Trace Element Sampling and Partitioning Modeling to Estimate Wastewater Composition and Treatment Performance at Coal Generators

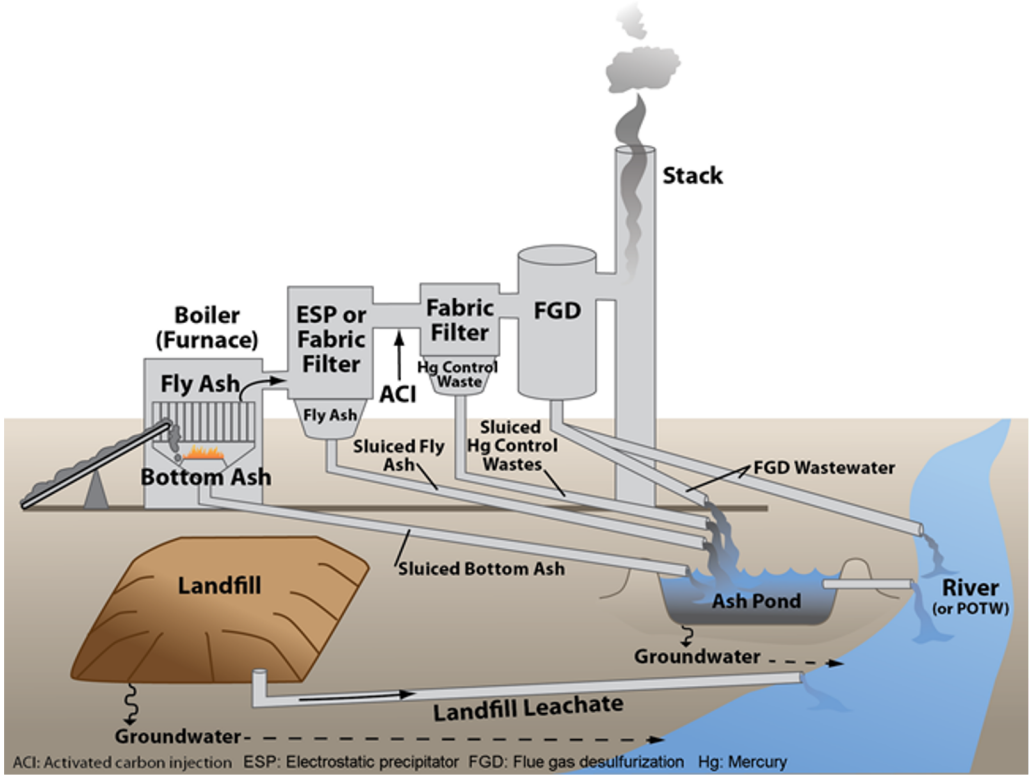
Principal Investigator: *Meagan S. Mauter, Associate Professor of Civil & Environmental Engineering, Stanford University*

Co-Principal Investigators: *James C. Hower, Research Professor of Earth & Environmental Sciences, University of Kentucky; Heileen Hsu-Kim, Associate Professor of Civil & Environmental Engineering, Duke University*

Senior Personnel: *Daniel B. Gingerich, Assistant Professor of Civil, Environmental & Geodetic Engineering & Integrated Systems Engineering, The Ohio State University*

Doctoral Researcher: *Alison Fritz, PhD Student, Civil & Environmental Engineering, Stanford University*

Regulatory Drivers and Alignment to Fossil Energy Objectives



Regulatory Drivers- Effluent Limitation Guidelines (2020)

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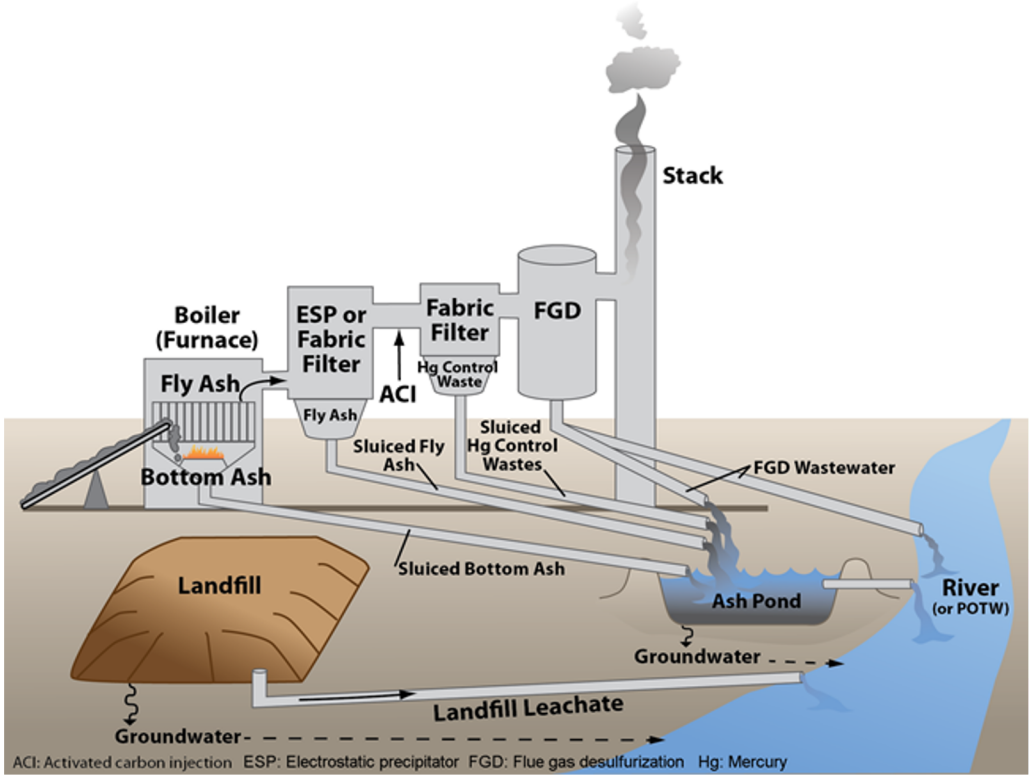

