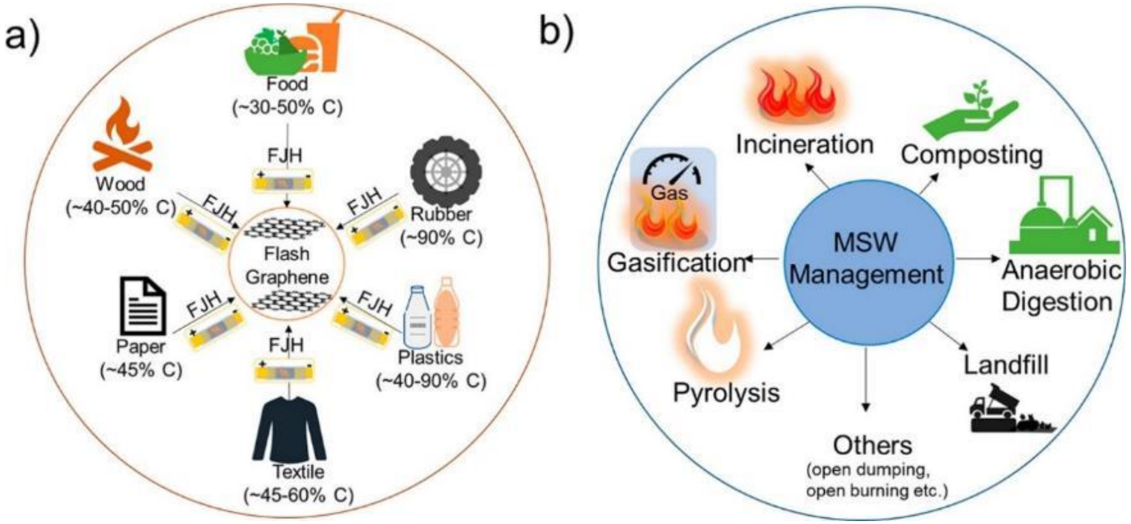
Bing Deng, Ph.D.
Prof. James M. Tour Research Group
bingdeng@rice.edu
Rice University

Flash Joule Heating



James M. Tour*, et al. *Nature* **2020**, 577, 647–651.

Carbon sources (mostly organic wastes, including coal, petroleum coke, biochar, carbon black, discarded food, rubber tires and mixed plastic waste) to high-quality graphene.

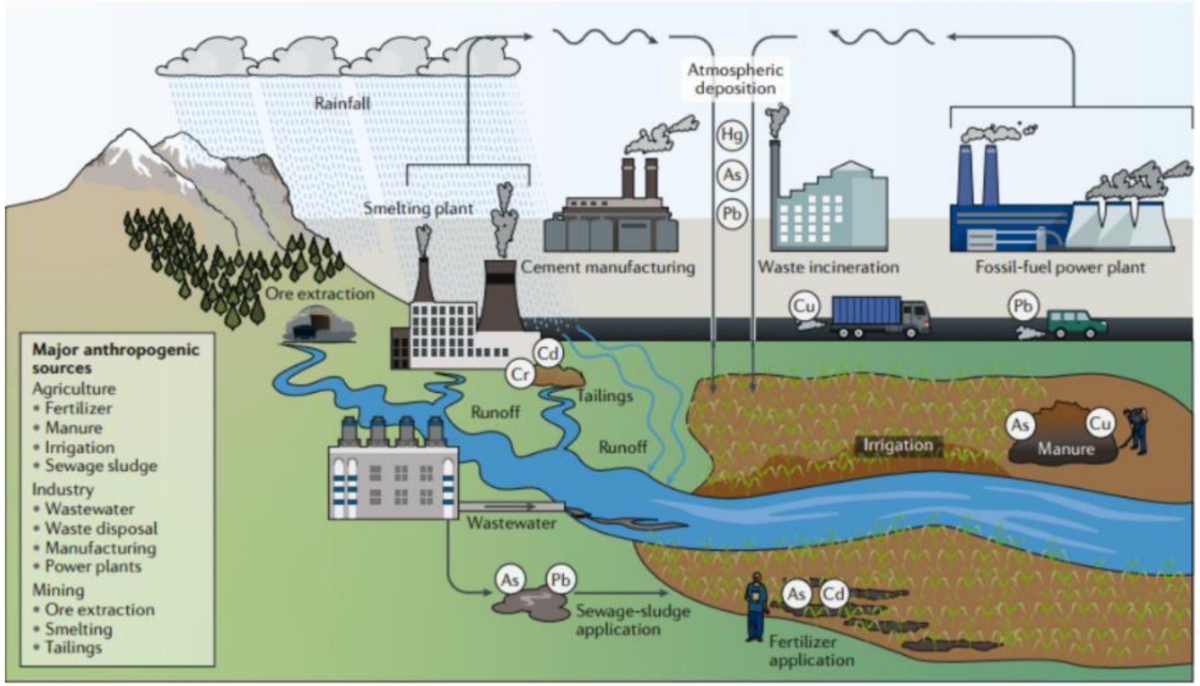


Features:

