

Data-Informed Models of Chemical Composition of Coal Fly Ash:

Contaminant leaching and reuse potential

DE-FE0031748

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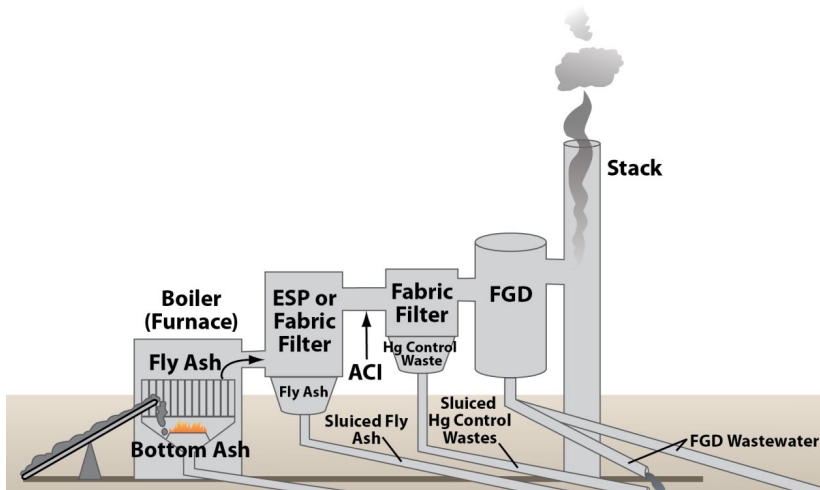
FECM/NETL Spring R&D Project Review Meeting



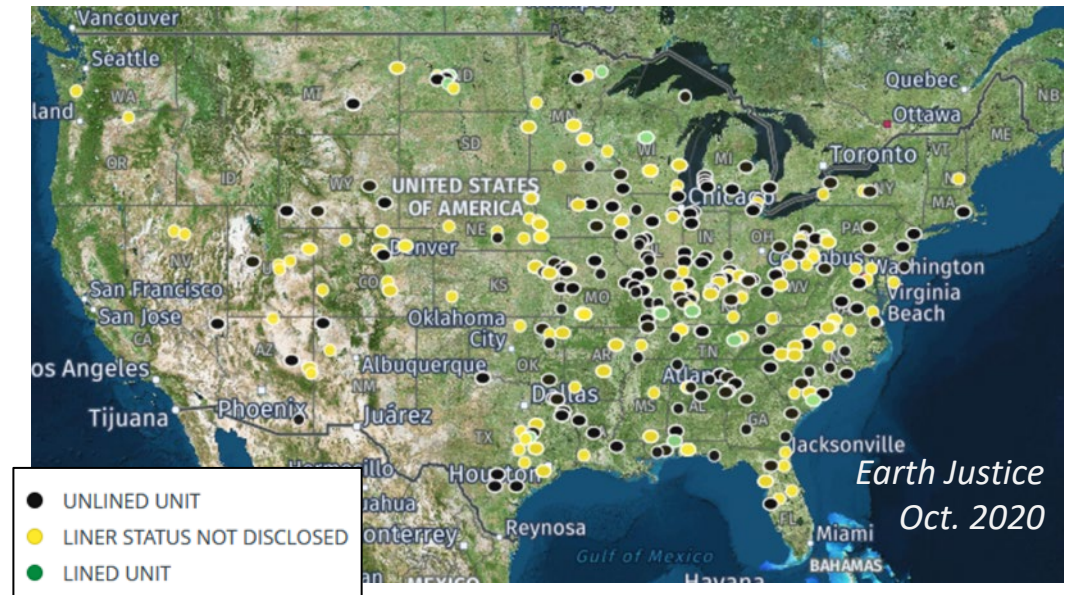
Coal Combustion Residues

Production rate:

~75-100 million tons yr⁻¹ in U.S.



Coal ash storage units
(industry reported for EPA Rule)



~55% for beneficial use
fly ash - concrete
gypsum - drywall

~2 billion tons
stored/discarded in landfills
and disposal ponds

Spills at Coal Ash Disposal Sites

Dan River Steam Station (NC), Feb. 2014



Sutton Plant at Sutton Lake (NC),
Sept. 2018



TVA Kingston (TN), Dec. 2008



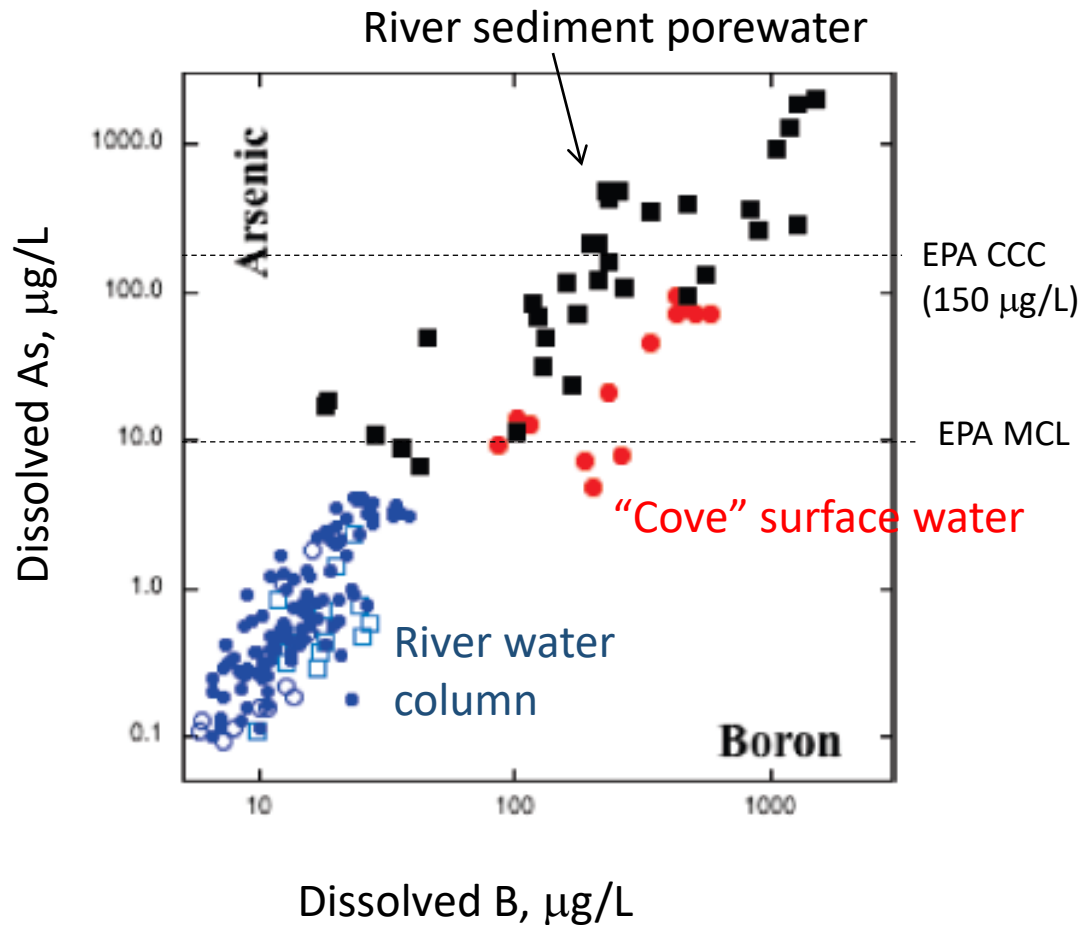
Knoxville News Sentinel



WRAL.com

Risks of Coal Ash: Leaching of contaminants

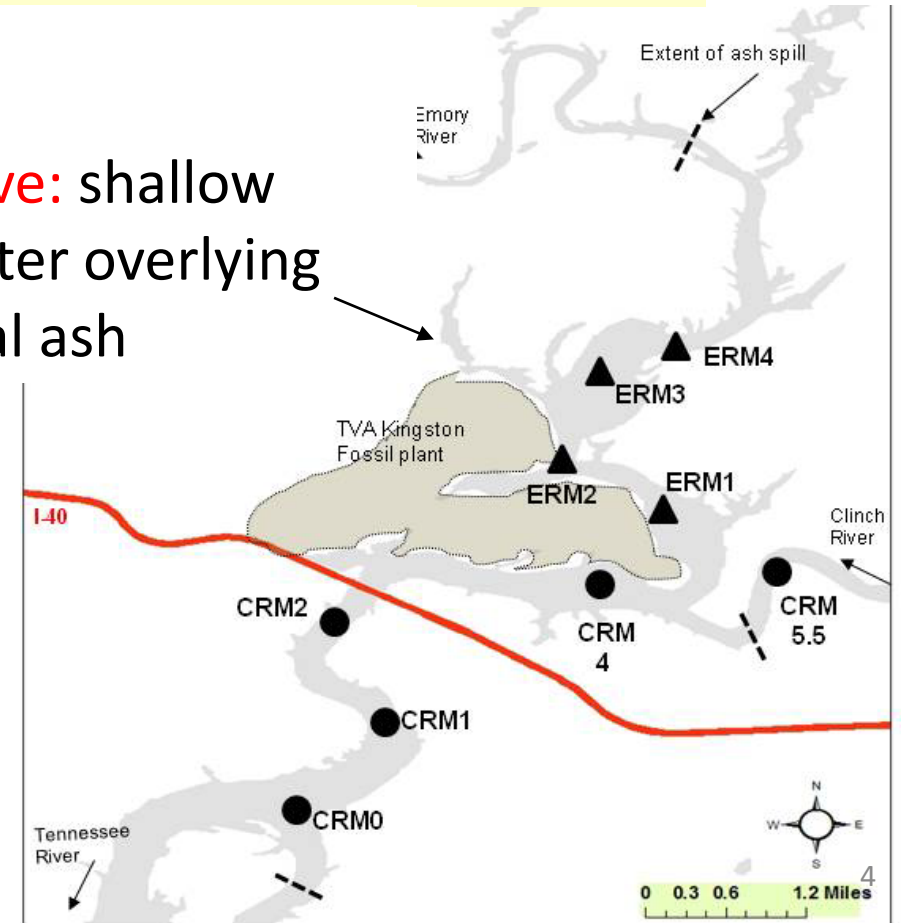
TVA-Kingston coal ash spill disaster: River water and sediments



Factors controlling arsenic concentration:

- Dilution with river water
- Redox gradients in the river

Cove: shallow water overlying coal ash



Risks of Coal Ash: Biouptake of contaminants

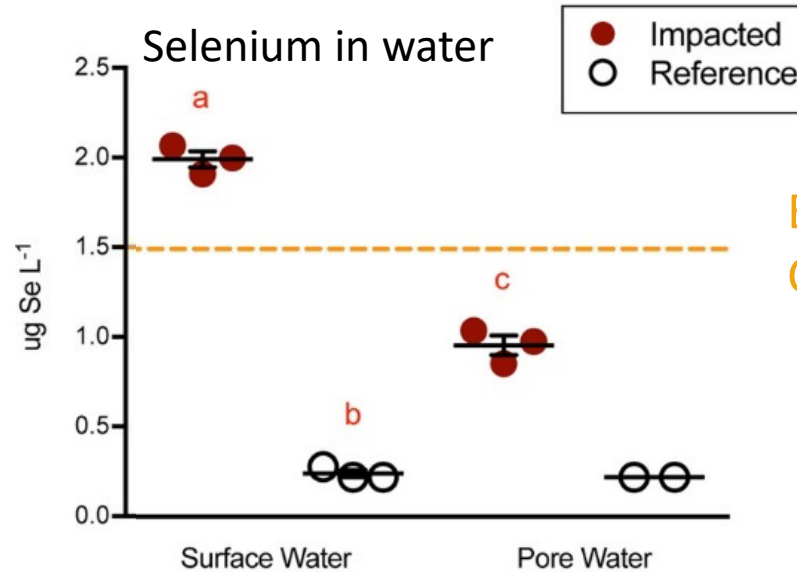
Ecological hazards of selenium

selenium toxicity for fish in
Belews Lake



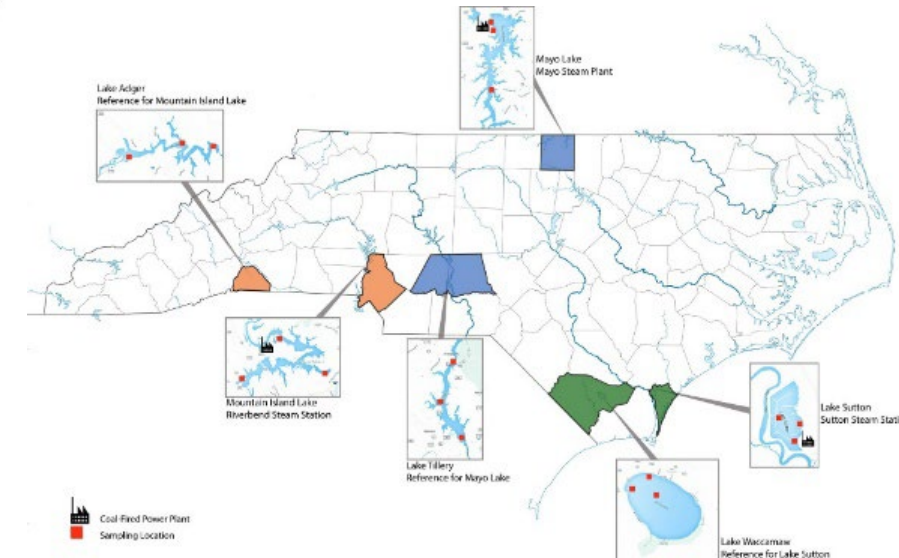
Lemly, A.D., *Aquatic Toxicology*, 2002

Sutton Lake vs. Lake Waccamaw



EPA Ambient Aquatic Life
Criteria

Brandt et al, *ES&T*, 2017



Coal Combustion Residues

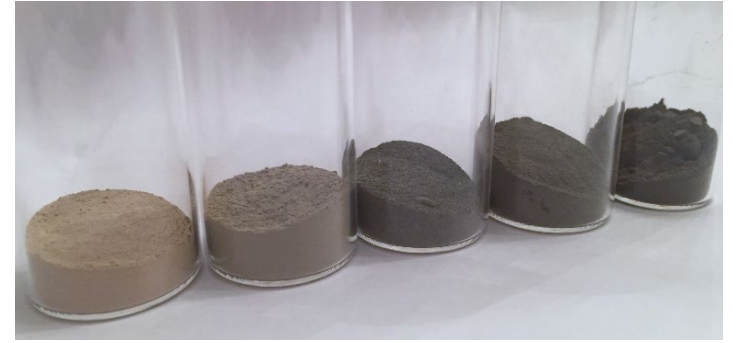
1. Environmental Risks

Arsenic and Selenium:

- Enrichment and chemical speciation in fly ash
- Predictive models for leaching potential

2. Resource Potential

- Resource reserves of coal ash disposal sites



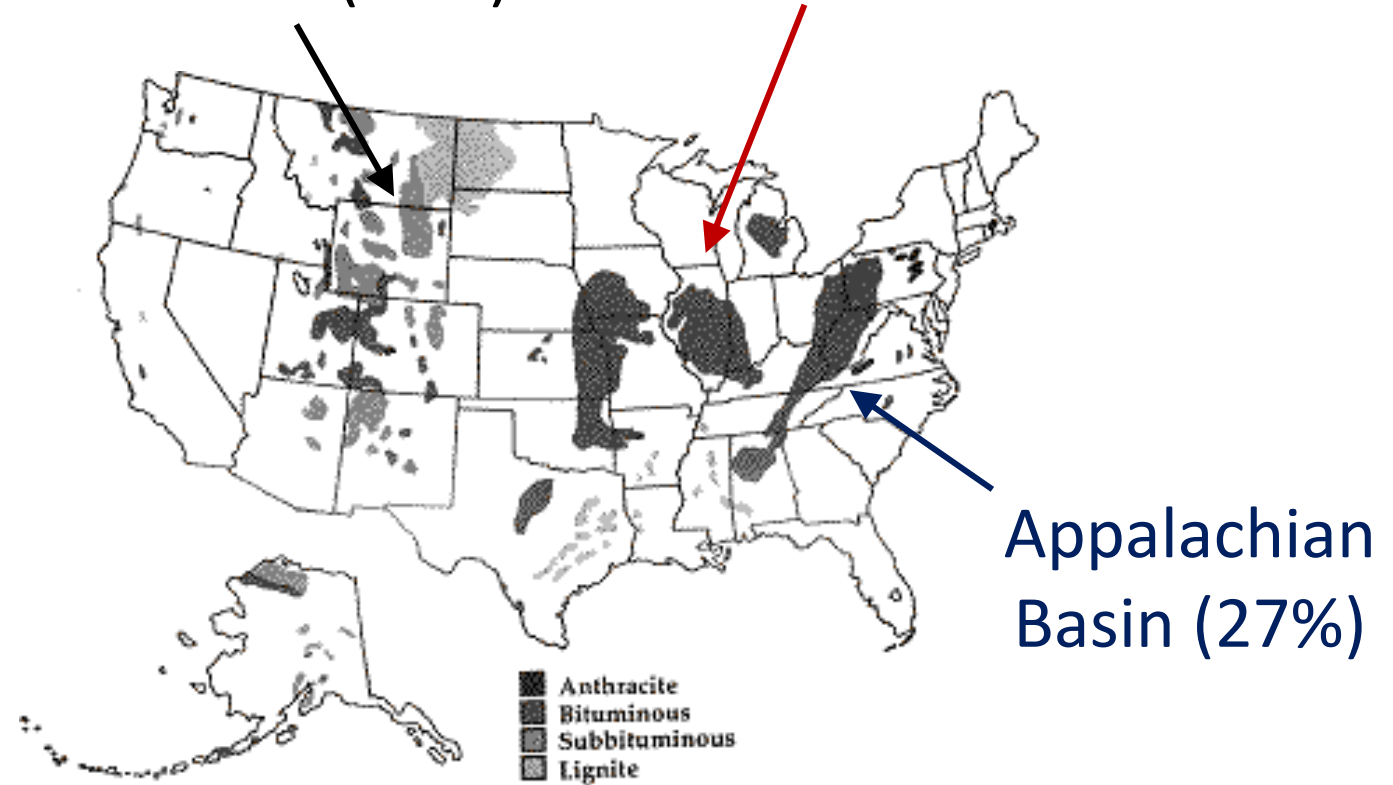
Risks of Coal Ash: Toxic Metals and Metalloids

Coal ash composition depends on coal origin

Coal Producing regions in the U.S.

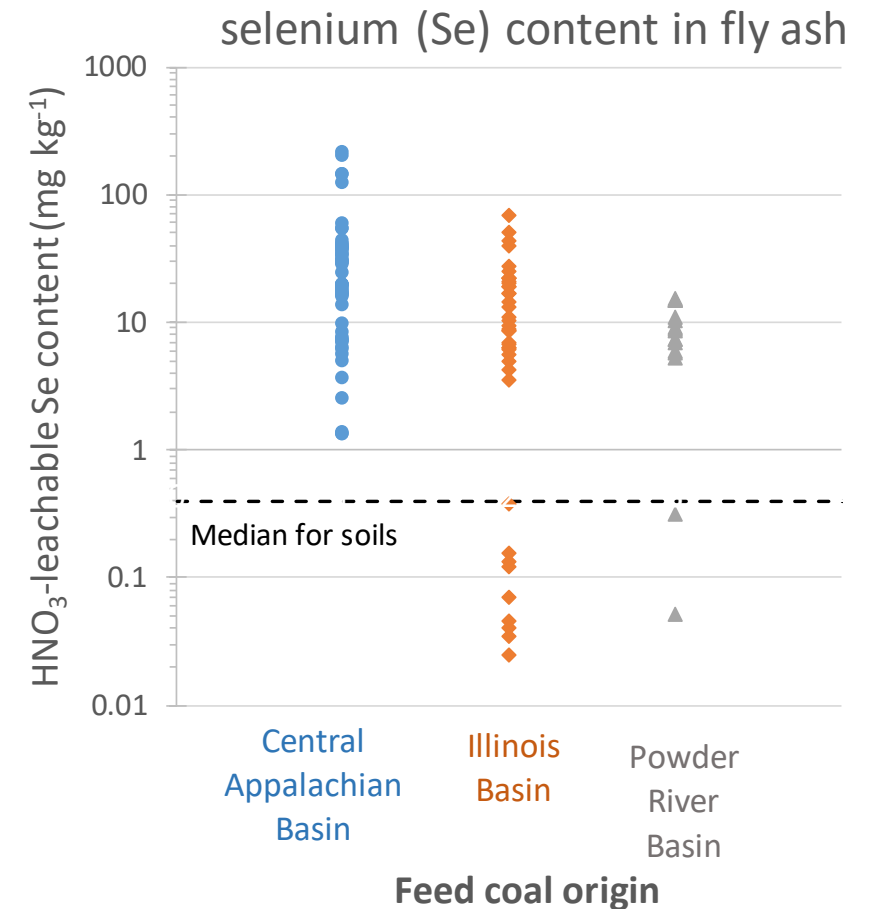
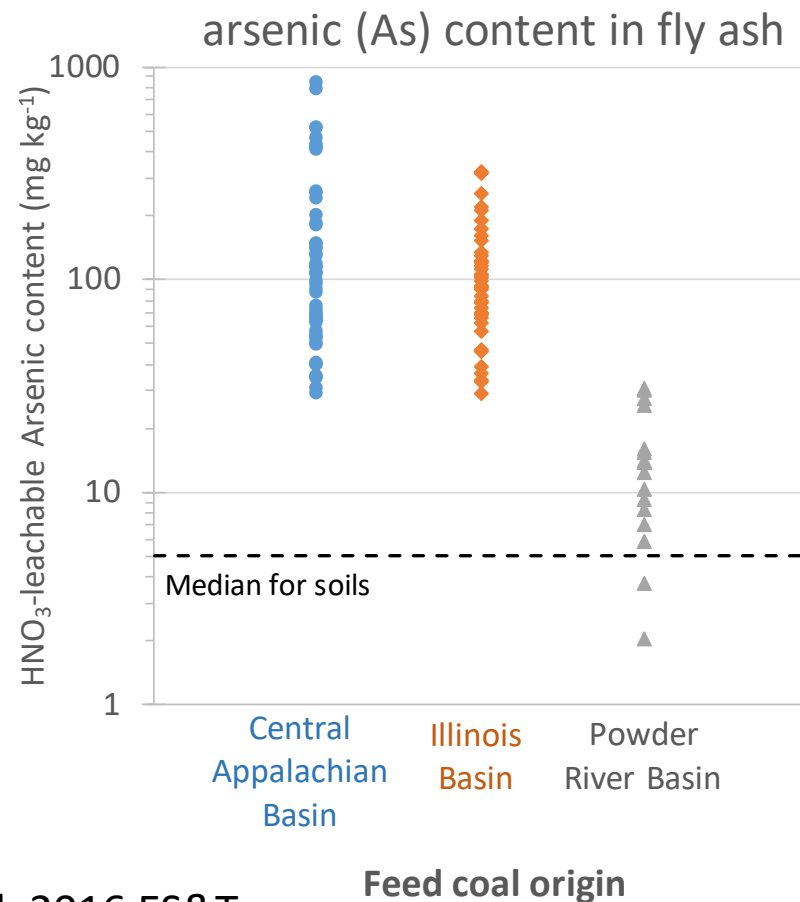
Powder River Basin (41%)