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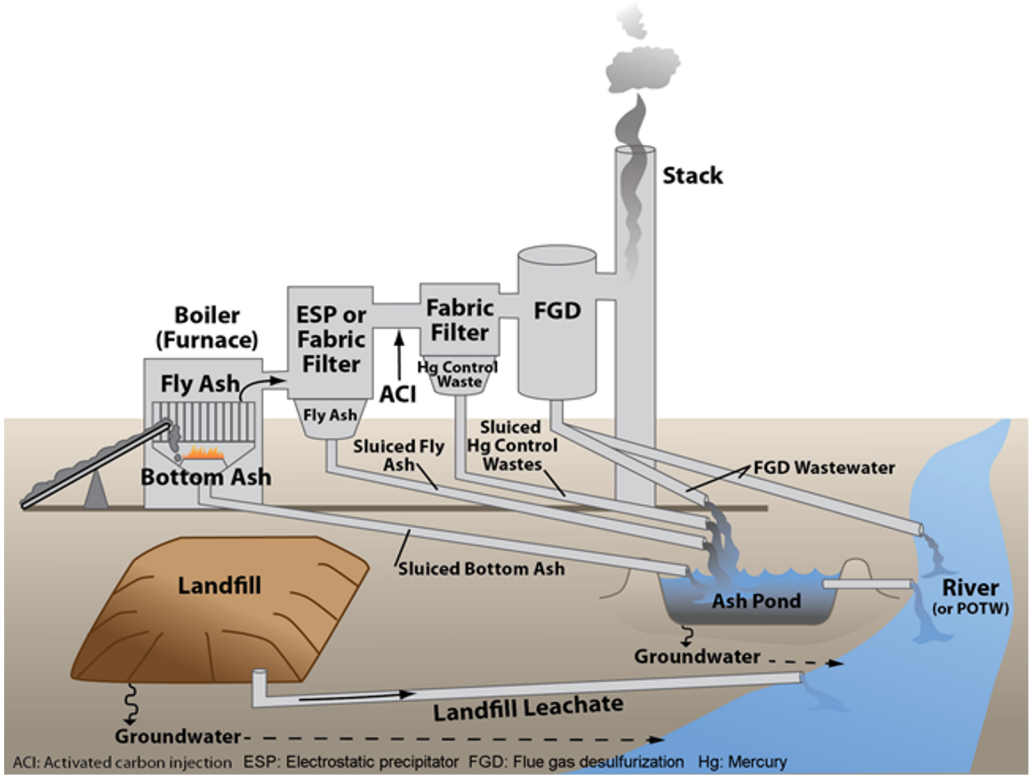

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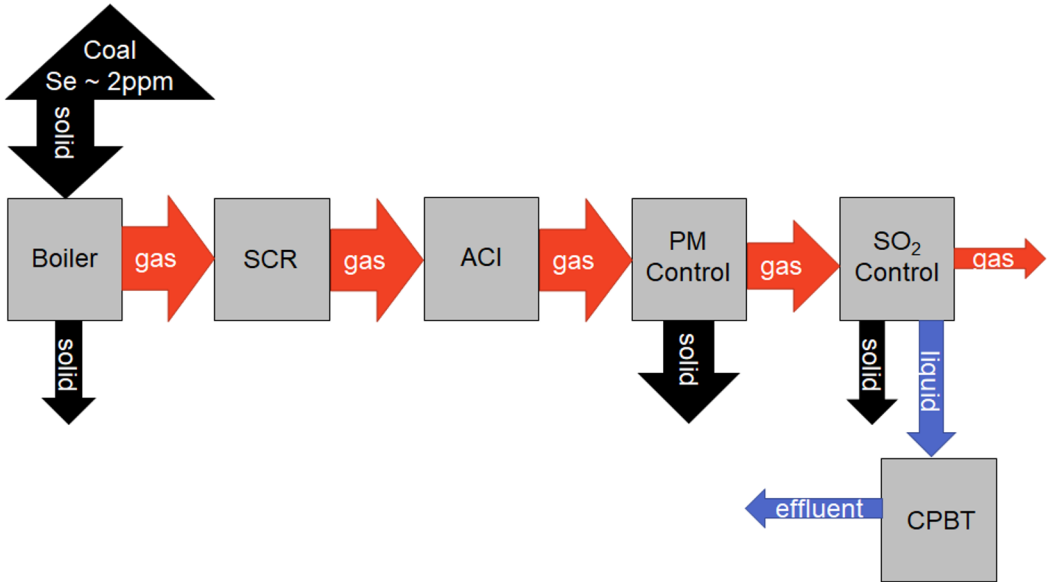
DOE Water Security Grand Challenges - Reduce water impacts in the power sector

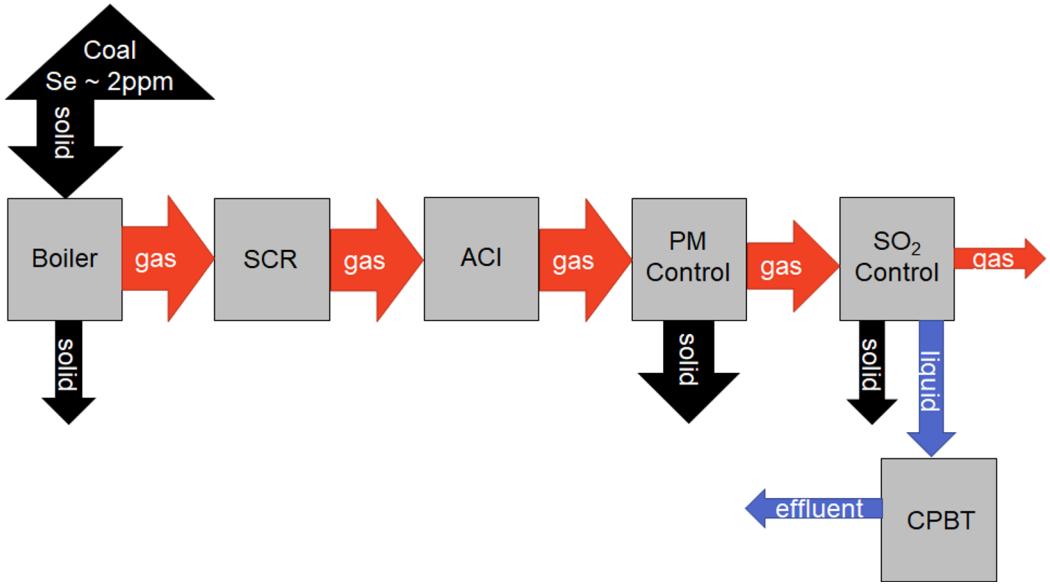
Statement of purpose

- Trace elements have variable concentration in coal, and behave predictably in air pollution control devices (APCD)



