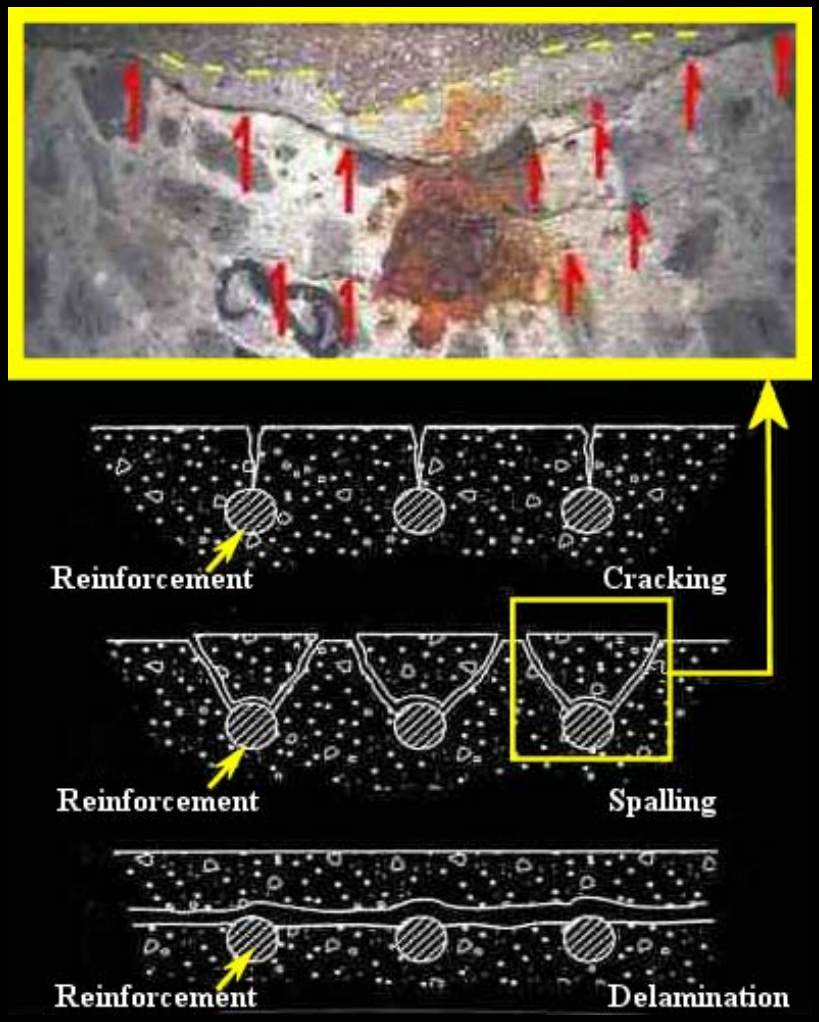
A Novel Corrosion Inhibitor

Derived from Acid Mine Drainage Sludge for Steel in Concrete

Dr. Michael Silsbee, Dr. Lykourgos Iordanidis, Dr. Boyd Clark and Dr. Richard Lee

Mine Water Treatment Technology Conference
August 15-18, 2005

The Problem: Corrosion



Background of Corrosion Problem: Steel Corrosion

- The Federal Highway Administration (FHWA) estimates direct costs to be $276 billion dollars/year
- Indirect (society) costs are conservatively estimated to be equal to direct costs

Background of Corrosion Problem: Life Cycle Analysis

- Indirect costs are approximately 10 times the total direct costs for highway bridges
- Indirect costs include traffic delays, lost productivity, etc.