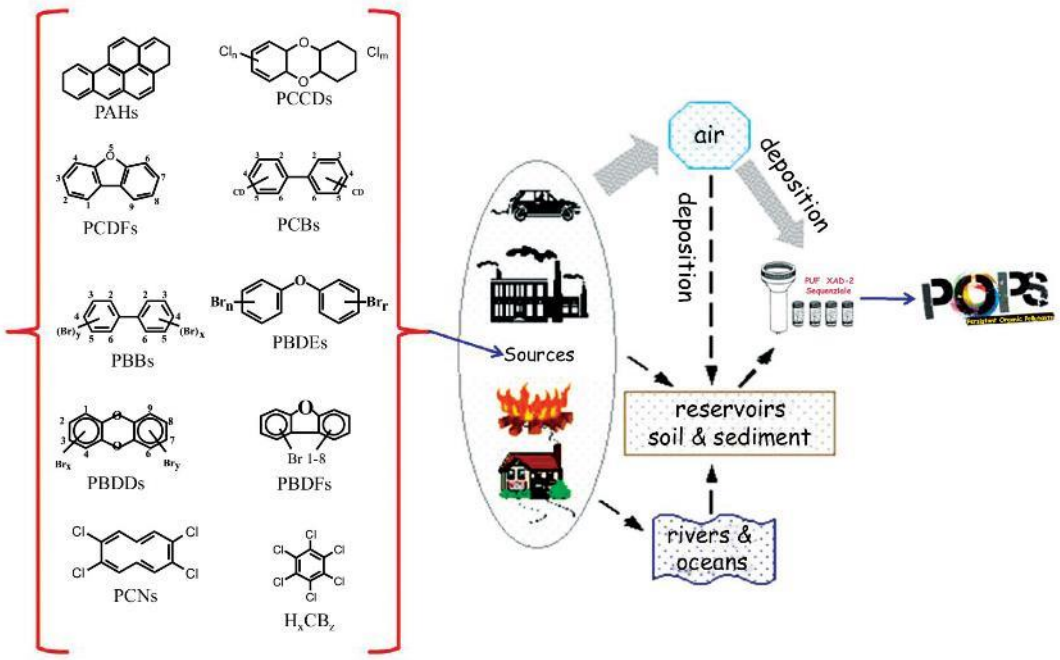
- **Pulse current input: millisecond scale**
- **Widely tunable temperature: RT to >3000 °C**
- **Ultrafast heating/cooling: 10^4 - 10^5 °C/s**
- **Low energy consumption: direct heating**
- **Cost: $30 per ton of materials treated**
- **Multimode and precise controllability: Alternating/Direct current, variable frequency**
- **Scalability: ton per day by Universal Matter.**

Barbhuiya, H. H. et al. *ACS Nano* **2021**, 15, 15461-15470
Algozeeb, W. A. et al. *ACS Nano* **2020**, *14*, 15595– 15604
Kyss, K. M. et al. *Carbon* **2021**, *174*, 430– 438
Advincula, P. A. et al. *Carbon* **2021**, *178*, 649– 656
Kyss, K. M. et al. *Comm. Engineering* **2022**, 1, 3

Multiple Pollutants in Soil



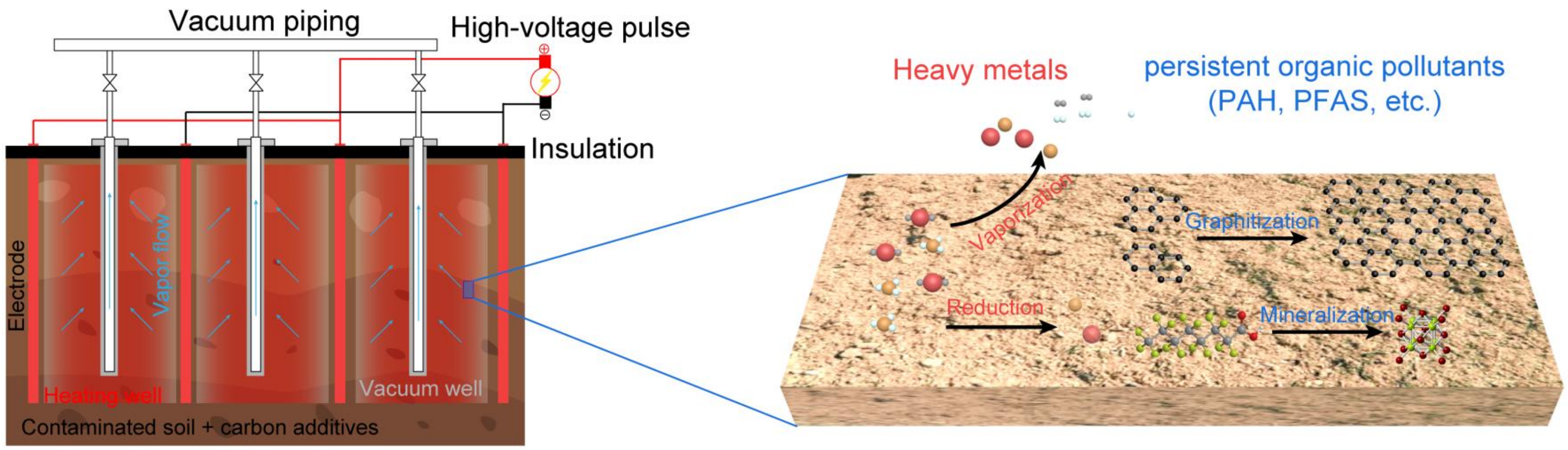
Nature Reviews Earth & Environment, **2020**, 1, 366



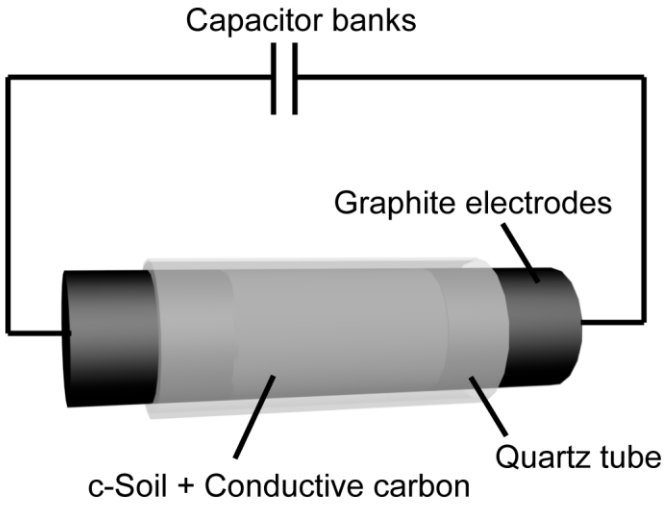
Current Organic Chemistry, **2018**, 10, 366