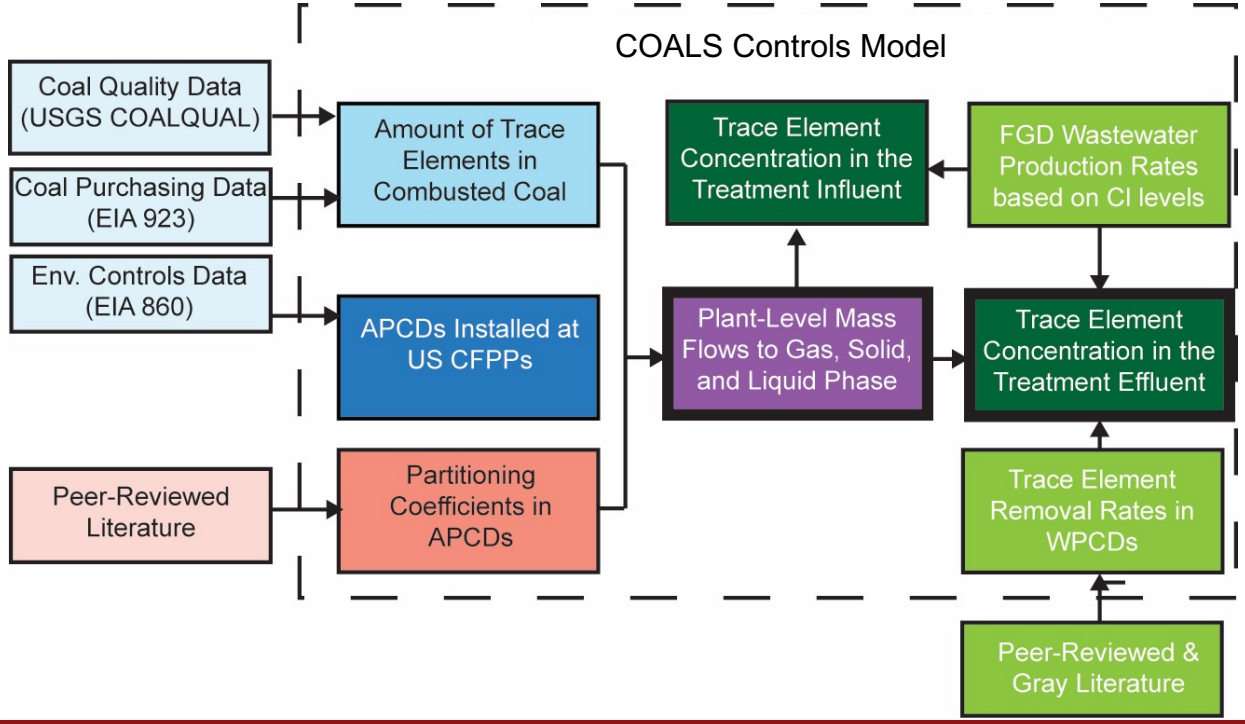
Statement of purpose

- Trace elements have variable concentration in coal, and behave predictably in air pollution control devices (APCD)
- This model improves on existing predictions for trace element partitioning at coal-fired power plants (CFPPs) by (1) accounting for plant-level variability and (2) providing validation



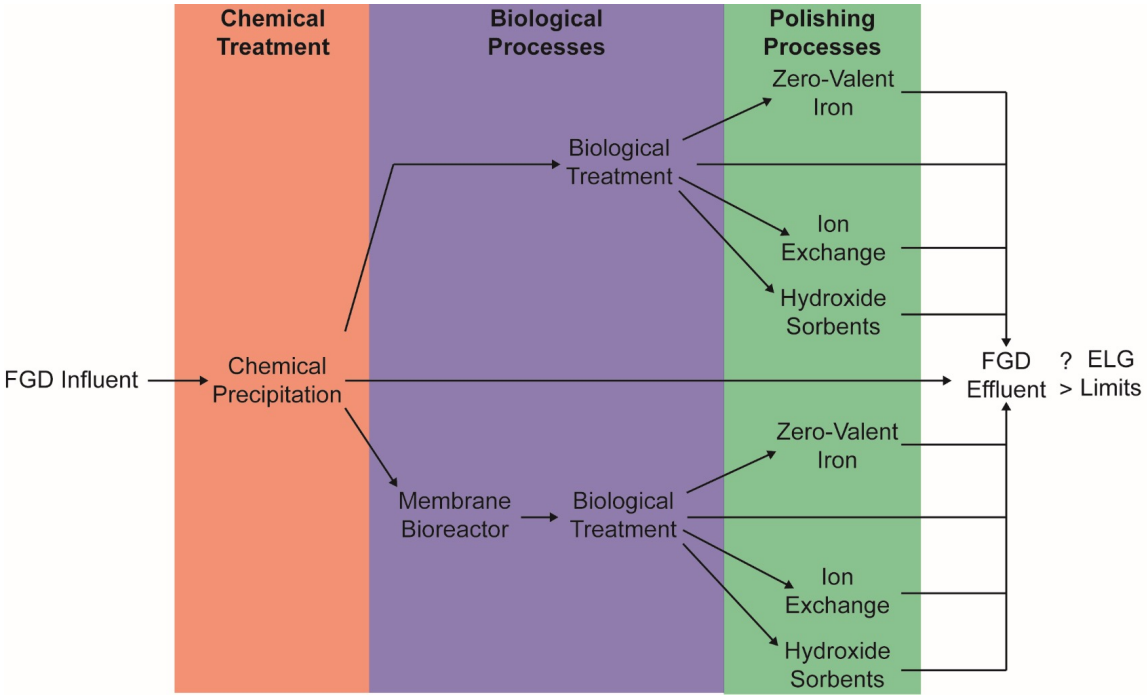
Project objectives

1. Develop a generalizable, open-source COntaminant behavior in Air, Liquid, and Solids (COALS) Controls Model to describe the quantity and partitioning behavior of trace elements **B, As, Se, Pb, Hg, Cl and Br** at US CFPPs

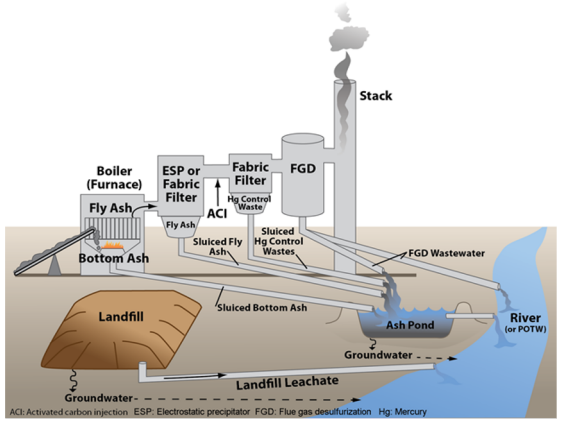


Project objectives

2. Characterize removal performance for trace elements of concern within the best available technologies (BATs) under the Effluent Limitation Guidelines (ELGs) for Flue Gas Desulfurization (FGD) wastewater treatment



Benefits for discharge management at CFPP



Enable solid, liquid, and gas discharge management by modeling trace element behavior

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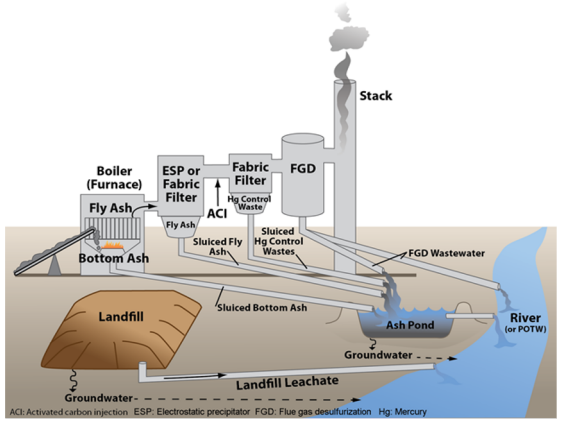

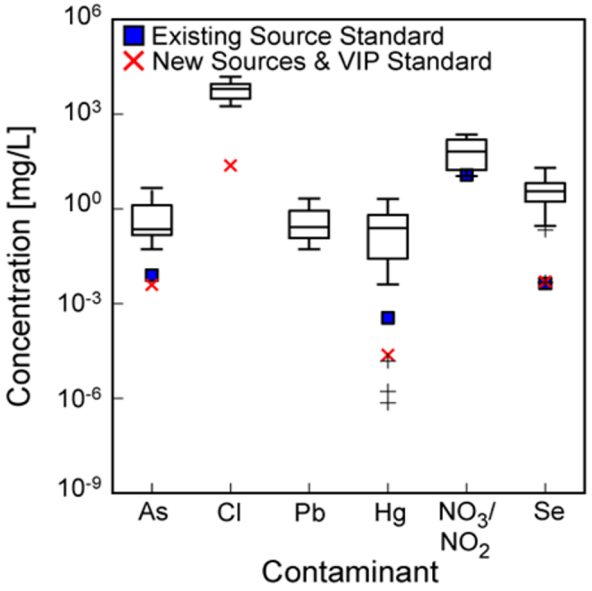

Enable solid, liquid, and gas discharge management by modeling trace element behavior