Illinois Basin (13%)



Risks of Coal Ash: Toxic Metals and Metalloids

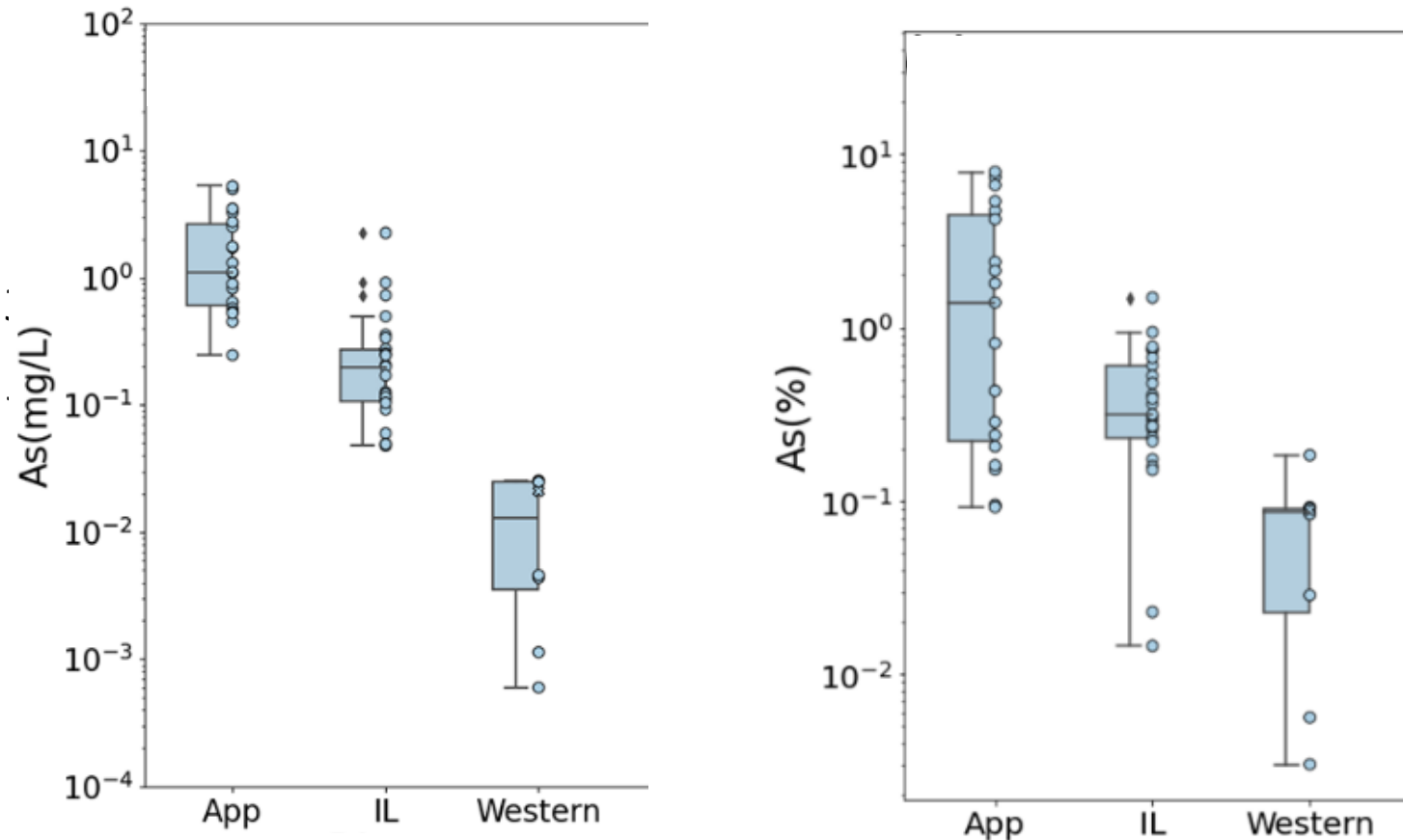
- Wide range of Arsenic and Selenium contents in coal fly ash
- Depends on geochemical properties of the feedstock coal



Leachable Arsenic in Coal Fly Ash

Soluble Arsenic in deionized water

1 g-ash per 15 mL

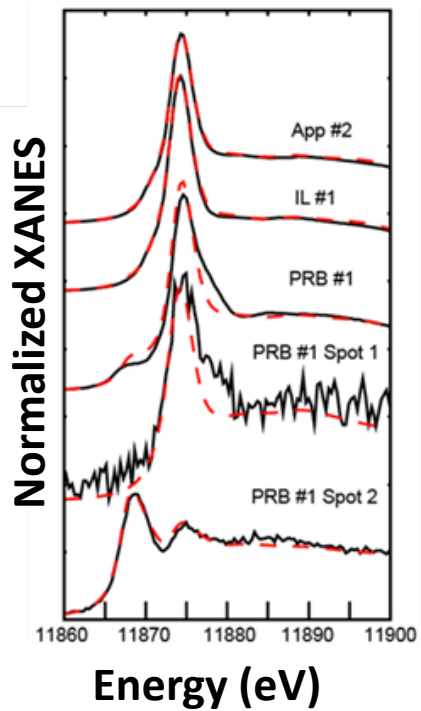


- Total elemental content is not always informative of leachable concentrations
- Speciation of arsenic may be an important factor

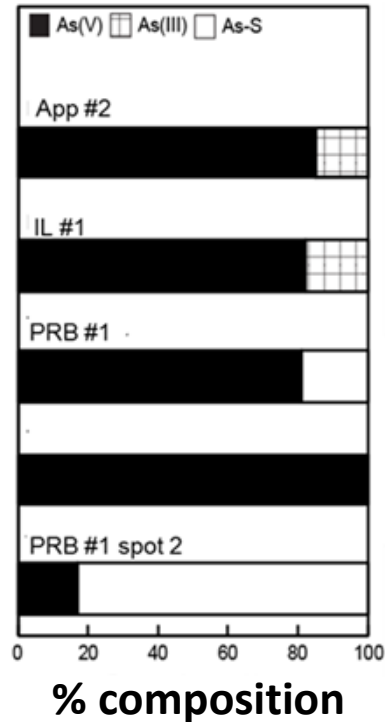
Chemical Forms of Arsenic in Coal Fly Ash

Arsenic is heterogeneously distributed within fly ash grains

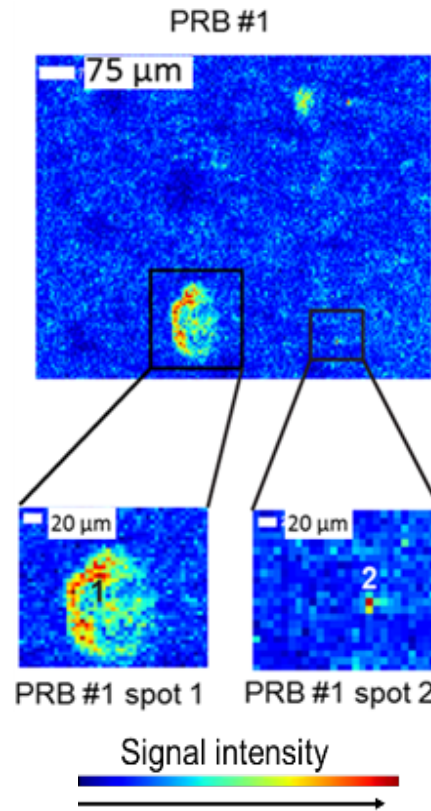
Arsenic K-edge XANES
(bulk fly ash)



Linear Combination
Fitting of Data



Arsenic spatial
distribution (μ -XRF)

