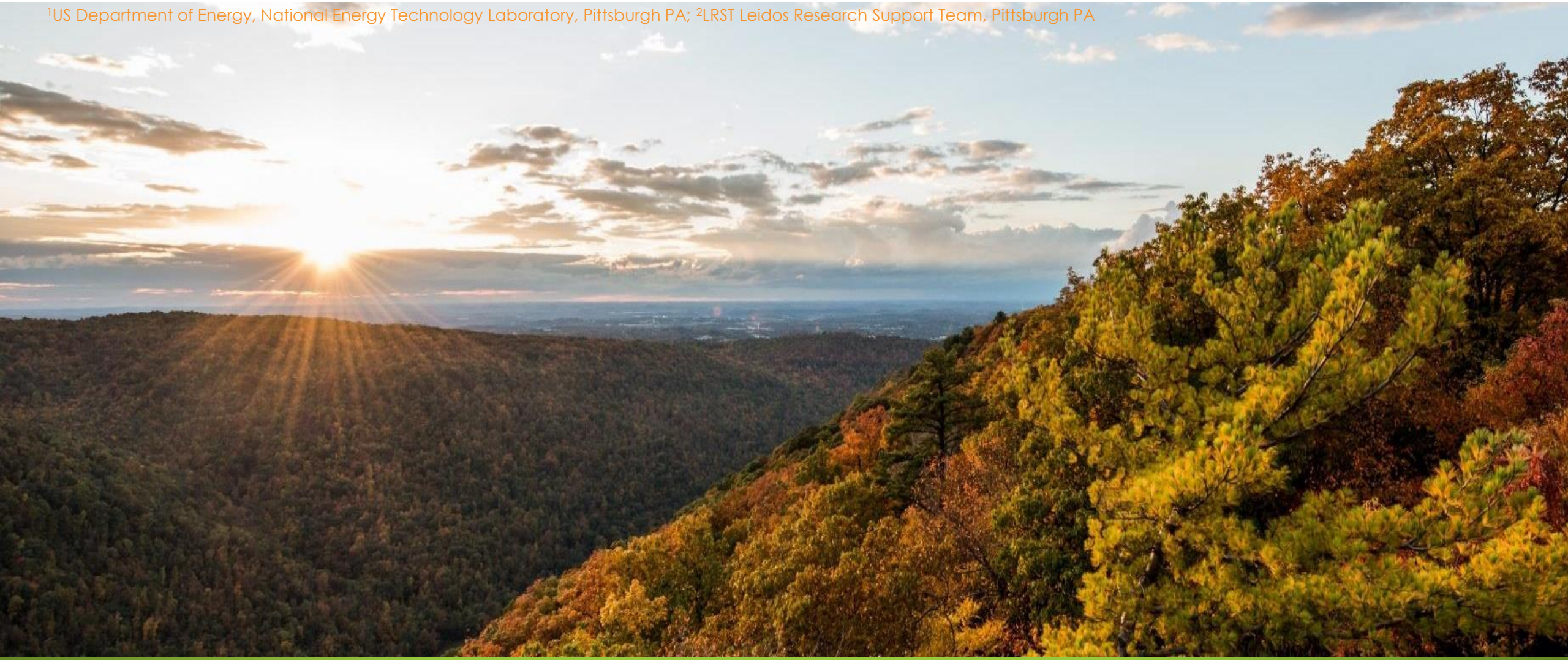
NETL Sorbent Technology for the Removal of Heavy Metals from Coal Waste Effluents

Qiuming Wang[1,2], Brian W. Kail[1,2], Walter C. Wilfong[1,2], McMahan L. Gray[1]

[1]US Department of Energy, National Energy Technology Laboratory, Pittsburgh PA; [2]LRST Leidos Research Support Team, Pittsburgh PA



Project Description and Objectives

- **Purpose of project:** Selective Removal of Heavy Metals for Effluent Stream.
- **Strategic alignment of project to Fossil Energy objectives:** develop sorbent materials for the selective removal of heavy metals (Se, Hg) for effluent streams.
- Status at beginning of project → Selectively remove trace amount heavy metals and meet EPA regulations.
- **Technology benchmarking** – Commercial sorbents showed low selectivity to trace amount heavy metals.
- Current Status of project
  - A series of NETL sorbents selectively reduced Se and Hg concentrations below the EPA discharge limit from authentic Auqatech FGD water and Somerset FGD water.
  - **Industry/input or validation** – 2-ton test proposed by Somerset Environmental Solutions, Inc. (Fall 2020)