Background of Corrosion Problem: Reducing Costs

- Employing better maintenance practices saves 46% of the annual corrosion costs of a black steel rebar bridge deck
- The total consumption of corrosion inhibitors in the United States has doubled from approximately $600 million in 1982 to nearly $1.1 billion in 1998

The State of Pennsylvania's Bridges

- 42% of Pennsylvania's bridges are structurally deficient or functionally obsolete
- Driving on roads in need of repair costs Pennsylvania's motorists $1.9 billion a year in extra vehicle repairs and operating costs

http://www.asce.org/reportcard/2005/page.cfm?id=78

Epoxy Coated Rebar After Service

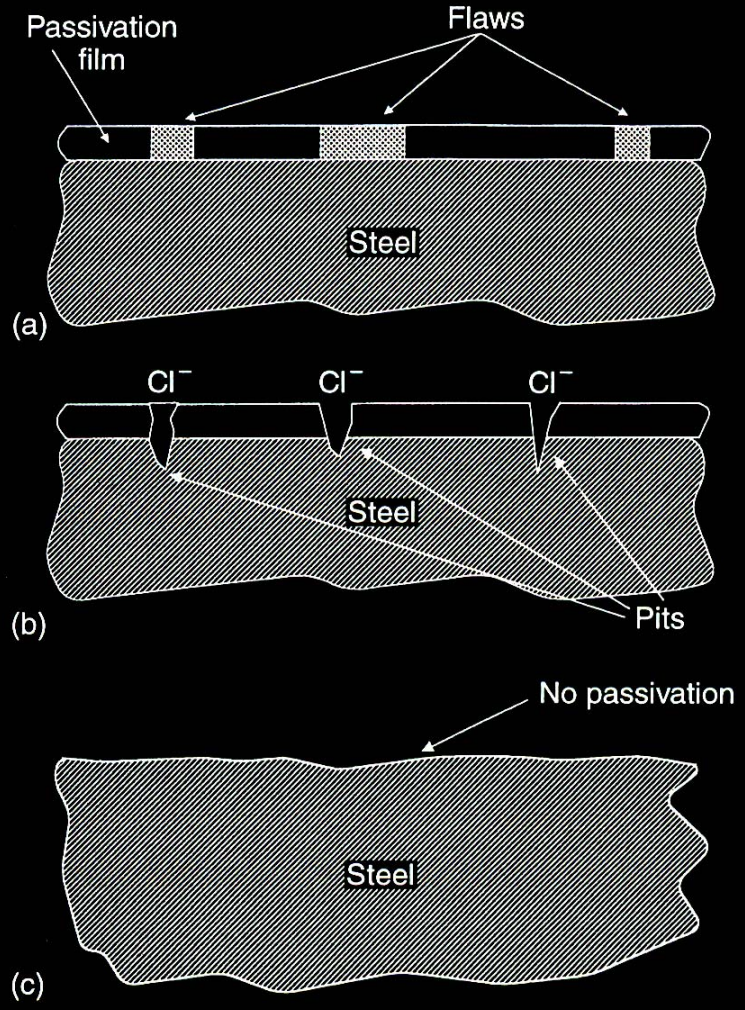
Intact ECR

ECR Containing Hairline Coating Cracks

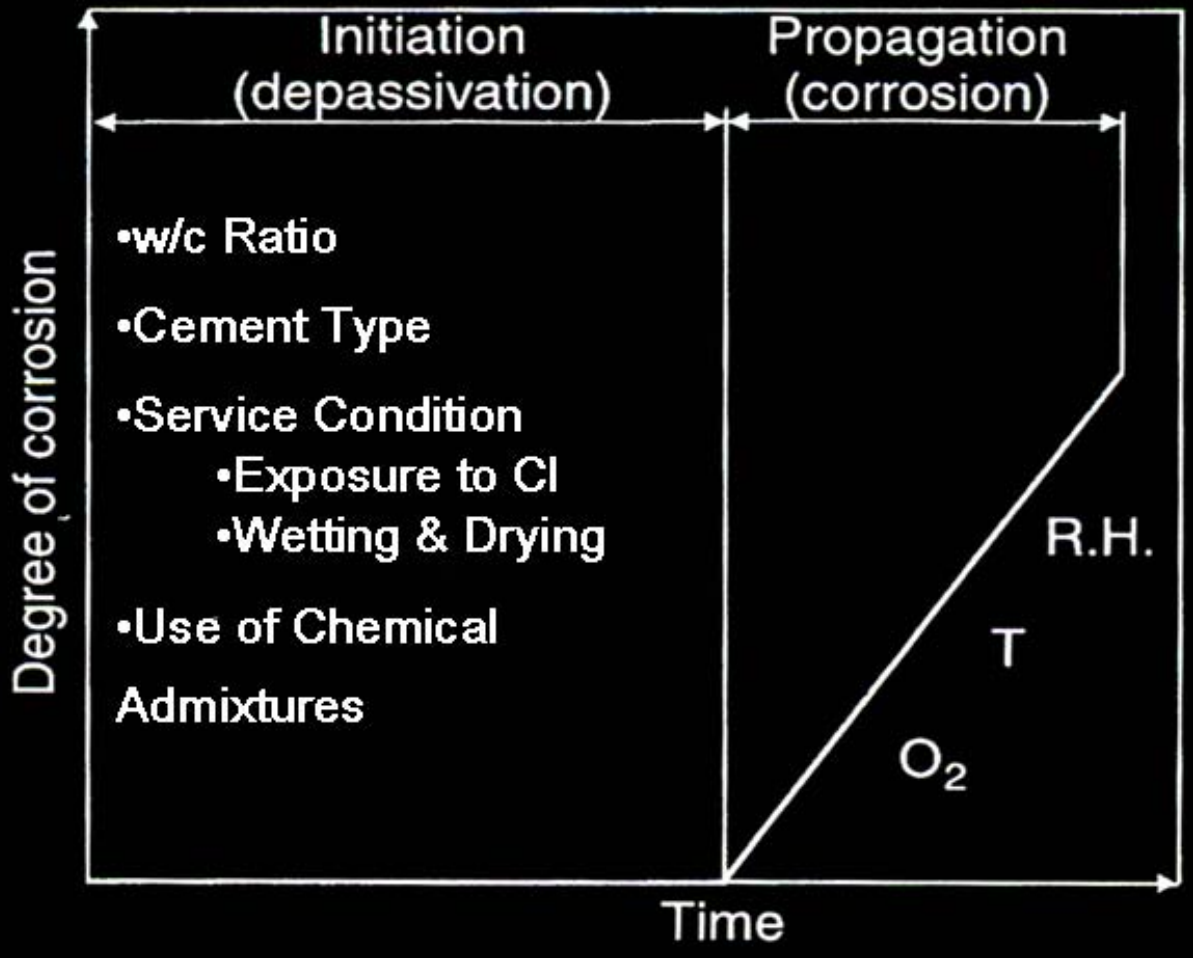
Delaminated ECR Revealing Severely Corroded Substrate