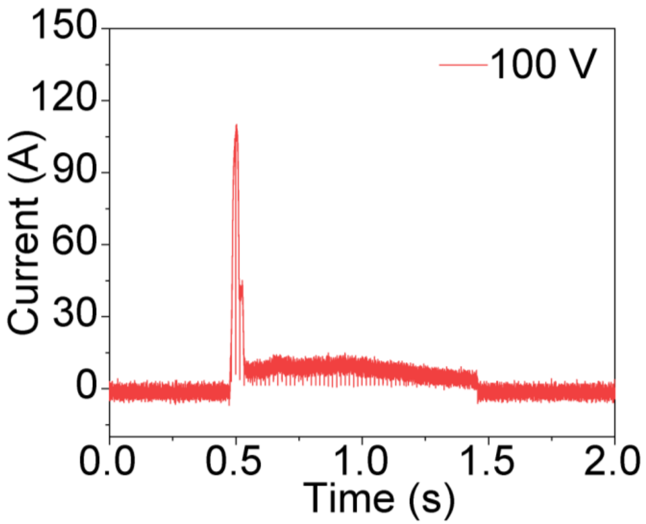
- ➢ **Major anthropogenic sources, agriculture, industry, and mining, release pollutants in soils.**
- ➢ **Among the heavy metals, Hg, Cd, and Pb are considered the most toxic. Other examples includes As, Cu, Ni, Cr, Co, etc.**
- ➢ **The persistent organic pollutants (POPs): Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticide (OCPs), total petroleum hydrocarbon (TPHs), etc.**

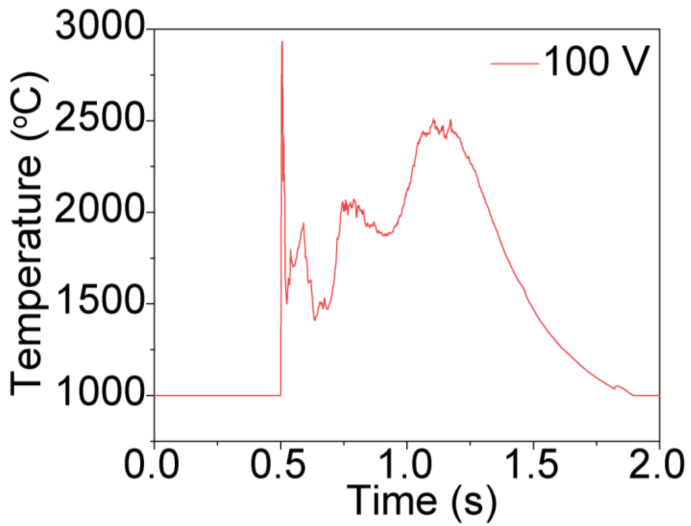
Electrothermal Remediation of Multipollutant Soil



- ❑ **Heavy metals: evaporative removal**
- ❑ **Polycyclic aromatic hydrocarbon (PAH): carburization to graphite**