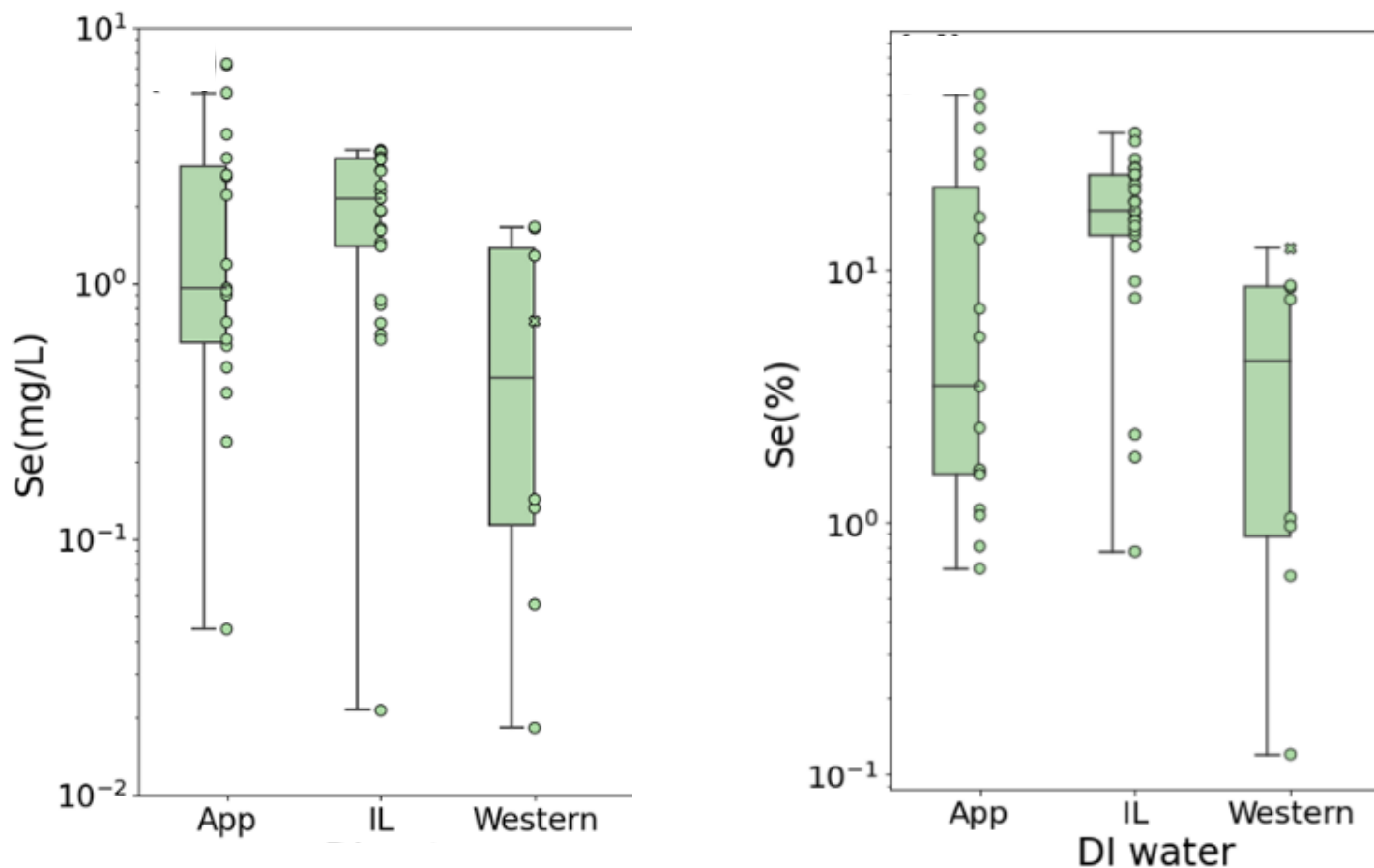


Arsenate As(V) is in one grain and mixed valence As in another grain

Selenium in Coal Fly Ash

Soluble Selenium in deionized water

1 g-ash per 15 mL

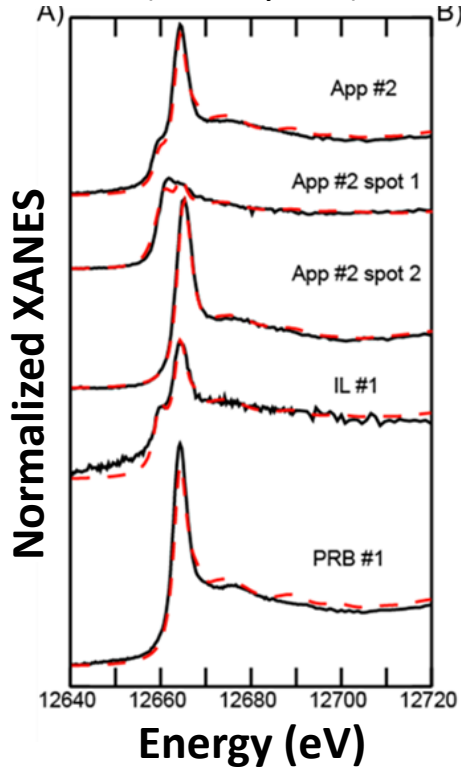


Wide range of %Leachable Se values

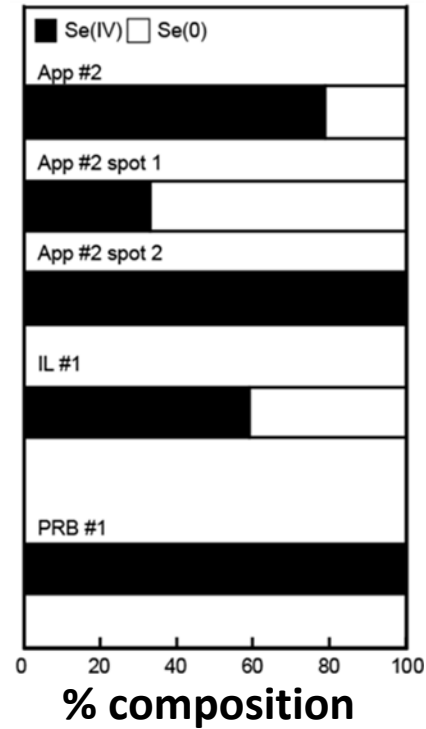
Chemical Form of Selenium in Coal Fly Ash

Variations of selenium species and spatial distribution within fly ash grains

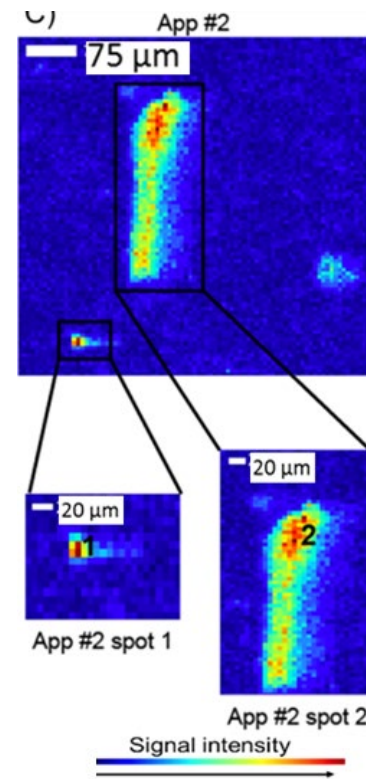
Selenium K-edge XANES
(bulk fly ash)



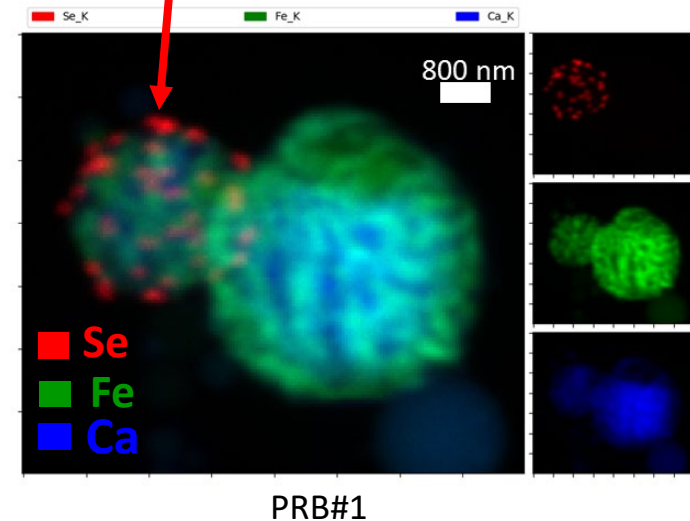
Linear Combination
Fitting of Data



Selenium spatial distribution (micro- and nano-XRF)