US Resource Conservation and Recovery Act (RCRA) Metals [1]

Metal	Toxic effect of living specimens	Treatment Standards for Wastewaters (mg/L; ppm)	Max Allowable Level in drinking water (mg/L; ppm), and Contamination Origination
As	Skin damage; circulatory problem; increased cancer risk	1.4	0.01, electronic production runoff
Cd	Kidney damage	0.69	0.005, discharge form metal refineries and battery plus paint production
Cr	Allergic dermatitis	2.77	0.1, discharge from steel and pulp mills
Pb	Children: physical and mental developmental delays; adults: kidney problems	0.69	0.015, corrosion of plumbing
Hg	Kidney damage	0.15	0.002, discharge/runoff from factories, refineries, and landfills
Se	Circulatory problems; numbness in digits	0.82	0.05, discharge from petroleum refineries and mines

- Toxic heavy metals in water sources have been proven to be a major threat to communities throughout the world. Much of the cost of industrial waste water treatment is driven by the need to remove heavy metals that cannot be discharged to local waterways.

[1] Jaishankar, M. etc. Toxicity, mechanism and health effects of some heavy metals, 2014, 7 (2): 60-72

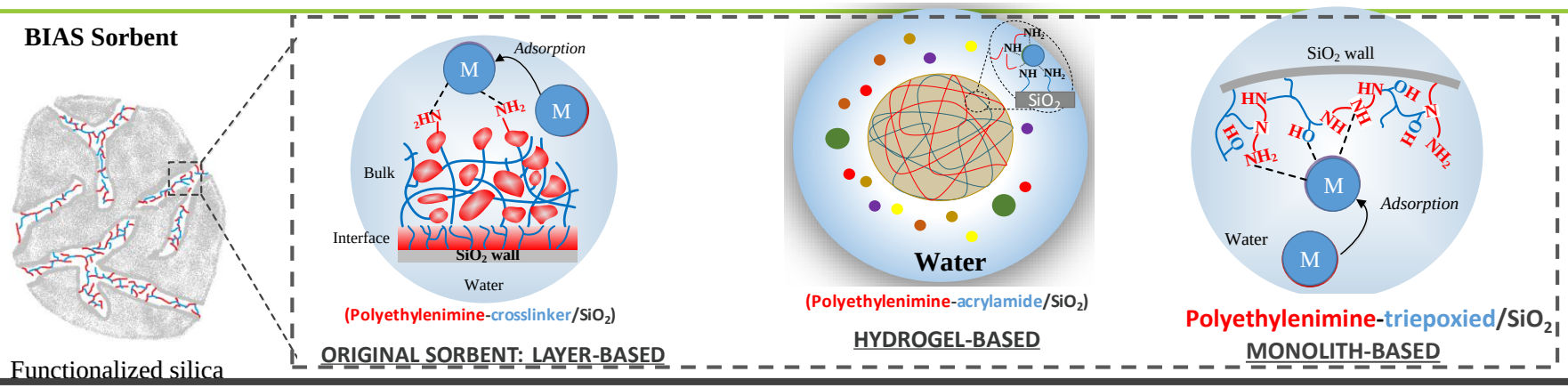
EPA Guidelines for Effluent Limitations Applied to the Discharge of FGD Wastewater [2]

Subcategory	Pollutant	Long-Term Average	Daily Maximum Limitation
Requirements for all facilities not in the VIP or subcategories specified below (BAT & PSES)	Arsenic (µg/L, ppb)	5.1	18
	Mercury (ng/L, ppt)	13.5	85
	Nitrate/nitrite as N (mg/L, ppm)	2.6	4.6
	Selenium (µg/L, ppb)	16.6	76
Voluntary Incentives Program for FGD Wastewater (BAT only)	Arsenic (µg/L, ppb)	5.0	5
	Mercury (ng/L, ppb)	5.1	21
	Nitrate/nitrite as N (mg/L, ppm)	0.4	1.1
	Selenium (µg/L, ppb)	5.0	21
	Bromide (mg/L, ppm)	0.16	0.6
	TDS (mg/L, ppm)	88	351

- Additional sources for most of these contaminant metals include flue gas desulfurization wastewater streams. Treatment and discharge of wastewater are regulated as described in the EPA Effluent Guidelines, which establish the numerical limits for mercury, arsenic, selenium, and total dissolved solids (TDS) for the wastewater treatment/discharge track from coal plants.