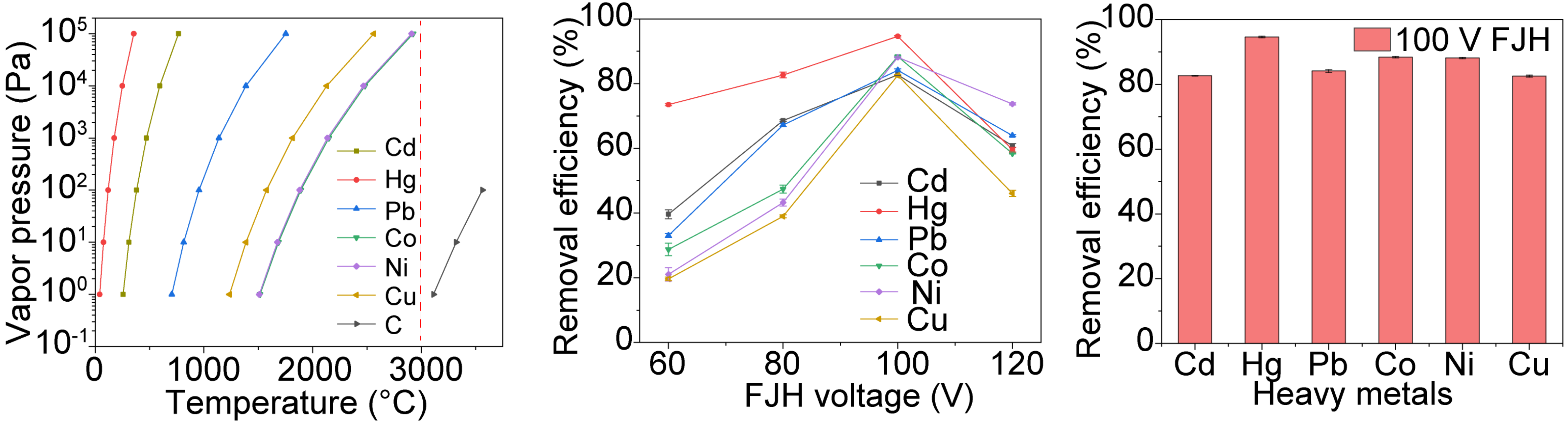






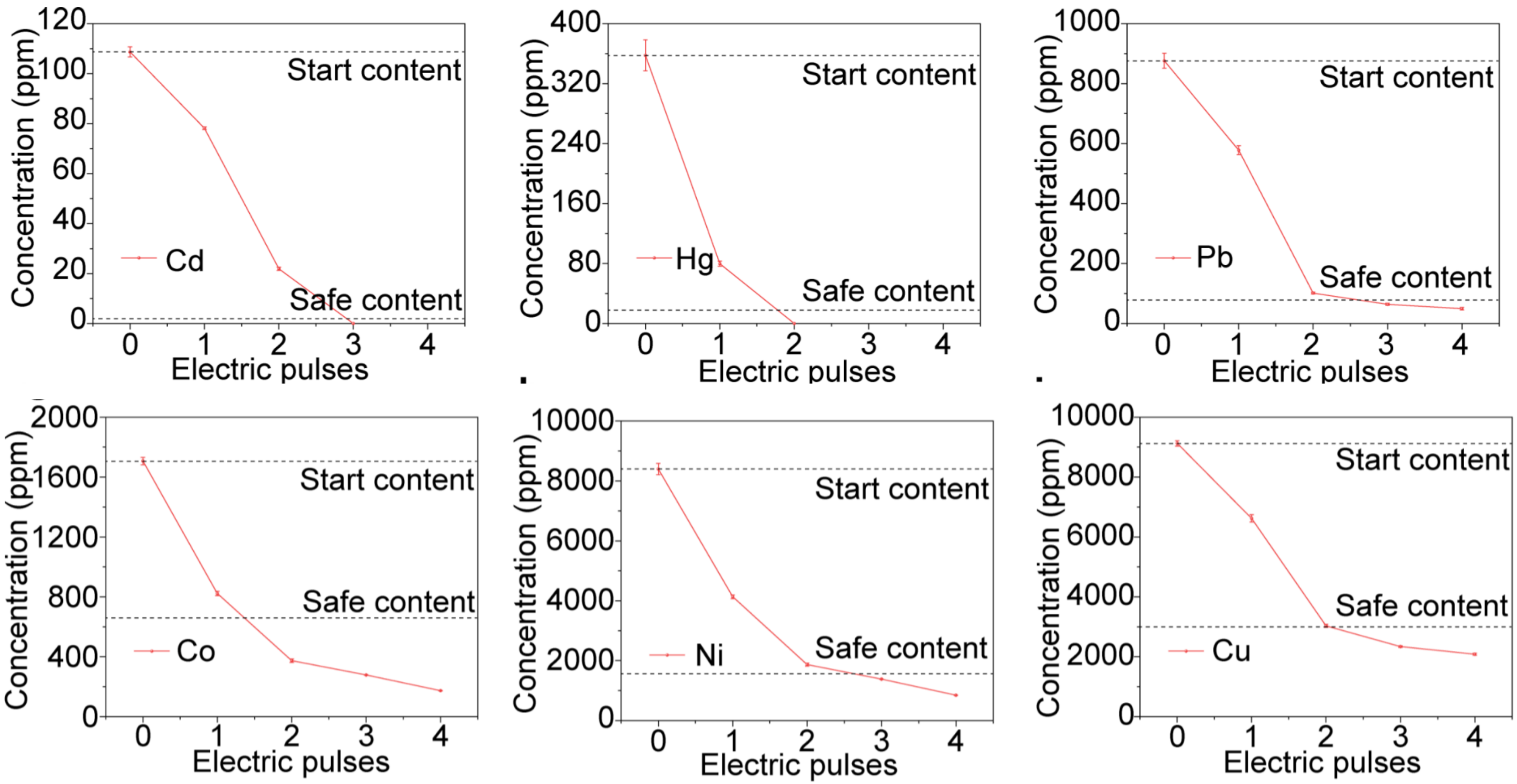
Bing Deng*,#, Robert Carter#, Yi Cheng#, James Tour*, et al, *Nature Communications.* In Revision.
Preprint: 10.21203/rs.3.rs-2874469/v1