Develop typical FGD wastewater compositions for treatment technology development

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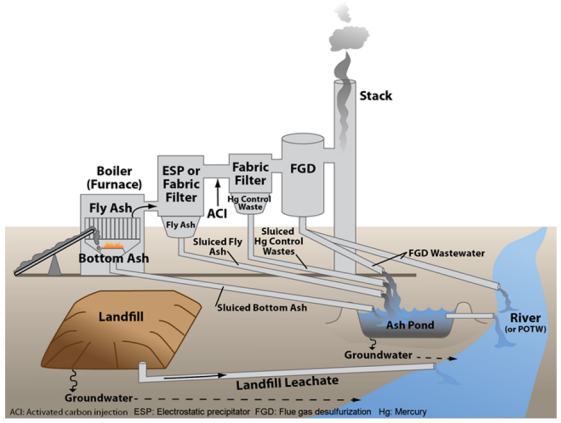

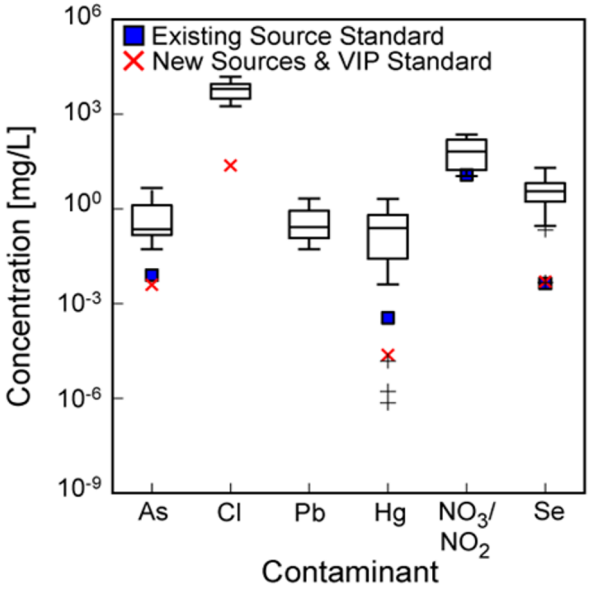

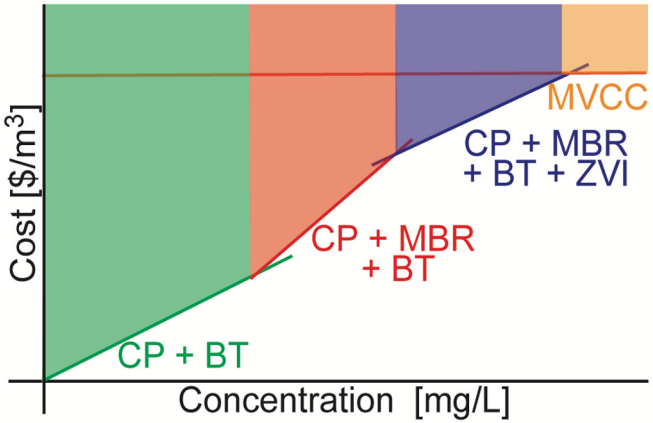

Enable solid, liquid, and gas discharge management by modeling trace element behavior

Develop typical FGD wastewater compositions for treatment technology development

Identify cost-effective FGD wastewater treatment technology options

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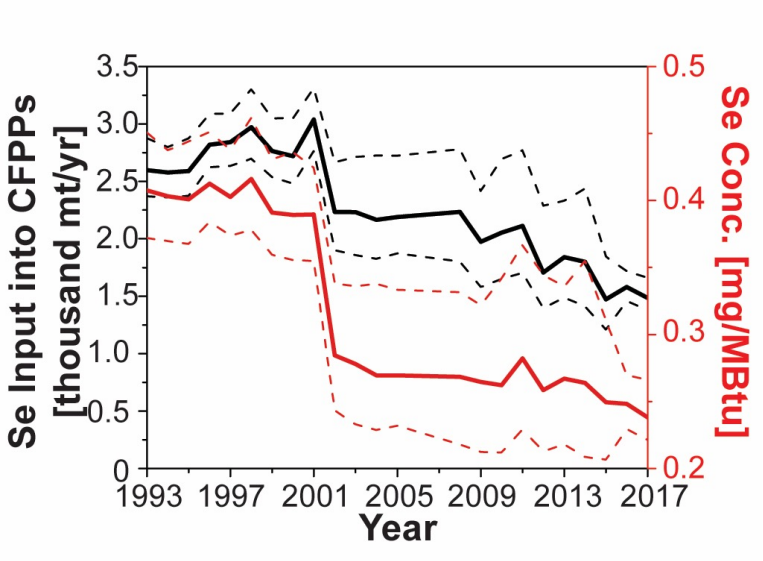
Industry collaboration

- The project uses data collected at LGE-KU partner facilities and includes non-steady state plant operation
- Partner facilities include Trimble County, Ghent, and Mill Creek Generating Stations

Trimble County Generating Station

Sample collection at Ghent generating station

Clean air act regulatory requirements have influenced the fate of trace elements at coal-fired power plants



Percent change in the mass of Selenium entering U.S. CFPPs between 1993 and 2017

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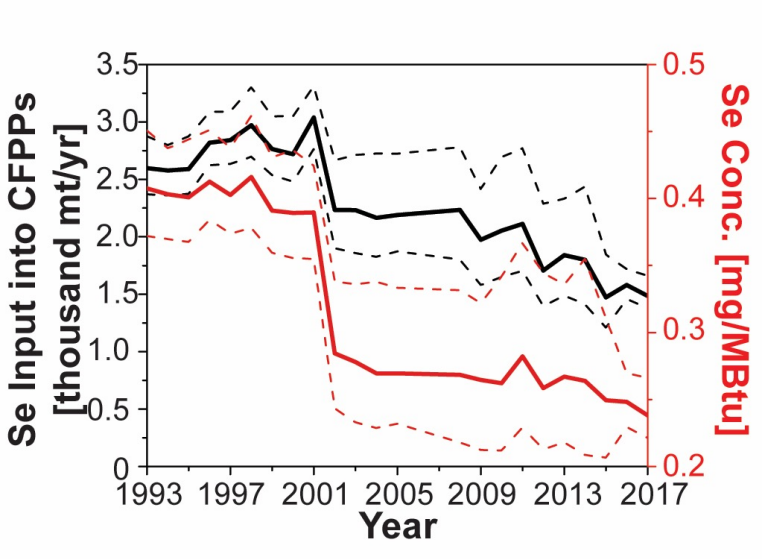