[2] https://www.federalregister.gov/documents/2019/11/22/2019-24686/effluent-limitations-guidelines-and-standards-for-the-steam-electric-power-generating-point-source

NETL Patented Sorbents



US 15782315: Stable Immobilized Amine Sorbents for REE and Heavy Metals Recovery from Liquid Sources

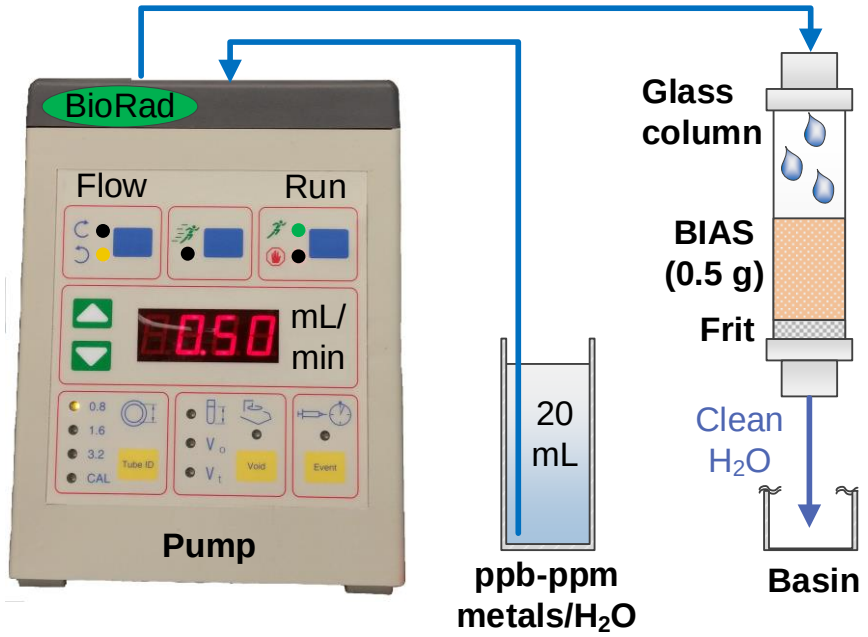
Coal waste	**Acid Mine Drainage**	**Frac Water**	**Drinking Water**
As, Se, Cr, Hg, Cd, Pb	REEs	Ba, Sr	Pb

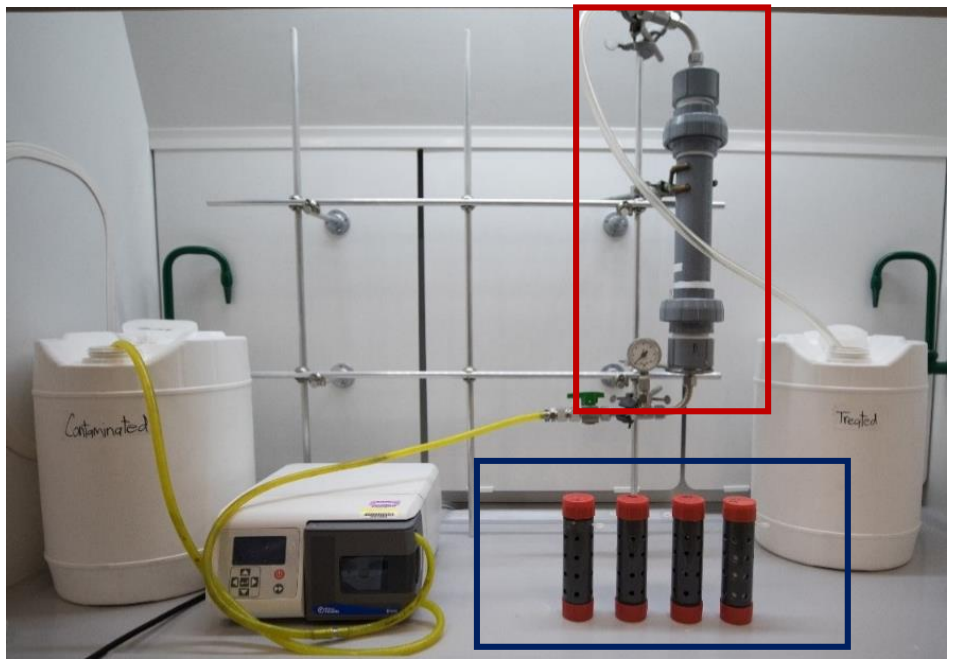
US 62875364
Metal-Loaded Basic Immobilized Amine Sorbents for The Removal of Metal Contaminants from Wastewater