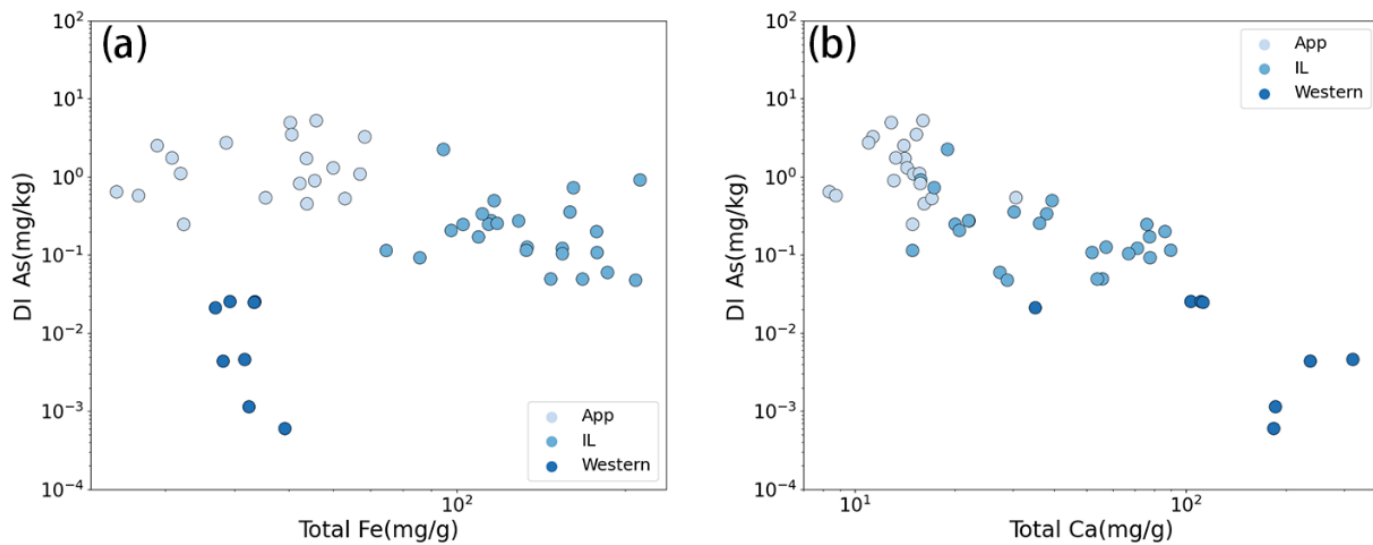


Discrete nanoscale selenium-bearing particles on fly ash grain



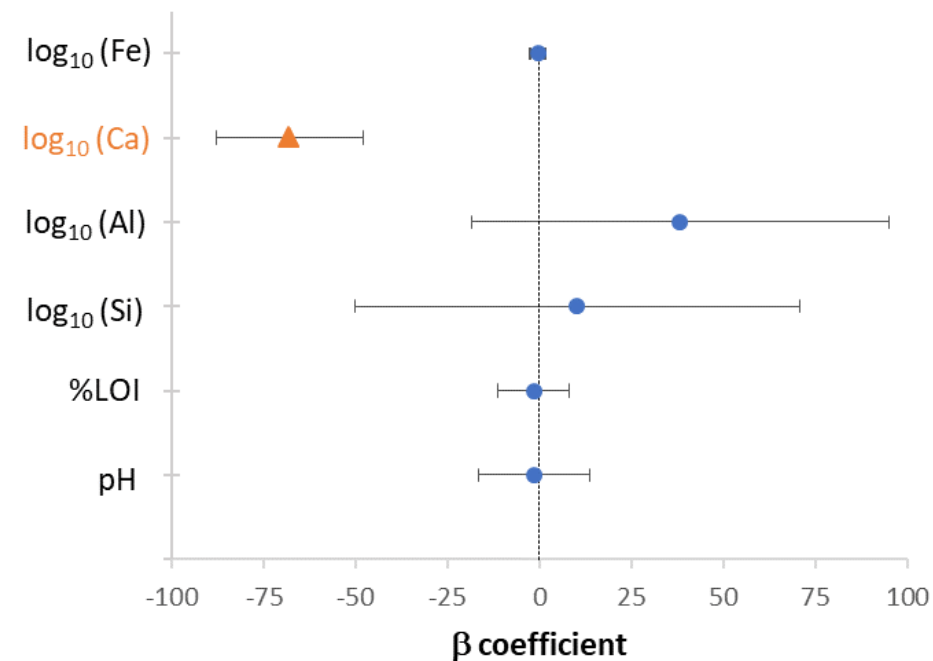
Functional parameters to predict leaching potential

Leachable Arsenic from coal fly ash



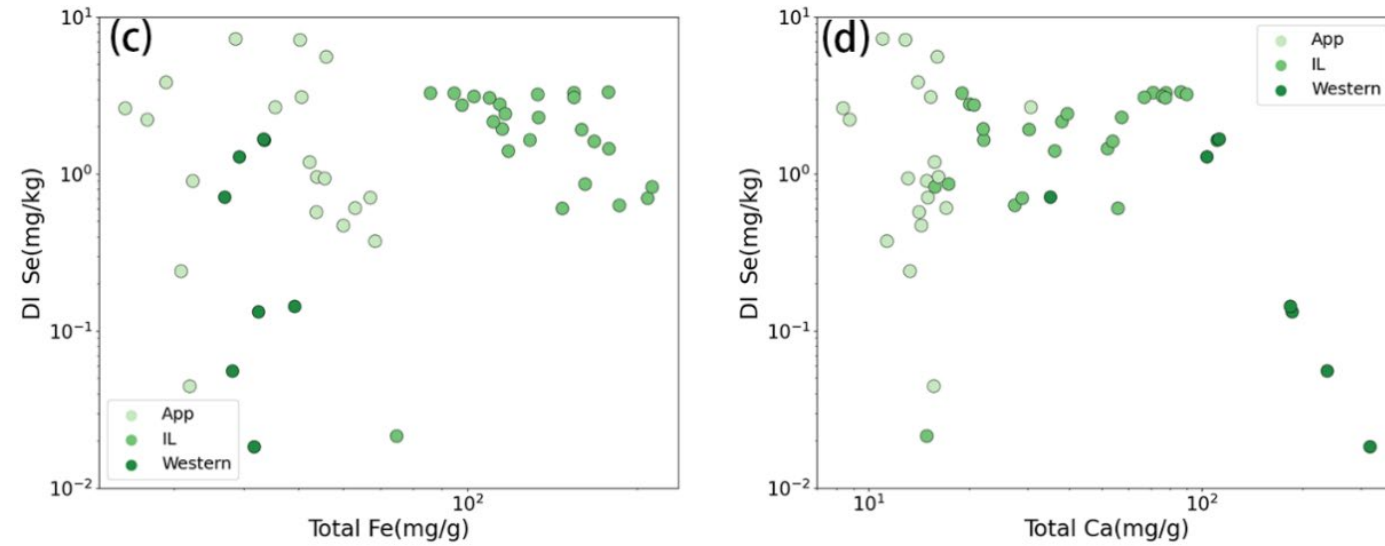
multivariate regression of leachable arsenic

predictor variable:



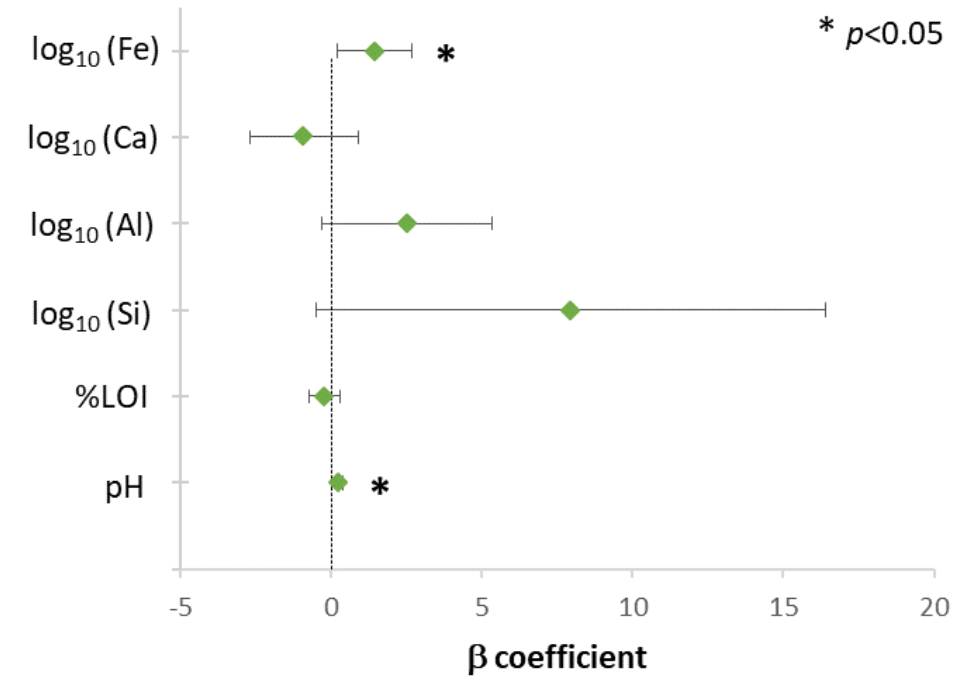
Functional parameters to predict leaching potential

Leachable Selenium from coal fly ash



multivariate regression of leachable selenium

predictor variable:



Coal Combustion Residues

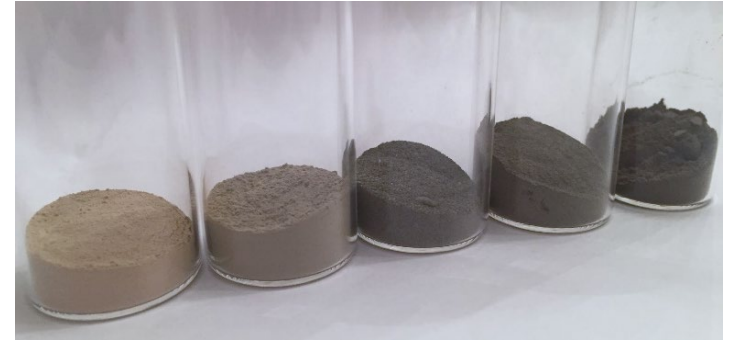
1. Environmental Risks

Arsenic and Selenium:

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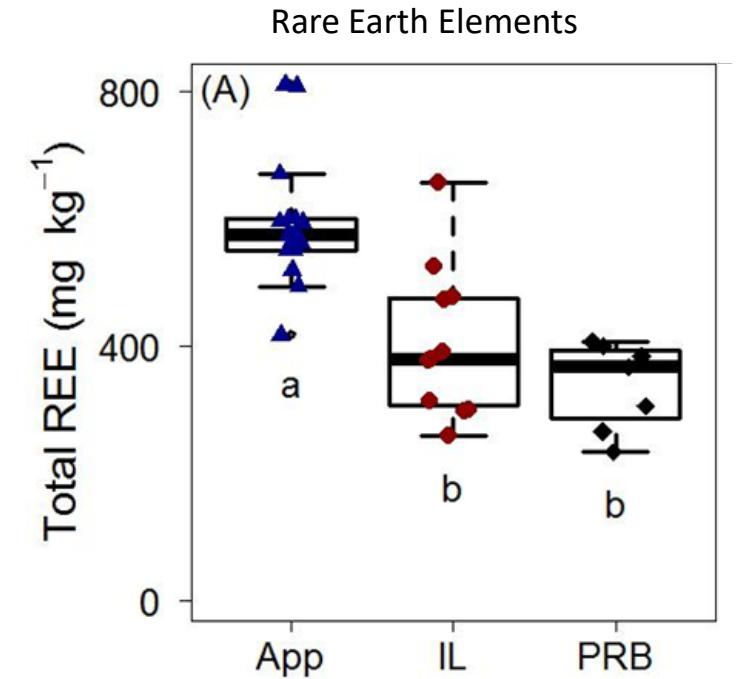
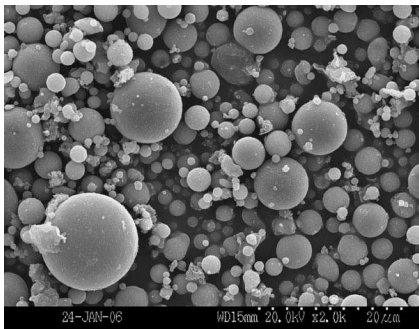
2. Resource Potential