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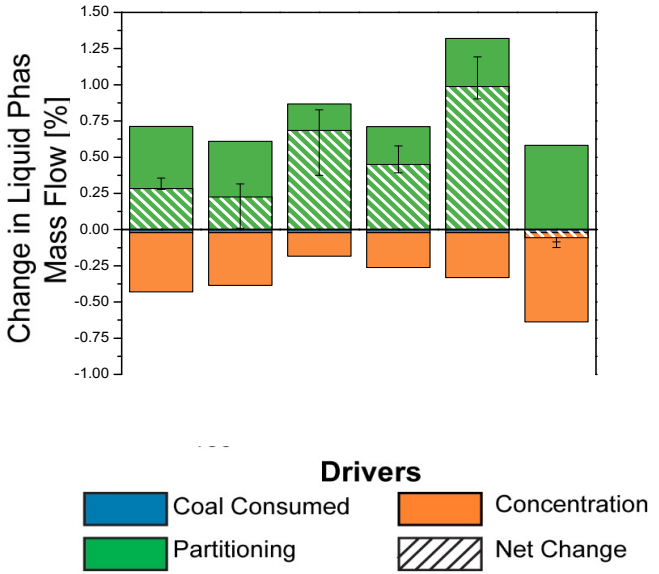

Attributional analysis of changes in the phase of trace elements exiting U.S. CFPPs

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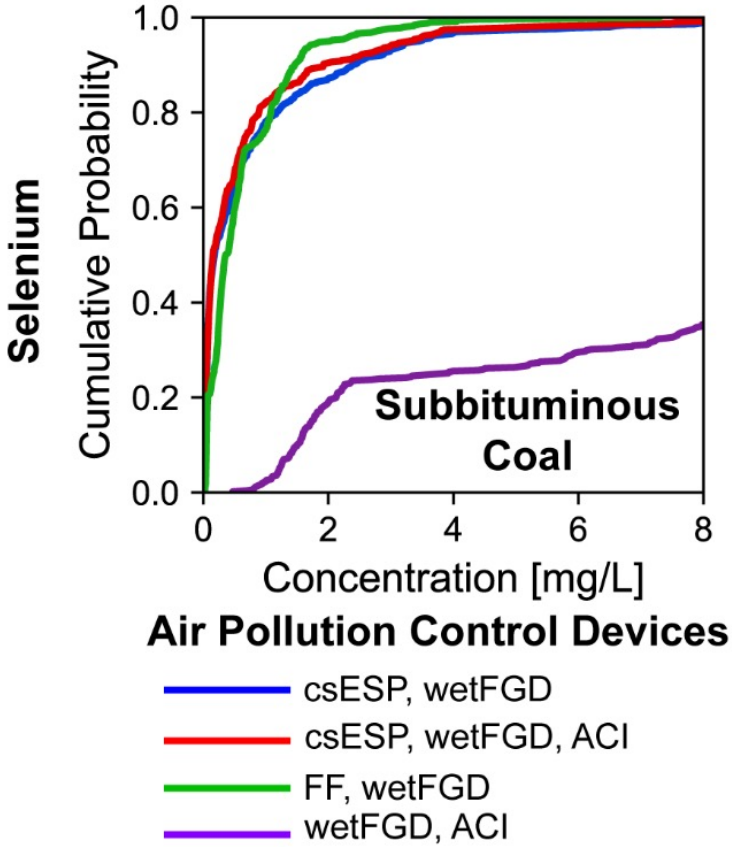
Simulated flue gas desulfurization wastewater composition shows different trends by air pollution control and coal rank



csESP = cold side electrostatic precipitator; ACI=Activated Carbon Injection; FGD=Flue Gas Desulfurization

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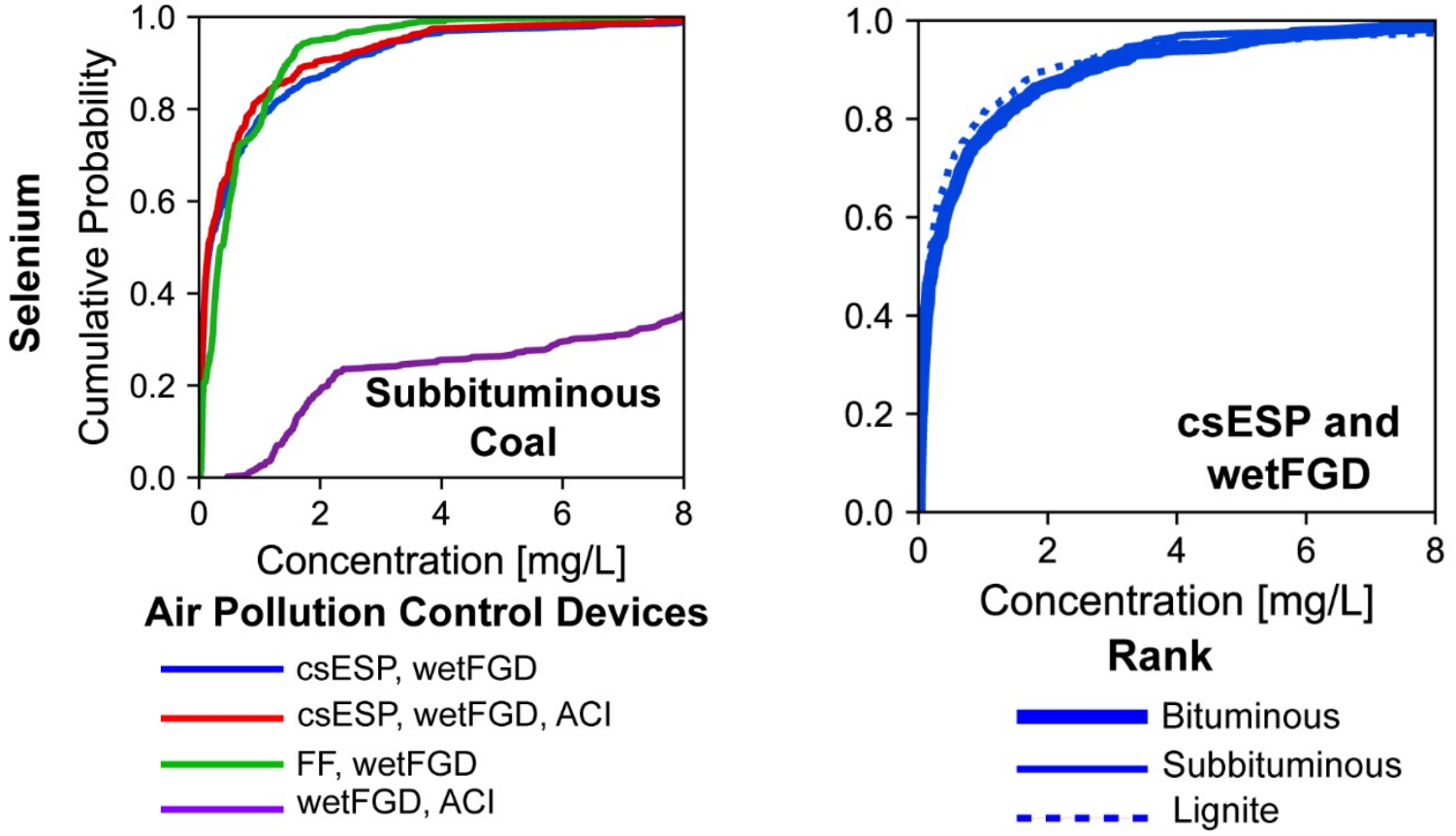