US 62875829
Multi-Functionalized Basic Immobilized Amine Sorbents for Removal of Metal Contaminants from Wastewater

- **US 15782315** was licensed to PQ cooperation
- **US 62875364** and **US 62875829** are being considered by Somerset Environmental Solutions.

Flow Test Reactor System





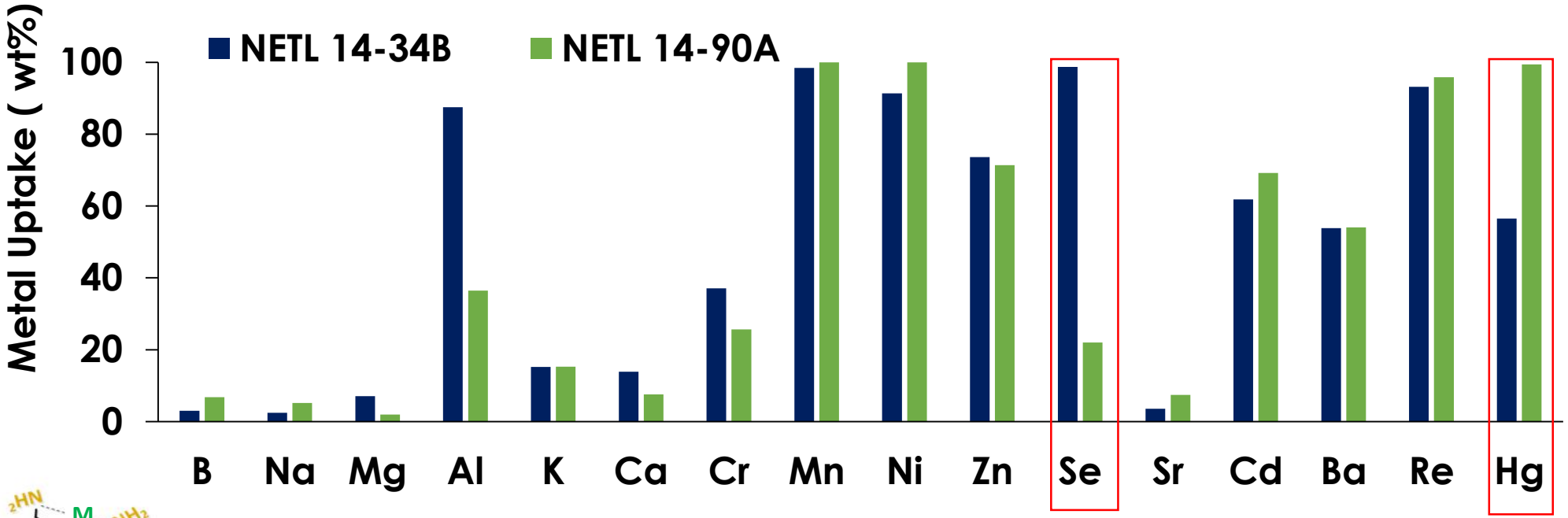
Lab Scale Flow Test System

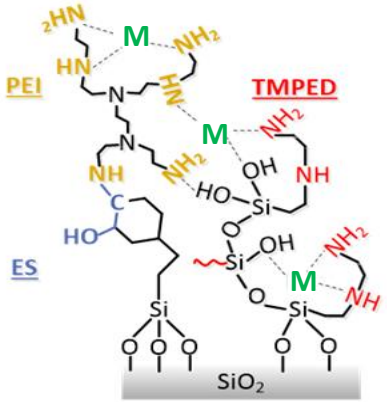
- Fixed bed
- 20 mL liquid, 0.5 mL/min
- Negligible pressure drop
- Room Temperature

150 g Packed Bed Reactor and
30 g Field Test Modules

- Developed a 150 g PBR capable of treating at least 150 L at flow rates ≥ 1.0 L/min.
- Developed field test modules to passively assist existing treatment systems, assessing kinetic uptake and total metal capacity.