- **Resource reserves of coal ash disposal sites**



Resource Opportunities for Coal Ash

- Concrete
- Structural fill
- Soil stabilization
- Road base
- Critical metals



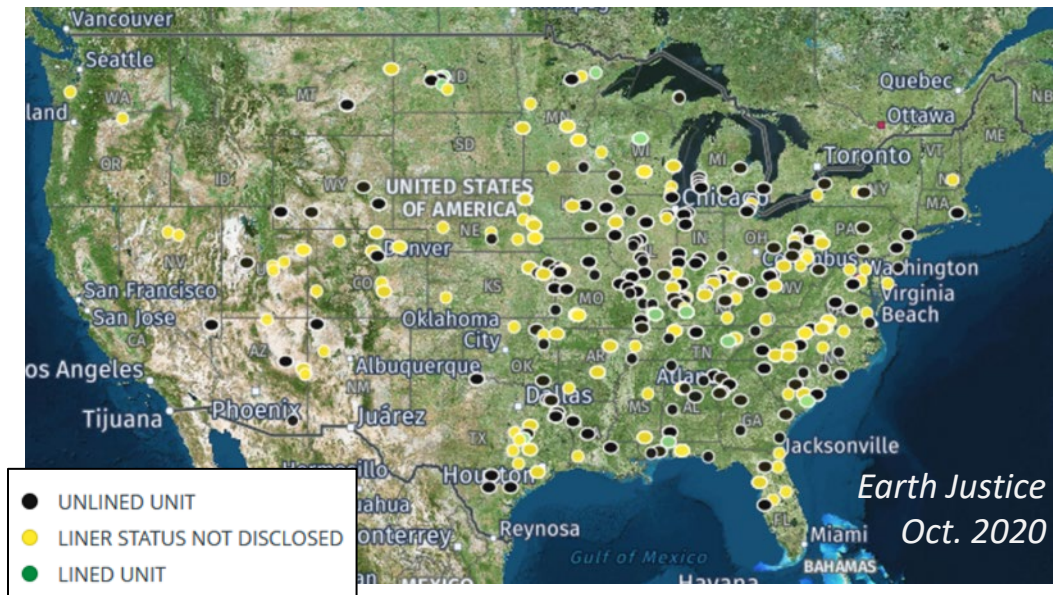
Taggart *et al.*, *ES&T*, 2016

Resource Opportunities for Coal Ash

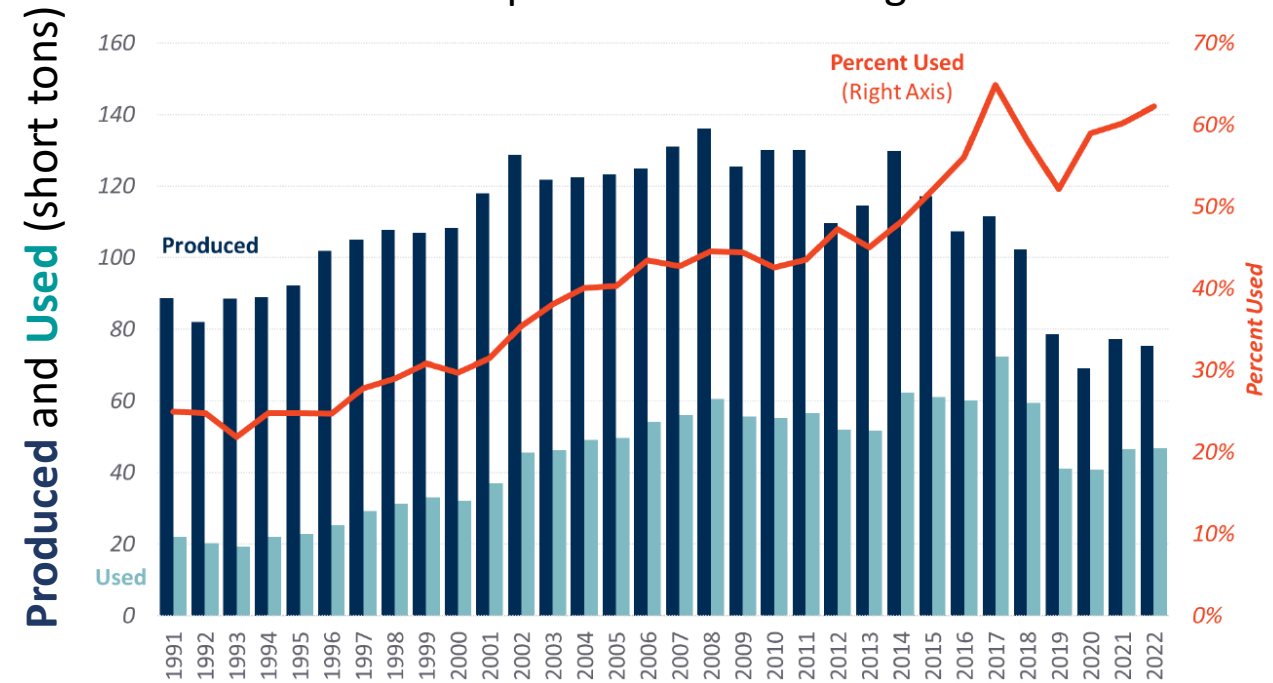
Coal ash storage units

(industry reported for EPA Rule)

- ~2 billion tons of discarded coal ash
- Recent EPA rules will require retrofitting & closure of units



U.S. Coal Combustion Residues Annual production and usage



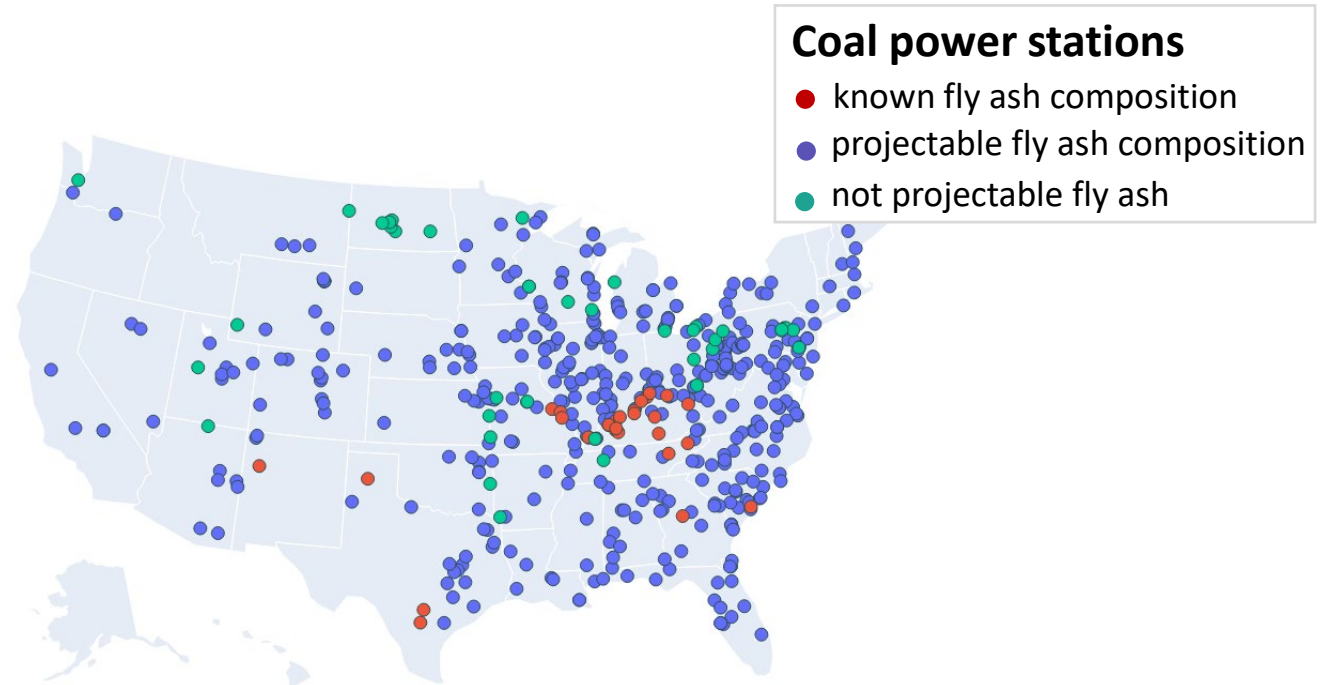
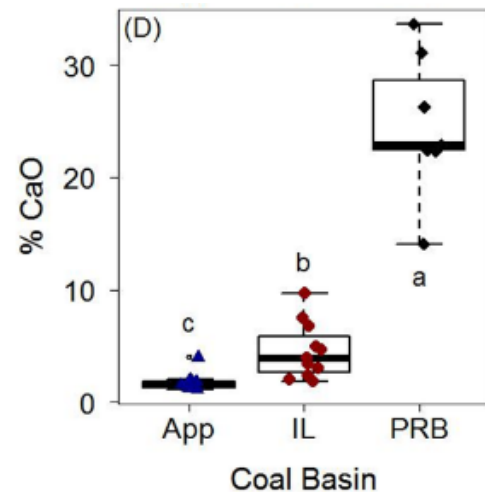
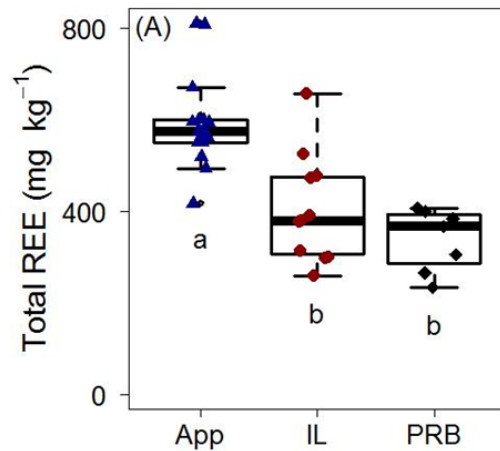
(American Coal Ash Association; <http://aca-usa.org>)

Chemical composition of legacy ash?

Resource Opportunities for Coal Ash

Can we estimate a resource 'reserves' of discarded coal ash?

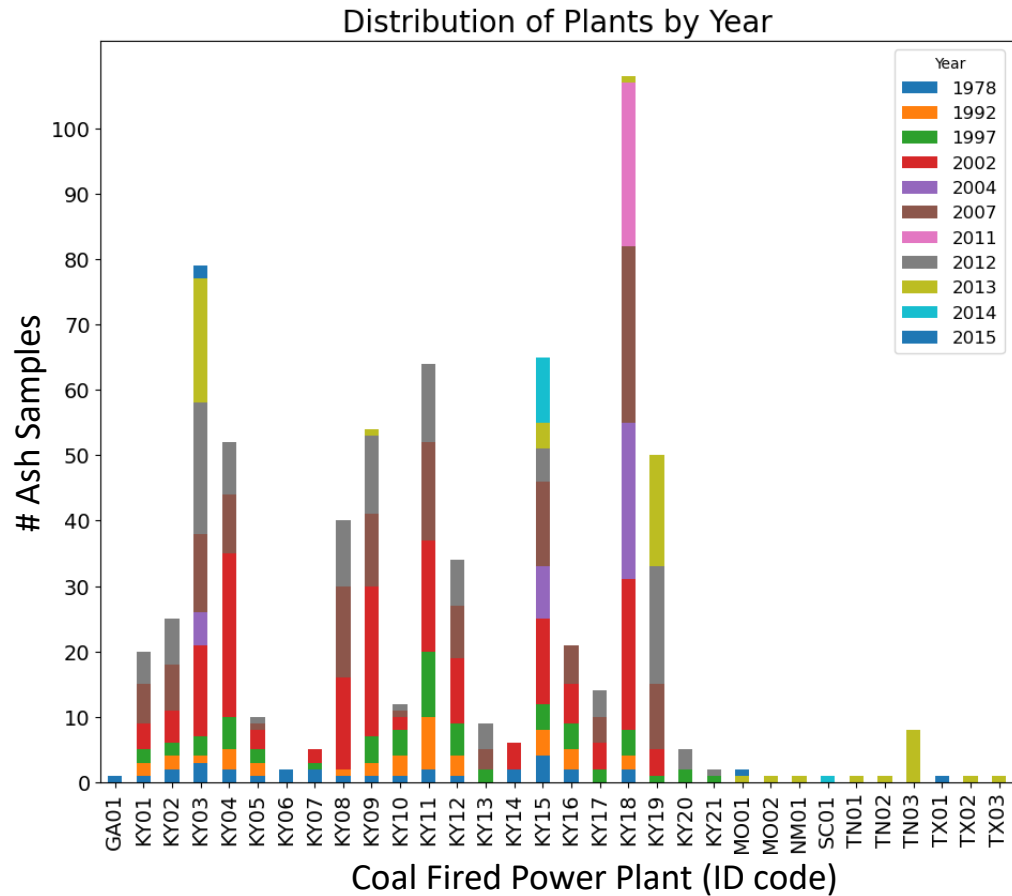
Fly ash composition depends on the coal source