Heavy Metal Removal by Electrothermal Vaporization



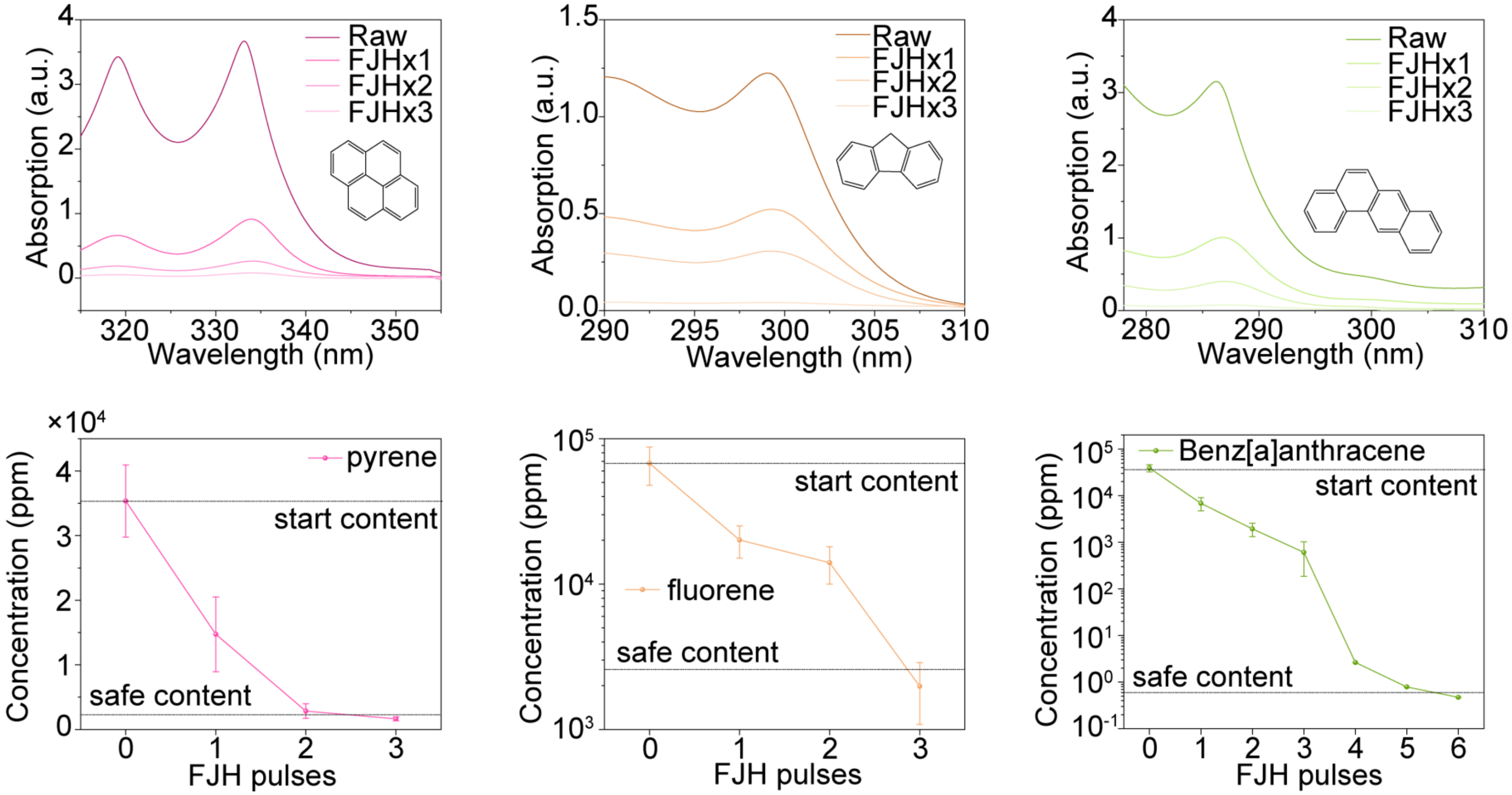
- ❑ The vapor pressure of heavy metals is high under 1000 – 3000 ºC
- ❑ The optimized voltage is 100 V for removal of heavy metals
- ❑ The removal efficiency reaches >80% for all heavy metals

Heavy Metal Removal by Electrothermal Vaporization



- After a few electric pulses, heavy metal contents were reduced to below safety limit.

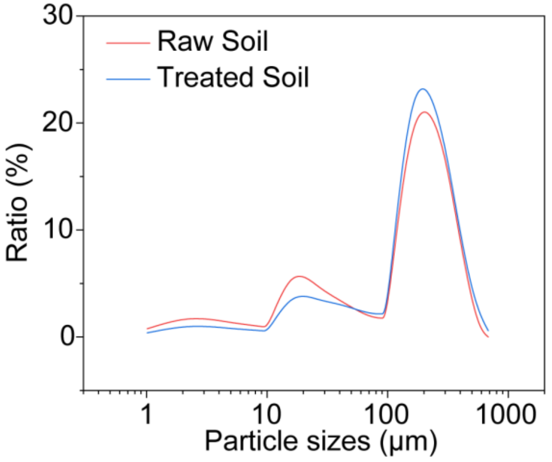
PAH Removal by Electrothermal Carbonization

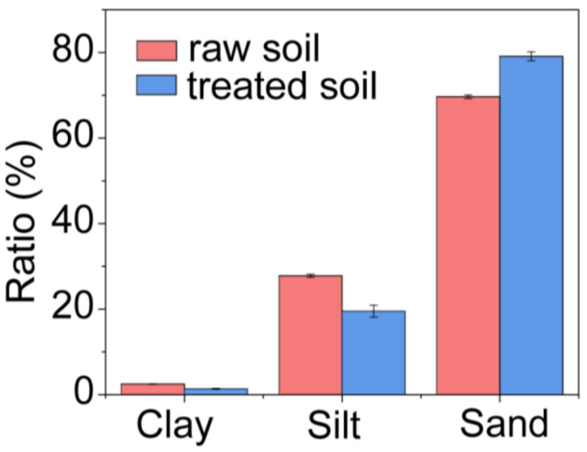


- **Polycyclic aromatic hydrocarbon (PAH): pyrenes, fluorene, benz[a]anthracene**
- **After a few electric pulses, the concentration of PAH were reduced to below the safety limit.**

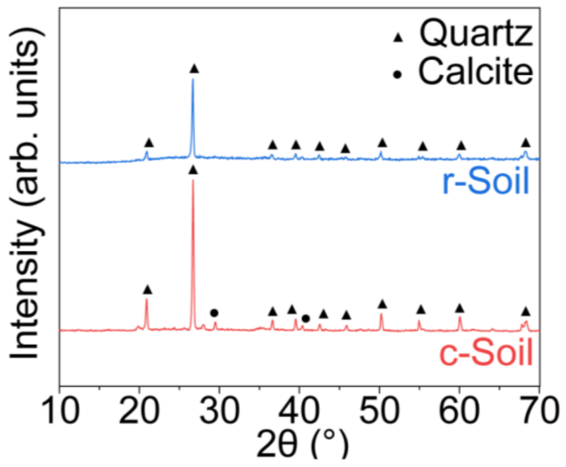
Soil Properties after the Electrothermal Process