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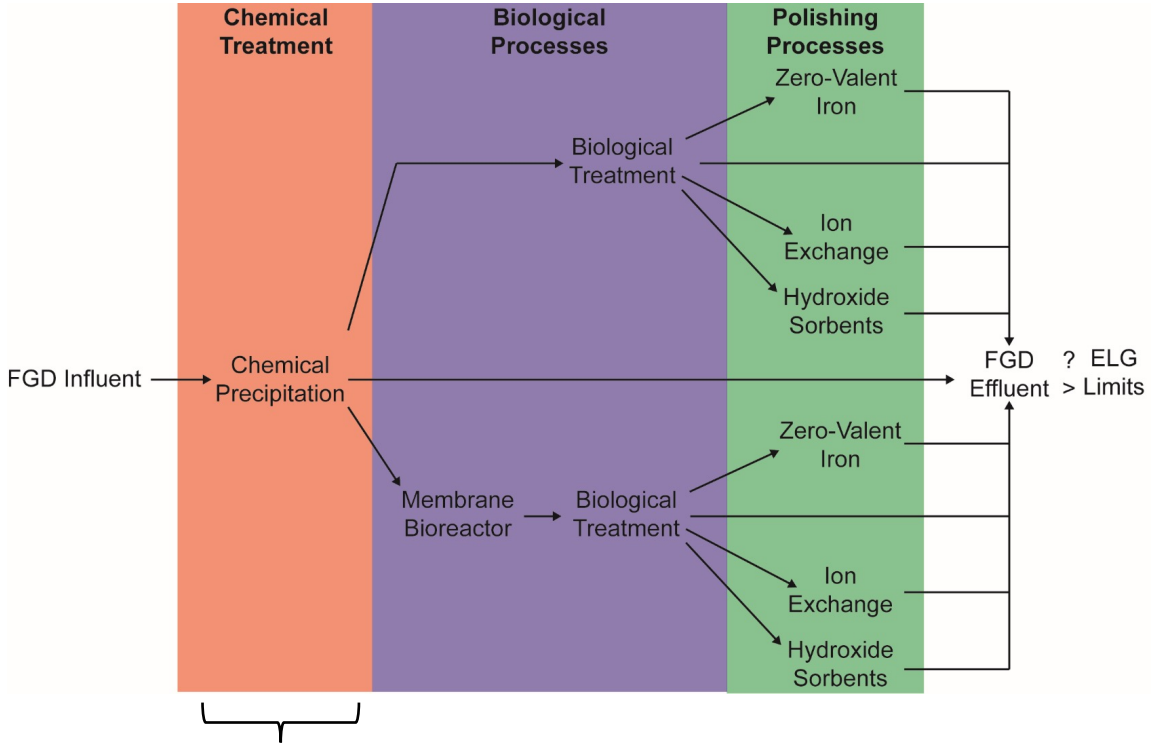
Competing ions can impact the performance of chemical precipitation and biological treatment, but the size and direction of the effect on removal efficiency are not known



Median Concentration (mg/L) Chemical Precipitation Influent			
Se	S	N	Cl
186	1400	35.4	8000

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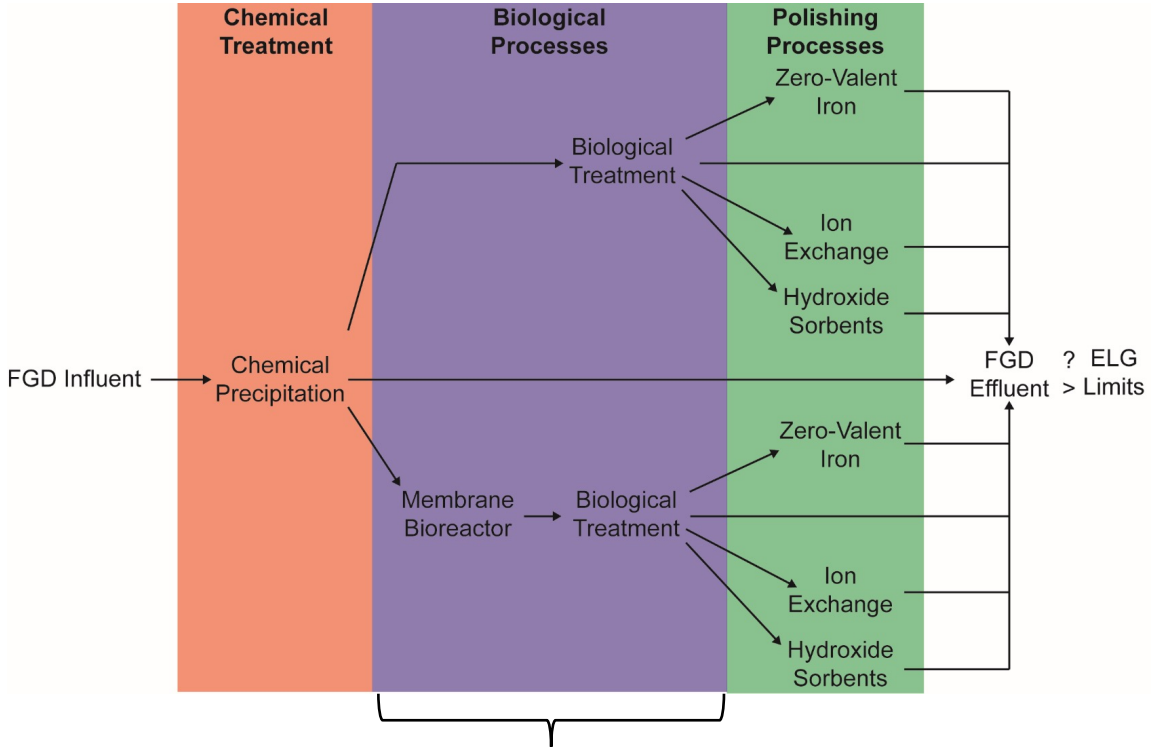
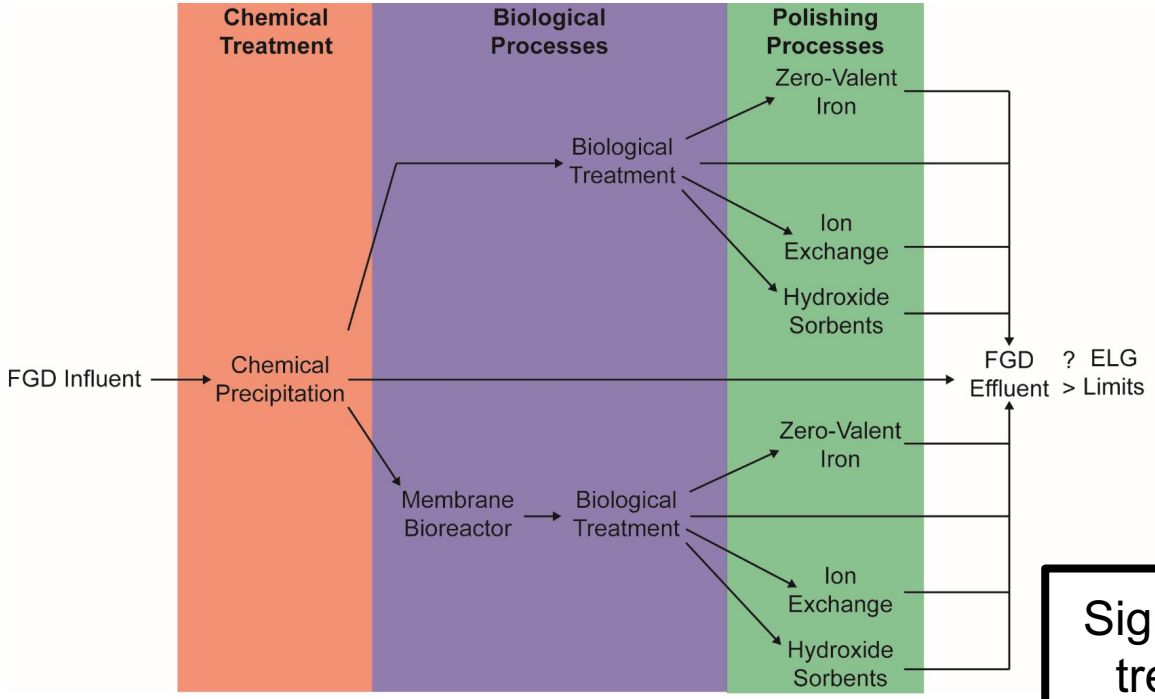