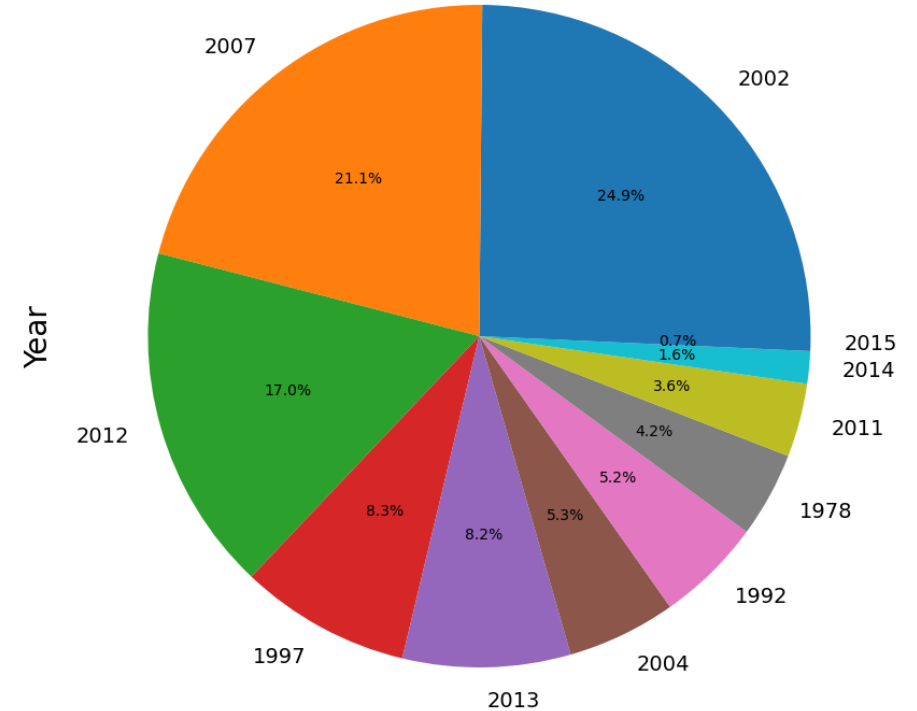
Summary of available coal fly ash composition data:

Total samples n=696
Power plants n=32

Major elements (Si, Al, Ca, Fe)
Minor elements (Mg, Na, K, Ti)
Trace elements (for subset)

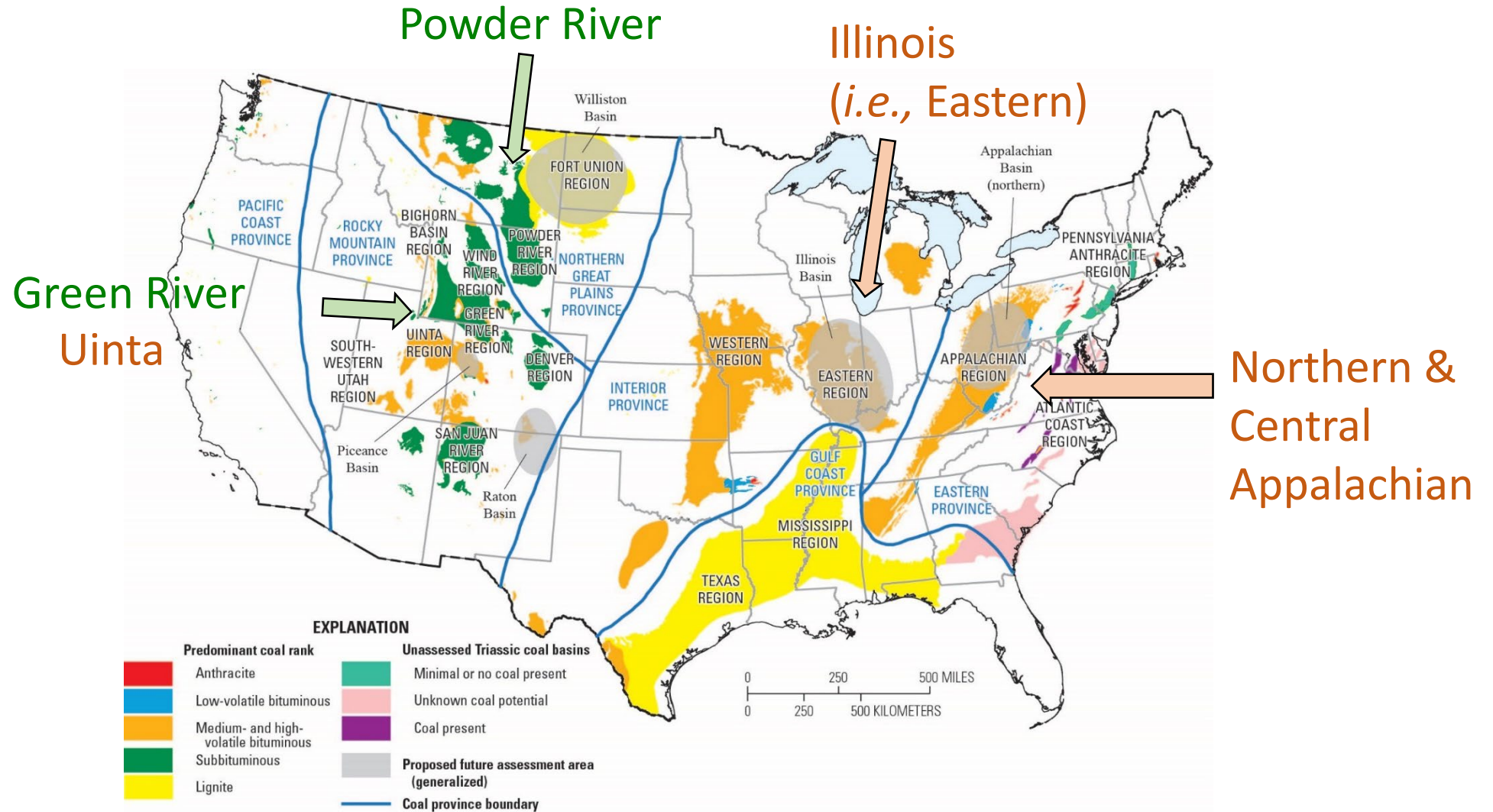


Distribution of Ash Years



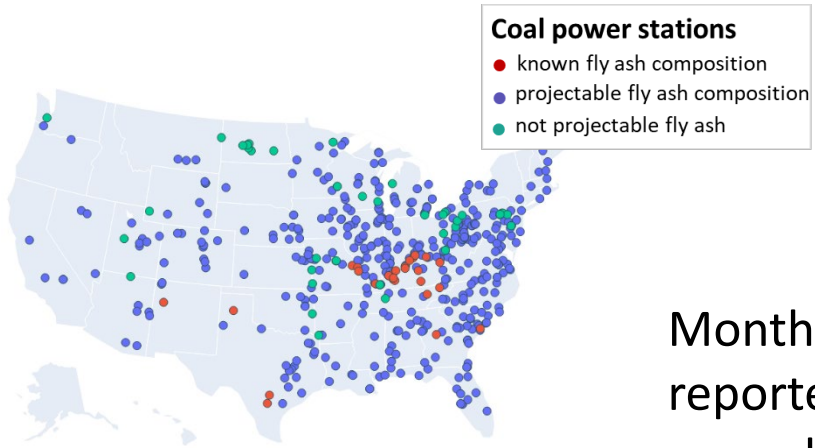
From previous studies:
Taggart et al, 2016; Hower et al., 1999; UK CAER

Major Coal Mine Regions

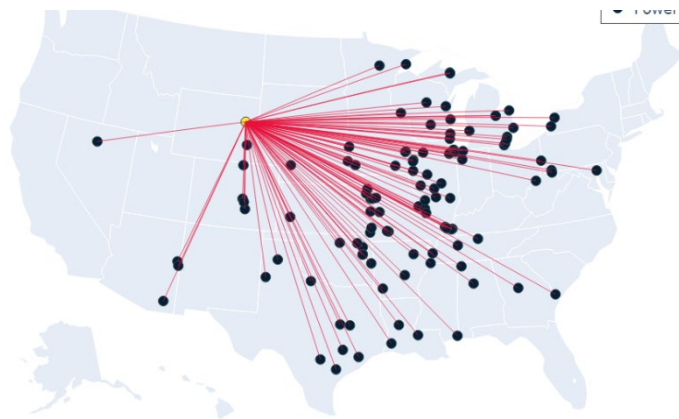


East, J. A. (2013). *Coal fields of the conterminous United States—National Coal Resource Assessment updated version* [Open-File Report 2012-1205]. USGS Publications Warehouse. <https://doi.org/10.3133/ofr20121205>

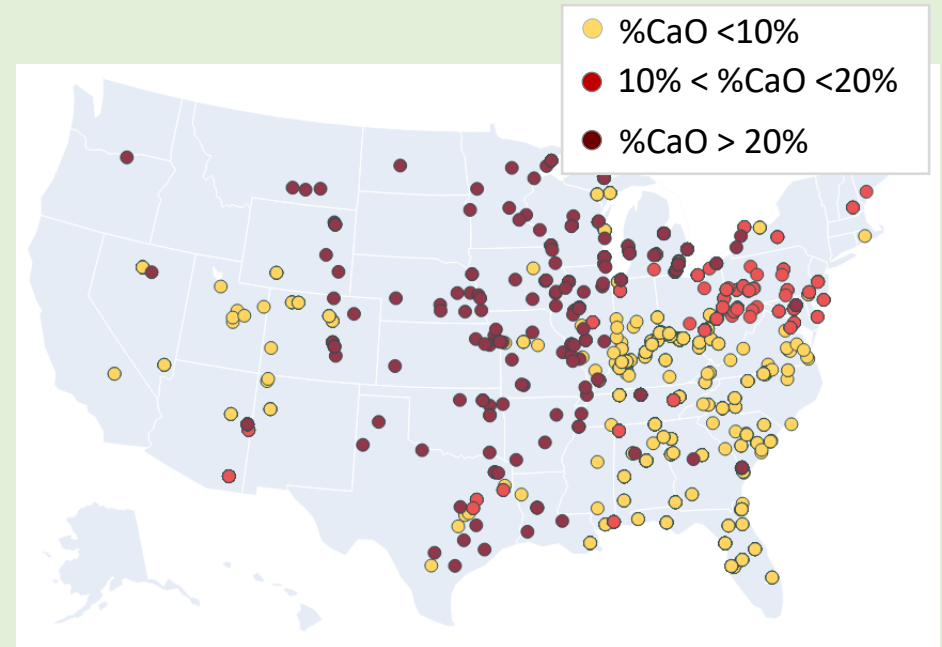
Can we estimate a resource 'reserves' of discarded coal ash?