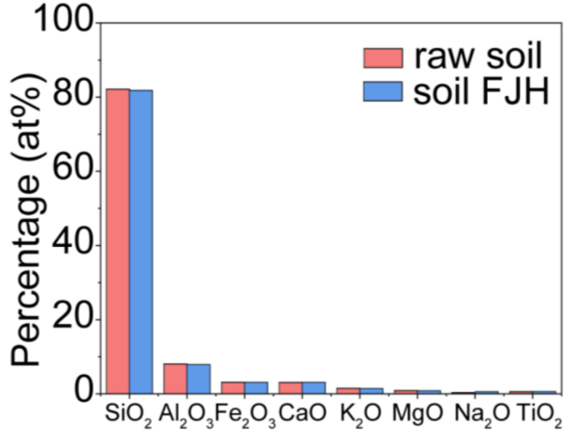
❑ Soil texture: sandy loam



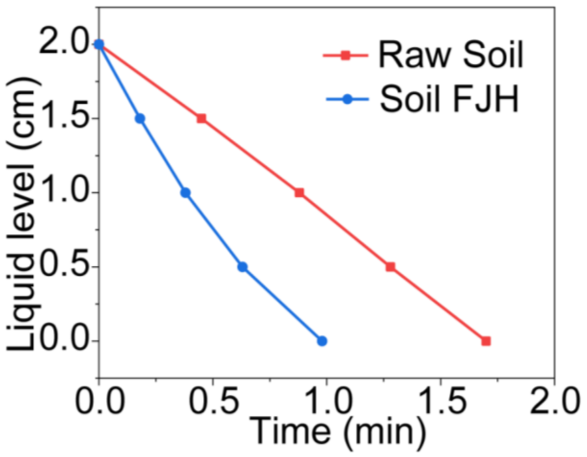


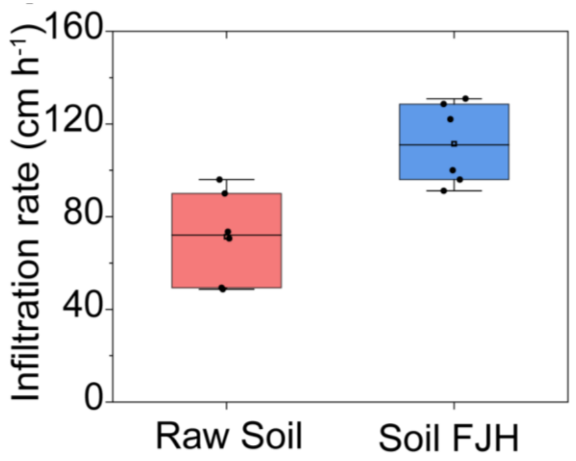
❑ Soil mineralogy





❑ Infiltration rate

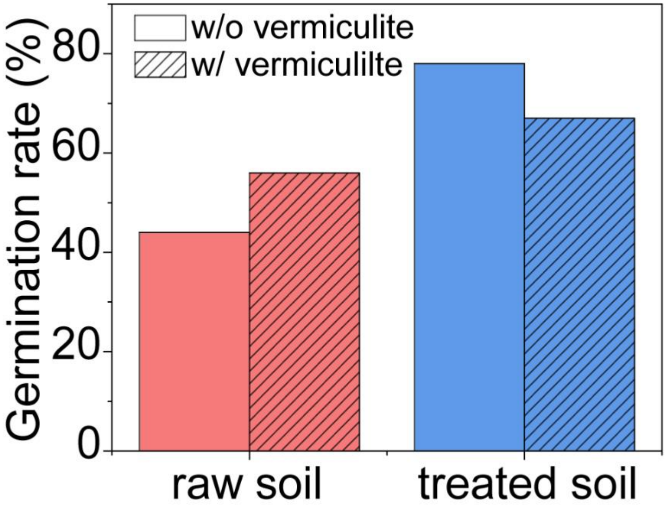


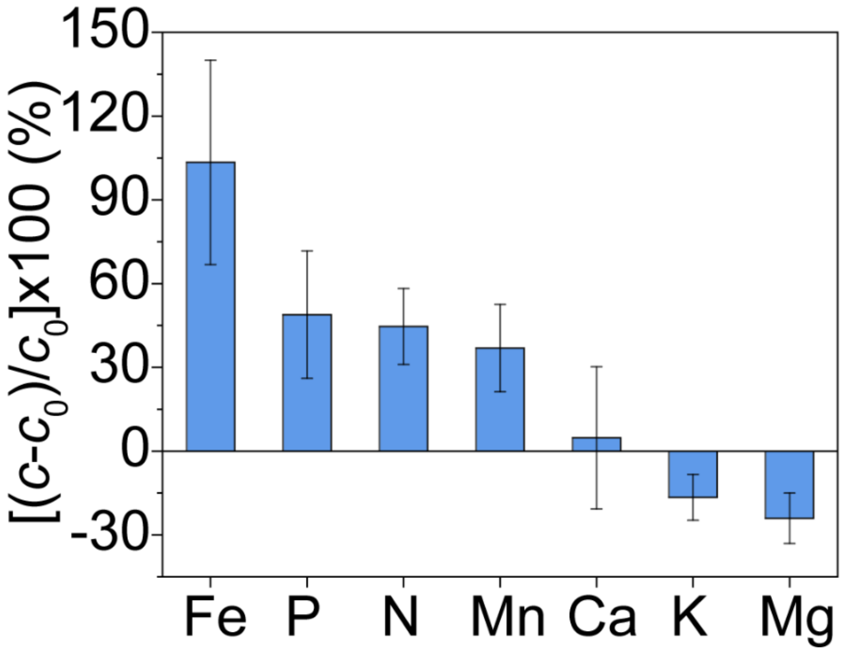


- ❑ **~50% increase of infiltration rate**
- ❑ **Reason: increased sand ratio, as water moves more quickly through the large pores in sand**

