Thank you. To understand *how* our reactor effectively captures these heavy metals without external power, let’s dive into the **Theoretical Framework**.

### Slide 17: Theoretical Framework (Overview)

Our study is grounded in three key principles that drive the reactor's performance:

1. **Electrochemical Thermodynamics**
2. The Primary Mechanism: **Reductive Cementation**
3. The Secondary Mechanism: **Adsorption and Co-precipitation**

**Next Slide :**

"Moving on to the theoretical framework, we examined the Electrochemical Thermodynamics that drive our proposed reactor.

The core principle governing this study is the spontaneity of the reaction, described by the Gibbs Free Energy equation you see at the top right:.

We calculated the theoretical values for our three target contaminants—Copper, Lead, and Zinc—against Aluminum as the sacrificial anode.

- Because Aluminum has a very low standard reduction potential of -1.66 Volts, it creates a large potential difference when paired with these metals.
- As you can see in the 'Cell Potential' column, we generated positive values ranging from +0.90 V for Zinc up to +2.00 V for Copper.
- Consequently, the Gibbs Free Energy values in the green column are all highly negative, ranging from -521 to -1,158 kJ/mol.

Mathematically, this proves that the cementation of these heavy metals by Aluminum is thermodynamically spontaneous.

However, this brings us to a critical engineering challenge illustrated by this diagram: the 'Passivation Paradox.'

Although aluminum is covered by a passive oxide layer, the metal–oxide–electrolyte interface behaves as a capacitor. The thin $Al_2O_3$ layer acts as a dielectric that allows charge accumulation and electrostatic interaction with metal ions, enabling electron transfer through tunneling or defect pathways.

This explains why our study focuses on mine wastewater. The acidity is crucial to dissolve this oxide shell, 'unlocking' the aluminum core and allowing the electron transfer to proceed."

## Primary Mechanism (Reductive Cementation)

"This brings us to the core engine of our reactor: the **Primary Mechanism of Reductive Cementation**.

Cementation is essentially a metal displacement process. As you can see in the table, the process is split into two half-reactions occurring simultaneously on the screen surface.

First, we have the **Anodic Reaction**. Our Aluminum screens act as the *sacrificial* electron donor. The metallic aluminum oxidizes, releasing three electrons per atom and dissolving into the solution as aluminum ions .

These released electrons are immediately consumed by the target contaminants in the **Cathodic Reaction**.

- The dissolved Copper, Lead, and Zinc ions accept these electrons.
- This causes them to reduce from their soluble ionic state into their insoluble, solid elemental state.

**Slide Title:** Secondary Mechanism: Adsorption and Co-precipitation

"While cementation is the primary driver, our reactor also relies on a critical **Secondary Mechanism: Adsorption and Co-precipitation**.

This mechanism is particularly important for polishing the water and capturing metals like Zinc that are harder to remove via direct cementation. It occurs in three sequential stages:

**[Point to Left Image: Proton Reduction]**

First, as the aluminum dissolves, a parallel reaction occurs where protons (H+) in the acidic water are reduced to Hydrogen gas (H2).

- You can see the hydrogen bubbles forming in the diagram.

- This consumption of acid causes a **localized rise in pH** right at the screen's surface, even if the bulk solution remains acidic.

**[Point to Center Image: Hydroxide Formation]**

This local pH shift triggers the second stage. The dissolved aluminum ions (Al3+) react with water to form **Aluminum Hydroxide (Al(OH)_3)**.

- These hydroxides form a fluffy, amorphous precipitate—often described as 'flocs'—which you see clouding around the screen.

**[Point to Right Image: Adsorption]**

Finally, these flocs act like a chemical sponge.

- In the **Adsorption & Polishing** stage, dissolved metal ions are physically trapped within the structure of these flocs or adsorbed onto their surface.
- This is critical for **Zinc removal**, as Zinc precipitates more readily at higher pH levels than it cements in highly acidic conditions.

In summary, this dual-mechanism approach ensures that even if direct cementation is slow, the contaminants are still captured by the generated aluminum hydroxides."

**Slide Title:** Novelty of the Study

Finally, we address the **Novelty of the Study**. We distinguish our proposed reactor from existing research in three critical ways.

**[Gesture to the Left Side]** Currently, Zero-Valent Aluminum is typically applied in two forms:

- As **loose powders**, which are difficult to recover and separate from the water after treatment.
- Or as **electrocoagulation** setups using simple plates or rods, which require a continuous external power supply.
- Furthermore, most studies evaluate these as *standalone* main treatment units.

**[Gesture to the Right Side]** In contrast, our study introduces a **Perforated Screen Reactor design**.

- **First**, by using perforated screens, we create a passive, flow-through system that does not require electricity, unlike electrocoagulation.
- **Second**, we specifically engineer this as a **Pretreatment Function**. We are not attempting to replace the entire treatment plant; rather, we are designing a compact 'roughing filter' to capture the bulk of heavy metals *before* they reach the main treatment stage.

- **Third**, this modular screen configuration offers a practical **Foundation for Future Scale-up**, solving the handling and recovery issues often associated with aluminum powders.