Median Concentration (mg/L) Biological Treatment Influent			
Se	S	N	Cl
63	1300	15	6600

Competing ions can impact the performance of chemical precipitation and biological treatment, but the size and direction of the effect on removal efficiency are not known



Significant impact on treatment efficacy could influence facility compliance with effluent limitations

Regression analysis is used to project trace element removal performance using wastewater composition

$$R = \frac{e^{\beta_0+\beta_1 x+\beta_2 S+\beta_3 N+\beta_4 C}}{1 + e^{\beta_0+\beta_1 x+\beta_2 S+\beta_3 N+\beta_4 C}}$$

Modeled results for selenium

	CP β	BT β
Intercept	0.74 (0.38)	5.9*** (0.86)
Se	1.4e-4*** (3.0e-5)	2.6e-3*** (2.2e-4)
S	-1.1e-5 (1.7e-5)	2.5e-4 (2.6e-4)
N	-1.1e-2*** (3.2e-3)	-4.2e-2*** (6.7e-3)
Cl	1.1e-4** (4.1e-5)	-5.0e-4*** (8.9e-5)
Adjusted R^2	0.37	0.75
n	64	36

* Significant at the 0.05 level
** Significant at the 0.01 level
*** Significant at the 0.001 level

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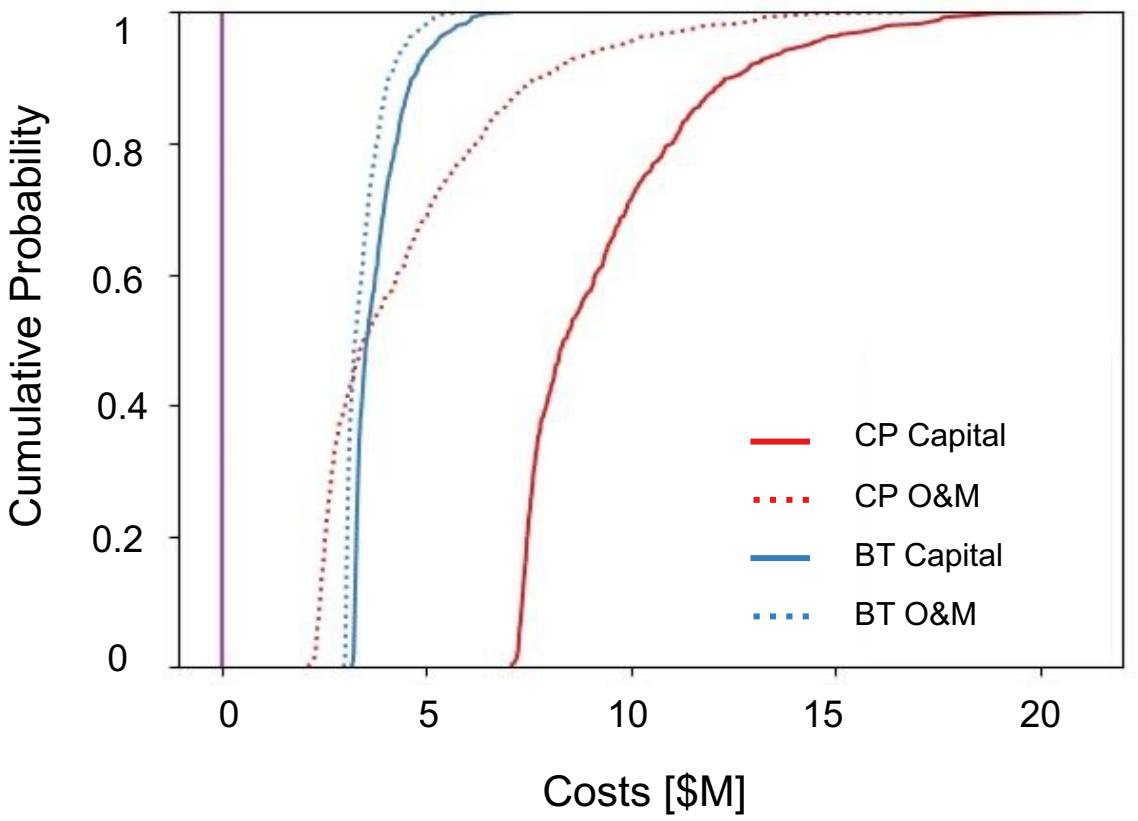
Impact of doubling the median concentration on removal efficiency

	CP	BT
Se	0.45%	1.11%
S	-0.27%	2.06%
N	-7.48%	-5.96%
Cl	11.7%	-62.0%

* Significant at the 0.05 level
** Significant at the 0.01 level
*** Significant at the 0.001 level

Treatment costs at the baseline 550 MW NETL coal fired powerplant vary by expected chlorine load