Corrosion Process

Why Chloride Accelerates Corrosion of Steel in Concrete



Factors Affecting Corrosion of Steel in Concrete



What Actually Happens

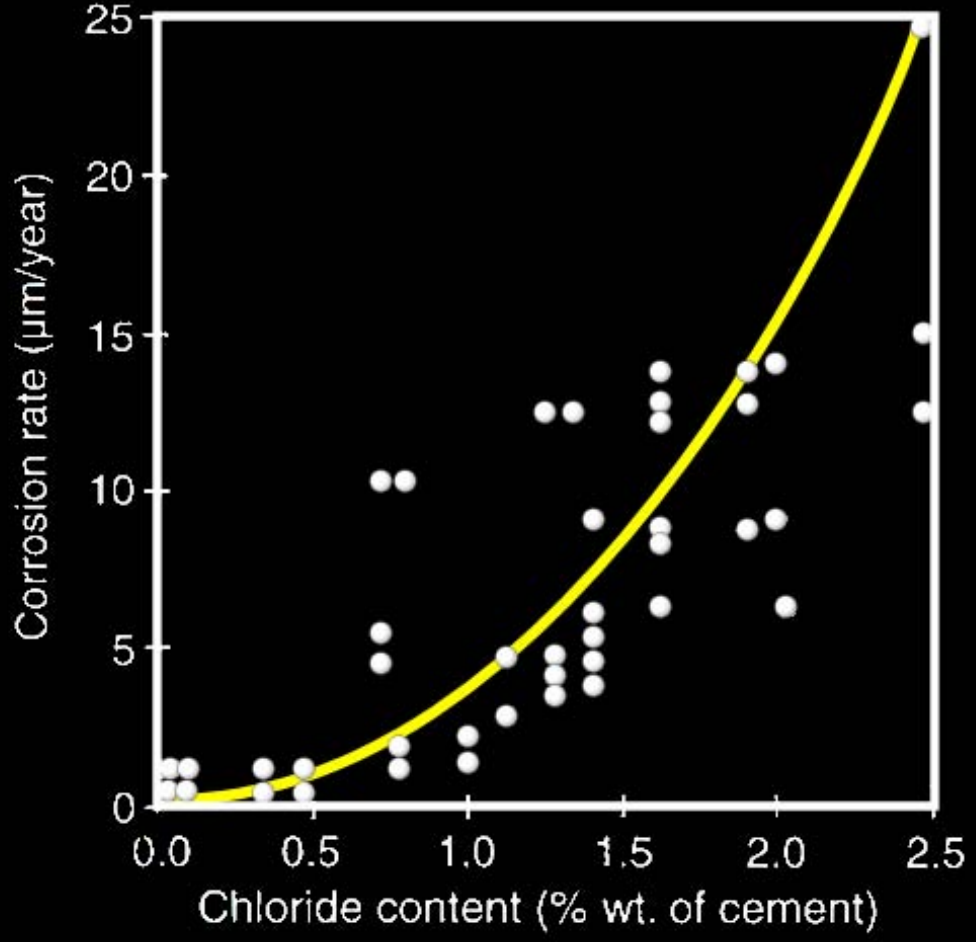
- Anodic Reaction
  - $2Fe \rightarrow 2Fe_2+ + 4electrons$
- Cathodic Reaction
  - $H_2O + O_2 + 4electrons \rightarrow 4OH-$
- Net Reaction
  - $2Fe + H_2O + O_2 \rightarrow Fe(OH)_2$

What Actually Happens

$$V_{Fe(OH)_2} >> V_{Fe}$$

The local paste is placed in tension and eventually the concrete cracks and spalls

Relationship between Chloride Content and Rate of Corrosion



A New Approach

Traditional Solutions

- Cathodic Corrosion Inhibitors
  - Aqueous Solutions of Amines and Esters
- Anodic Corrosion Inhibitors
  - $Ca(NO_2)_2$

Traditional Solutions

- Cathodic inhibitors are cations that migrate to the cathode and interfere with reduction of O_2 and H_2O to OH ions.
- Anodic inhibitors accumulate at the anode and interfere with oxidation of Fe^0 to Fe^{2+}

These inhibitors do not act until corrosion initiates.

Dominate Market Technology
Calcium Nitrite

- Corrosion produces $Fe(OH)_2$ which migrates out into the paste where it eventually oxidizes to $Fe(OH)_3$
- Calcium nitrite rapidly oxidizes $Fe(OH)_2$ to $Fe(OH)_3$. In doing so the rebar becomes surrounded by a barrier of $Fe(OH)_3$

The Answer*

- Form a compound in the concrete which sequesters chloride in concert while liberating nitrite

-OR-

- Add a compound to trap the chloride

**Based on Chemhydration patents*

Advantages

- Combines the benefits of chloride sequestration with nitrite liberation. As proven by short-term studies:
  - Anticipated to reduce the loss of nitrite in service
  - Use permits the non-uniform distribution of the admixture
  - Permits new applications (e.g., extraction of Cl from existing concrete without the need to impress a current)

Advantages

- Interferes with corrosion by two mechanisms
- Chloride sequestration and Nitrite release
  - Chloride sequestration is more important in extending the time to corrosion
  - Nitrite release will not offer meaningful benefit until sufficient chloride has approached the embedded steel to initiate corrosion
  - In situ formation of the nitrate salt should also be effective in interfering with corrosion as chloride replaces nitrate

Advantages

- Is stable in the presence of sulfate
  - This extends the applications to seawater exposure
  - The poor corrosion resistance of steel in Type V cement concretes is well known
- Enhances the corrosion resistance of Type V cement concretes