- Monthly coal purchases reported by power plants:
- coal tonnage
 - Mine location (county, state)
 - >40 yr records available



Extrapolation of coal fly ash composition and quantity at each power plant

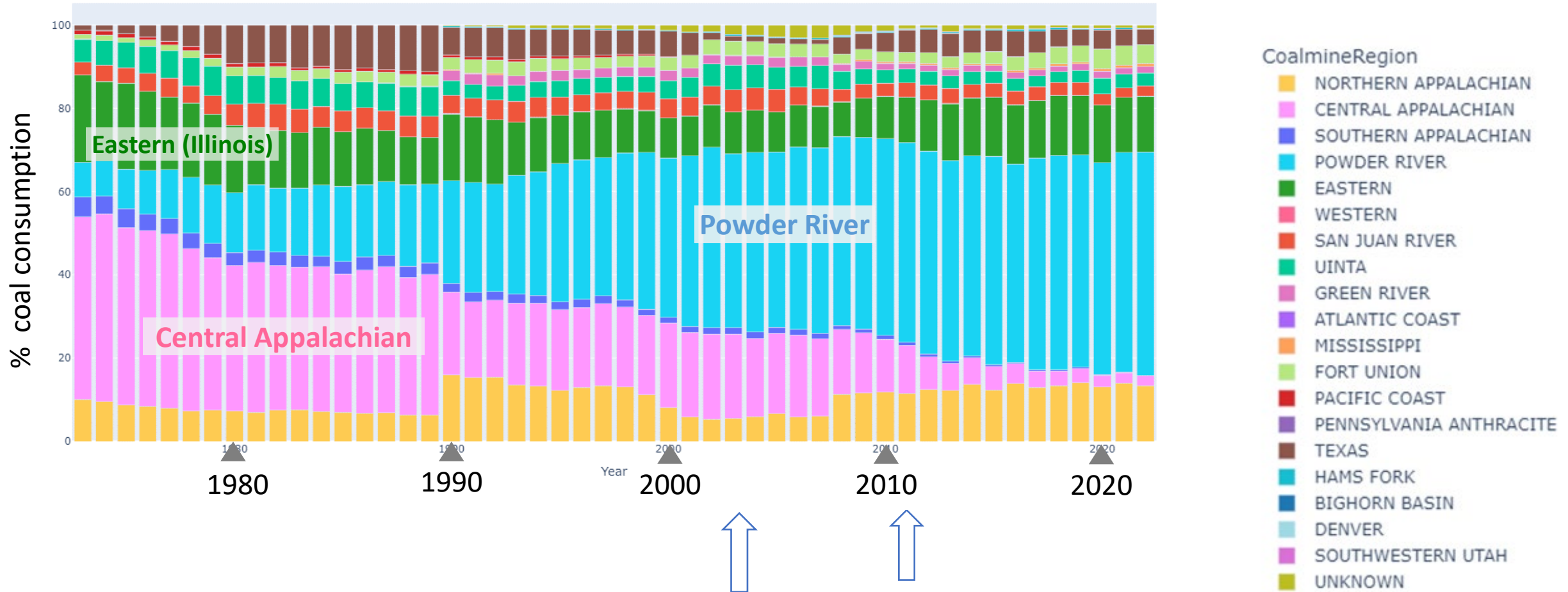


Based on 2014 coal purchase records

Temporal trends in coal resources responding to:

- Air quality policies
- Natural gas
- Railroad infrastructure

Coal purchases by U.S. power plants



Data source:
EIA-923, EIA-423

Clean Air Interstate Rule (2004)

Mercury & Air Toxics Std (MATS)
Cross-State Air Pollution Rule (CSAPR) (2011)

Next steps:

Develop a model of legacy coal ash composition in impoundments at major power stations

For each power plant in year t :

Predictor variables:

Coal consumption expressed as mass proportion $x(i,t)$ of coal from region i



Dependent variables:

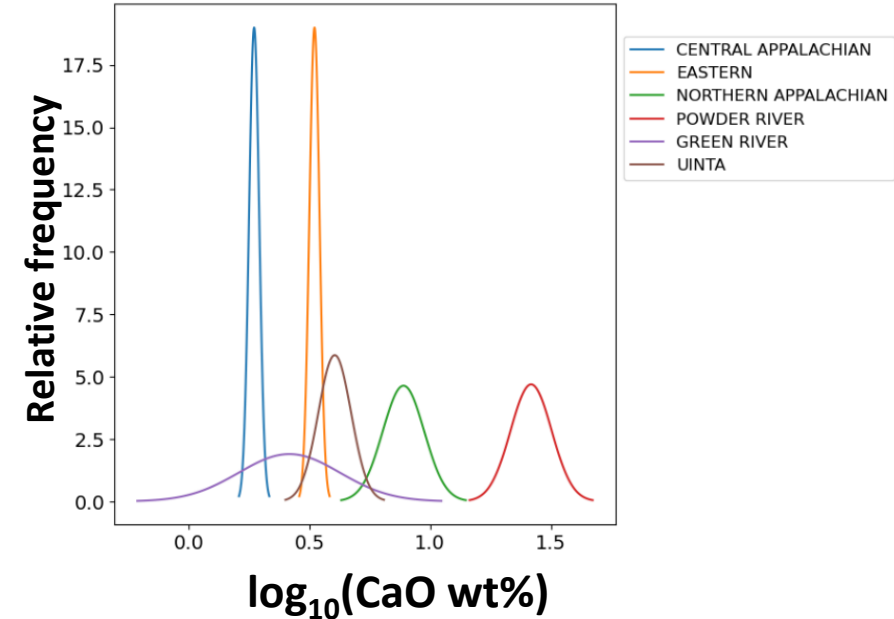
Coal ash chemical content

- Major elements (wt% as oxide)
Ca, Fe, Si, Al
- Minor elements (wt% as oxide)
Mg, Na, K, Ti
- Trace toxic elements
- Critical metals

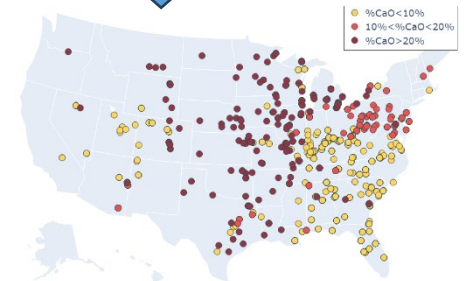
Regression



Major element content in coal ash as a function of coal source



Resource Reserves Dataset of Coal Ash

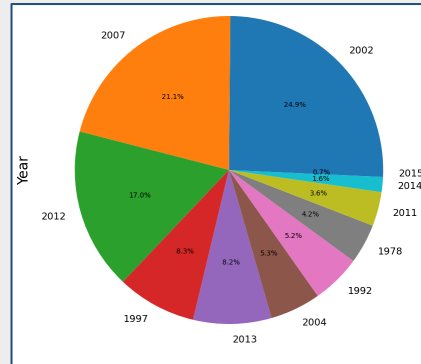


Training data set:

Coal ash samples $n=696$

Power plants $n=32$

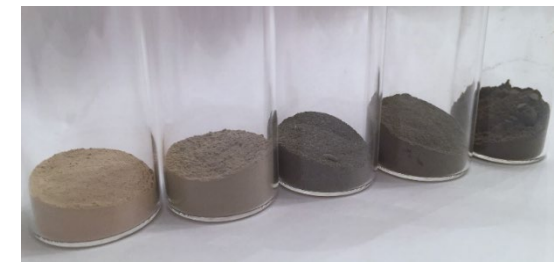
USGS CoalQual data



Coal Ash: Risk or Resource?

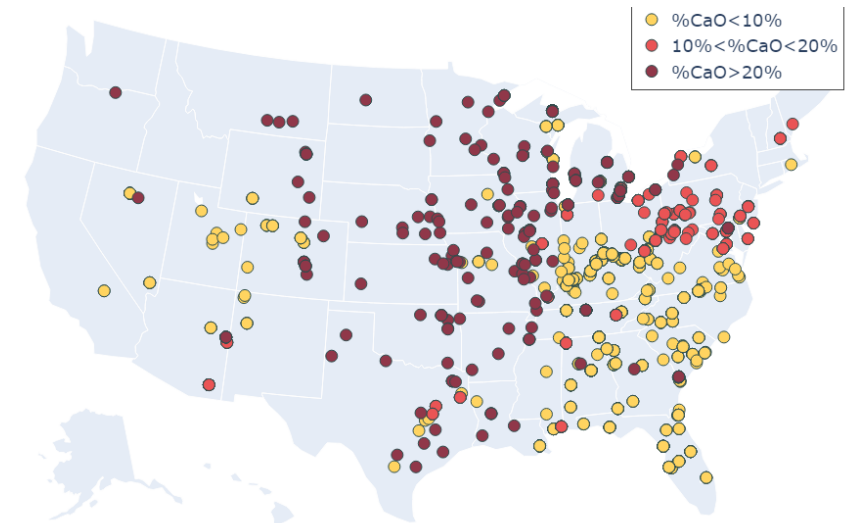
1. Environmental Risk

- Massive volume of coal ash at unlined disposal sites
- Potential for As and Se leaching depends partly on coal feedstock
- As and Se speciation is highly heterogeneous



2. Environmental Resource

- Large total reserve of discarded coal ash that will need to be excavated
- Alternative resource for material additives and metals



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