Soil Properties after the Electrothermal Process

❑ **Plant growth: broccoli sprouts**





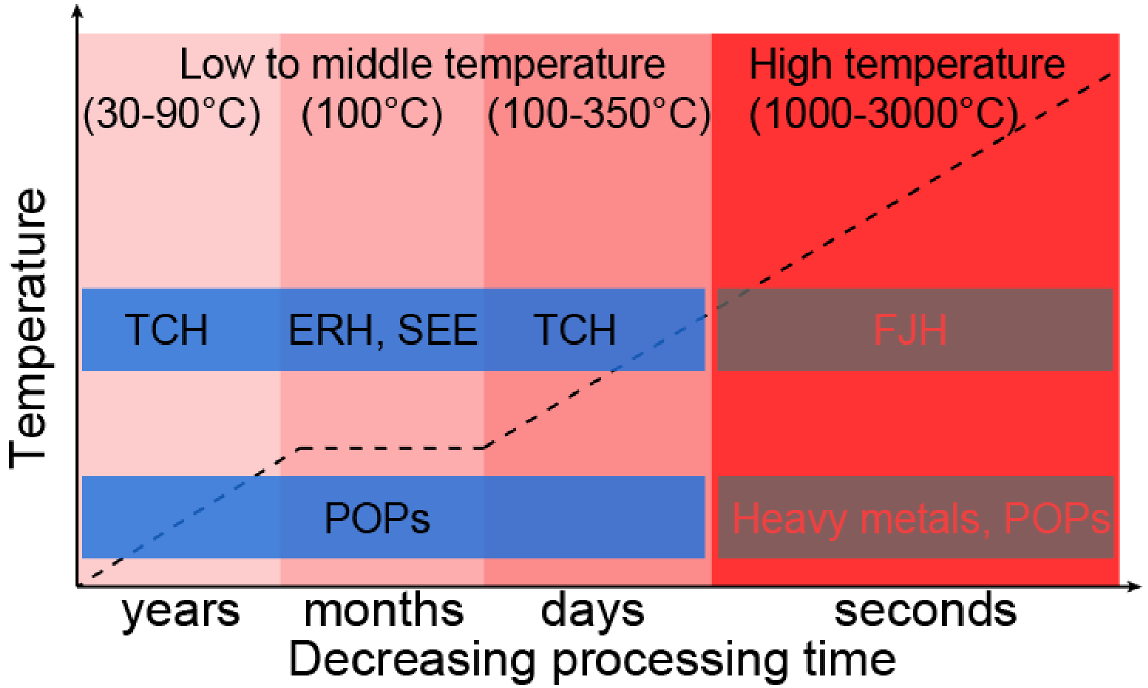
Note: treated soil denotes 1:1 mixture with raw soil

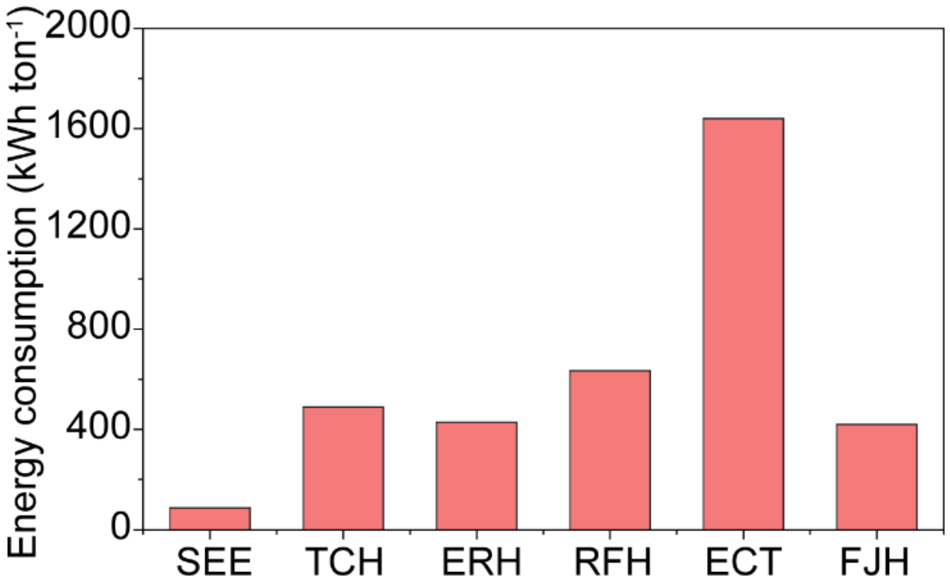
❑ **20 to 30% higher germination rates**

❑ **The exchangeable Fe, P, N, Mn and Ca in treated soil improved by 4 to 103%, while K and Mg decreased by 16 to 24%**

❑ **High-temperature process facilitate the mineralization process of soil organic matters**