Treatment of Authentic Aquatech FGD Wastewater

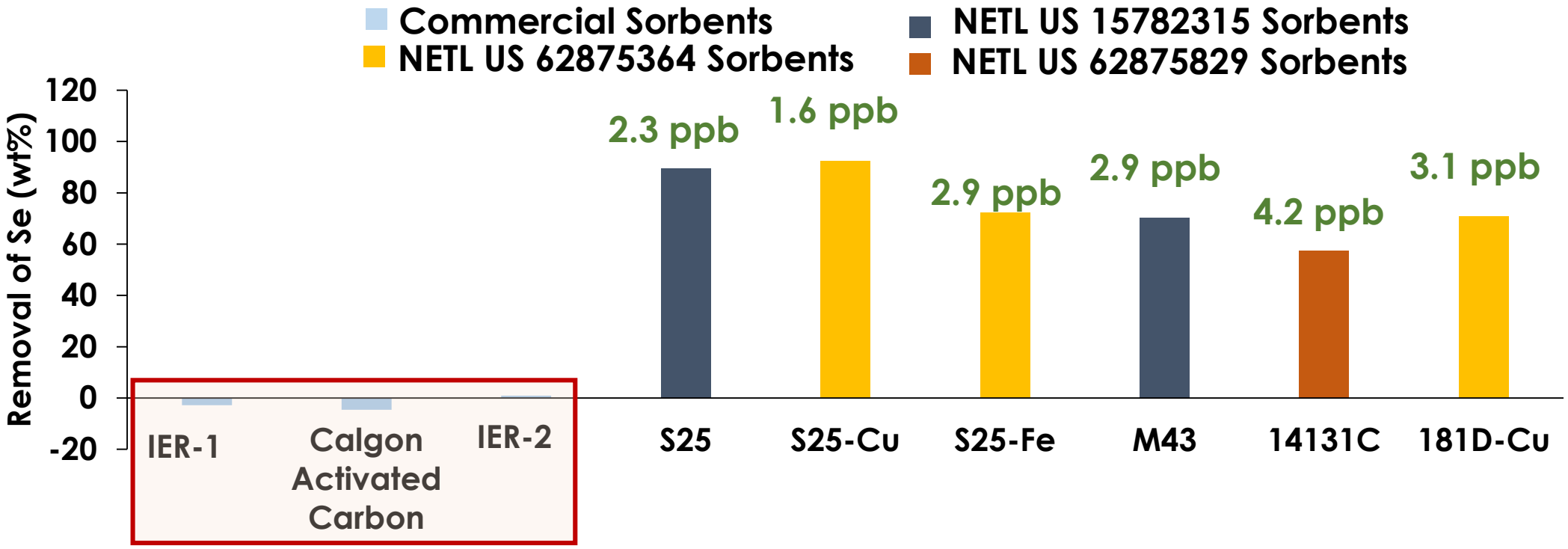




- **NETL US 62875829 Sorbents;**
- Ignore fouling metals: Na, Mg, K, and Ca;
- > 90% capture of target metals (Se, Hg), while simultaneously removing 99% of Mn, >90% of Ni, 70% of Cd, and 99% of Re;
- Introduction of a secondary functionality increased the selectivity toward a specific contaminant.

Treatment of Authentic Somerset FGD Wastewater

Commercial Sorbents Vs. NETL Sorbents



- Commercial activated carbon and ion exchange resins (IER) showed no adsorption of Se;
- NETL sorbents removed Se from Somerset FGD water and meet EPA regulations.

Concluding Remarks

- Highlight applicability of technology to Fossil Energy and alignment to strategic goals.
  - A library of novel patented sorbent materials has been developed at NETL that demonstrates high affinity to heavy metals, such as Se, Cd, Hg and Cr, when operating in varied pH environments typical of coal waste effluent streams.
  - Initial testing on FGD effluent streams has shown sorbent formulations that selectively reduced Se, Hg and Cd concentrations to a number lower than EPA pretreatment standards.
- Define project's next steps and current technical challenges.
  - Sorbents that apply to the treatment of raw FGD wastewater will be developed.

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