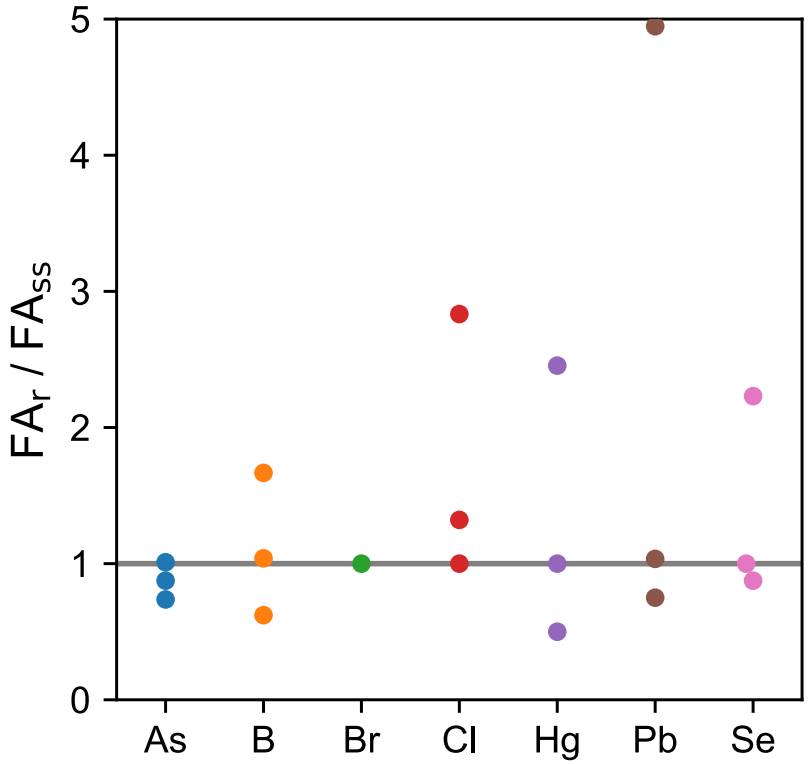
Treatment costs for the fleet are poorly described by the median values for the fleet.

[CP+ BT, i = 10%, n = 25 years]

CP=Chemical Precipitation; BT=Biological Treatment

Cost functions: Environmental Protection Agency. Technical Development Document for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category.

Partitioning fractions for fly ash change during powerplant ramping conditions for chlorine, arsenic, bromine and mercury

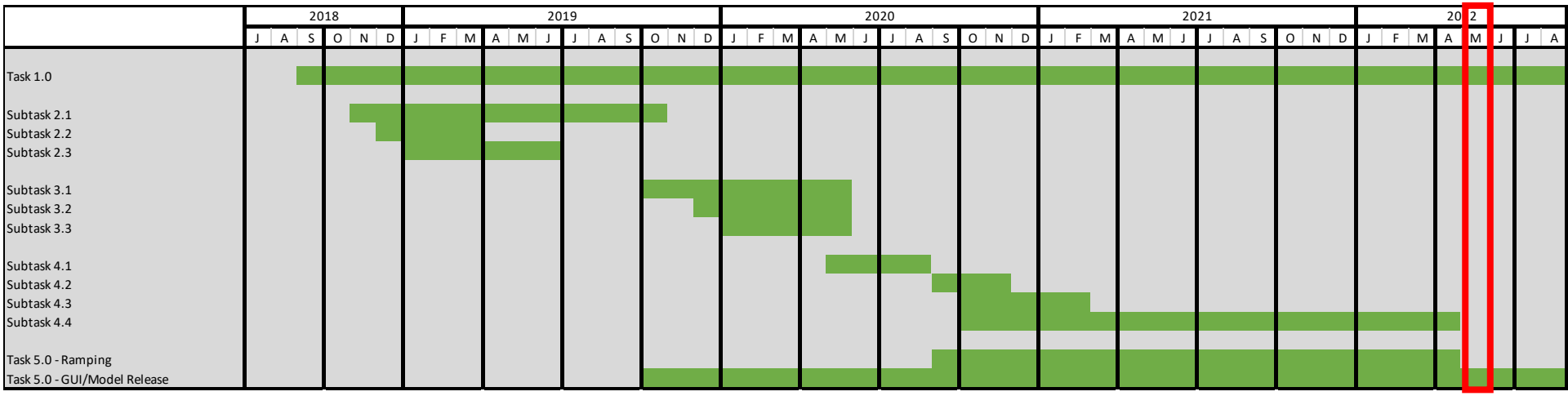


$$\frac{FA_r}{FA_{ss}} =$$ Fold increase in partitioning to flyash under ramping conditions

$\frac{FA_r}{FA_{ss}} = 1$

No change in partitioning behavior under ramping conditions

Next steps for model development



Task 5 – Complete modeling of the relationship between ramping and APCD/WPCD performance using the data that has been collected at Partner Facilities and updates to graphical user interface.

Dissemination of results to industry

- 3 manuscripts published in Energy Policy and Environmental Science & Technology

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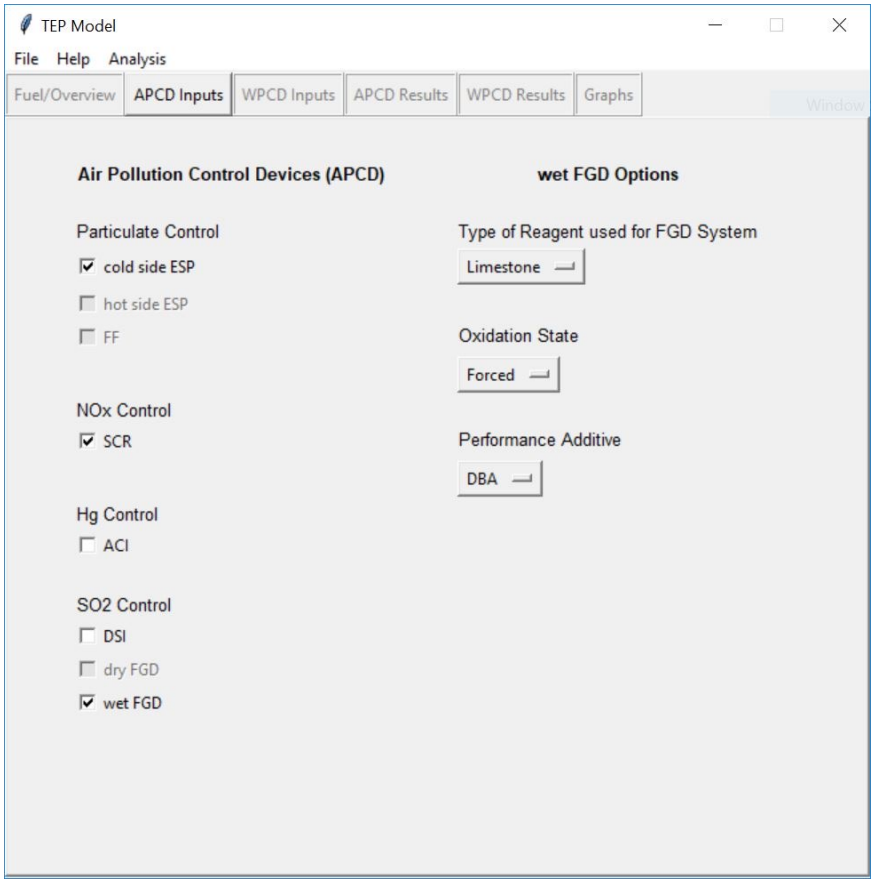
- Public GitHub project and Open Science Foundation project were created for the COALS Controls Graphical User Interface



Concluding remarks

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- The objectives contribute towards DOE FE strategic objectives to improve environmental stewardship of and reduce environmental impacts from coal-based facilities of the future
- The objectives address water impacts in the power sector highlighted in DOE Water Security Grand Challenges

Acknowledgement and Disclaimer

This material is based upon work supported by the Department of Energy Award Number DE-FE0031646.