Comparison with Existing Thermal Desorption Methods



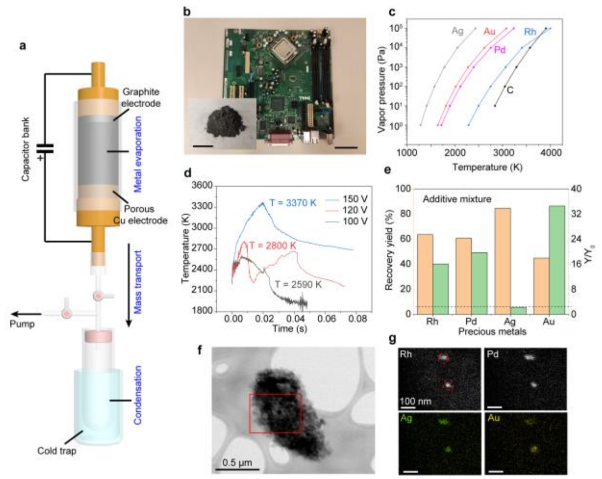


Thermal conduction heating (TCH), electrical resistance heating (ERH), steam-enhanced extraction (SEE), radio frequency heating (RFH), electrochemical technique (ECT), flash Joule heating (FJH)

- **The temperature of FJH (1000 – 3000 °C) is significantly higher than thermal desorption processes (<400 °C).**
- **The energy consumption of the HET process is comparable to or less than thermal remediation technologies.**

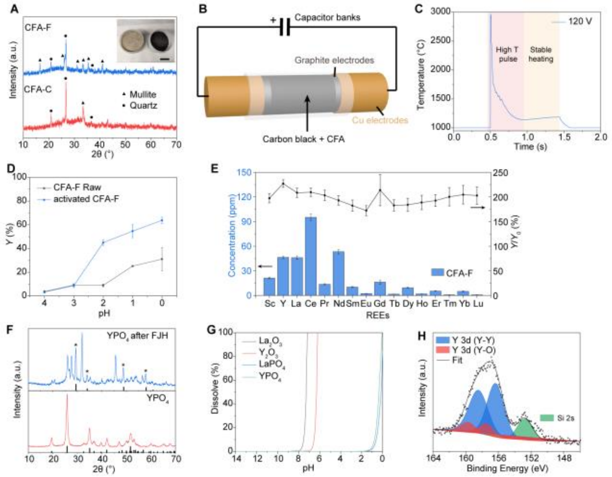
Flash Joule Heating for Resource Recovery and Decontamination

Precious metal recovery from e-wastes



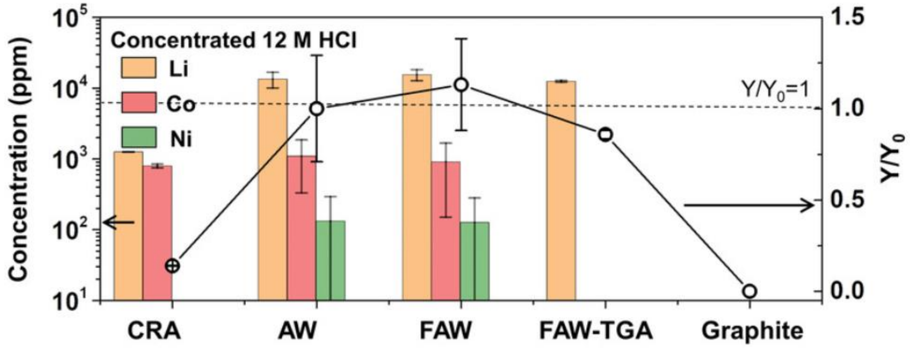
Bing Deng, et al. *Nat. Commun.* **2021**, *12*, 5794

Rare earth recovery from fly ash, red mud, e-waste



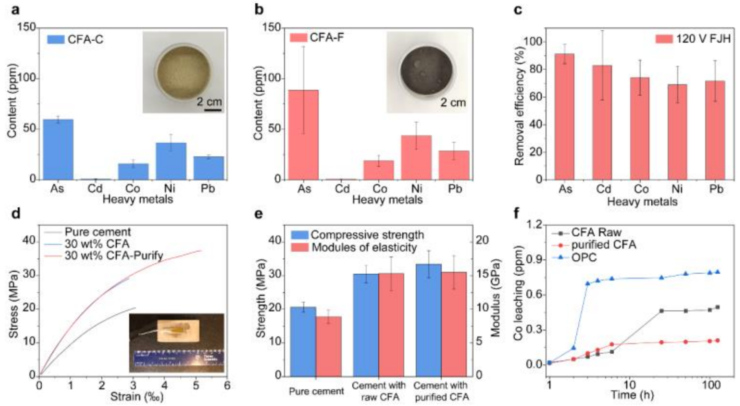
Bing Deng, et al. *Sci. Adv.* **2022**, 8, eabm3132

Battery metals from waste Li-ion battery



Weiyin Chen, et al. *Adv. Mater.* **2023**, 35, 2207303

Heavy metal removal from fly ash for cement



Bing Deng, Wei Meng, et al. *Commun. Eng.* **2023,** Accepted.

As a new energy-efficient thermal process, FJH is promising in critical metals recovery from wastes, heavy metals removal for remediation, etc.

Acknowledgement

Collaborators:
Dr. Xin Wang
Prof. Mason Tomson
Dr. Wei Meng
Prof. Satish Nagarajaiah
Dr. Mine Ucak-Astarlioglu (ERDC)
Dr. Yuan Liu
Prof. Janet Braam
Bo Wang
Prof. Michael S. Wong

Prof. James M. Tour
The Tour group at Rice University

Dr. Zhe Wang
Dr. Duy Xuan Luong
Robert A. Carter
Carter Kittrell
Dr. Emily A. McHugh
Phelecia Scotland

Dr. Pual A. Advincula
Lucas Eddy
Kevin M. Wyss
Dr. Weiyin Chen
Dr. Yi Cheng
Khalil JeBailey

U.S. DEPARTMENT OF ENERGY
DARPA
AFRL
THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER
ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER
Air Force Office of Scientific Research