Corrosion Inhibitor

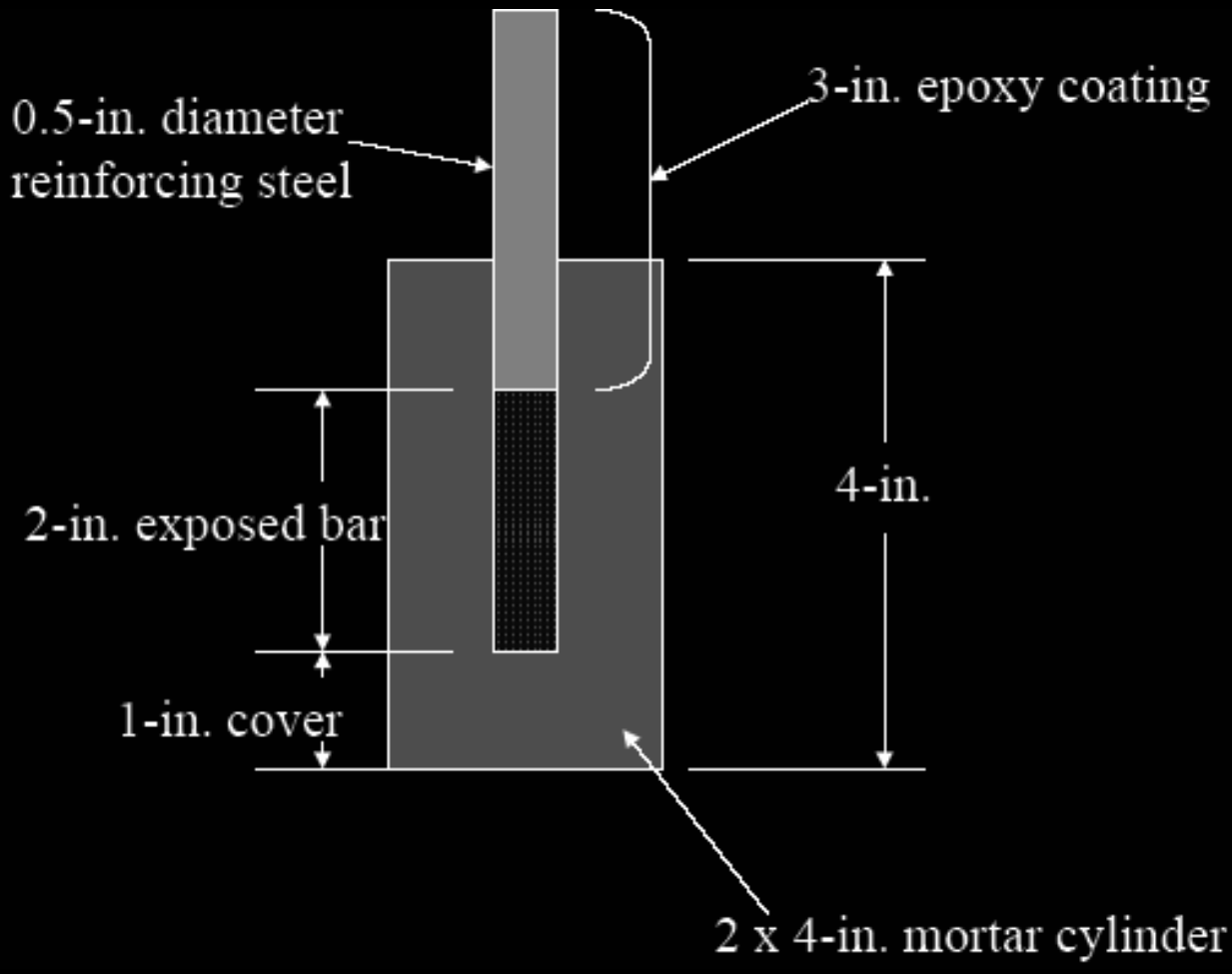
Corrosion Inhibitor

- Based on the concept of chloride scavenging and corrosion inhibitor
- Chemistry requires large amount of calcium and iron

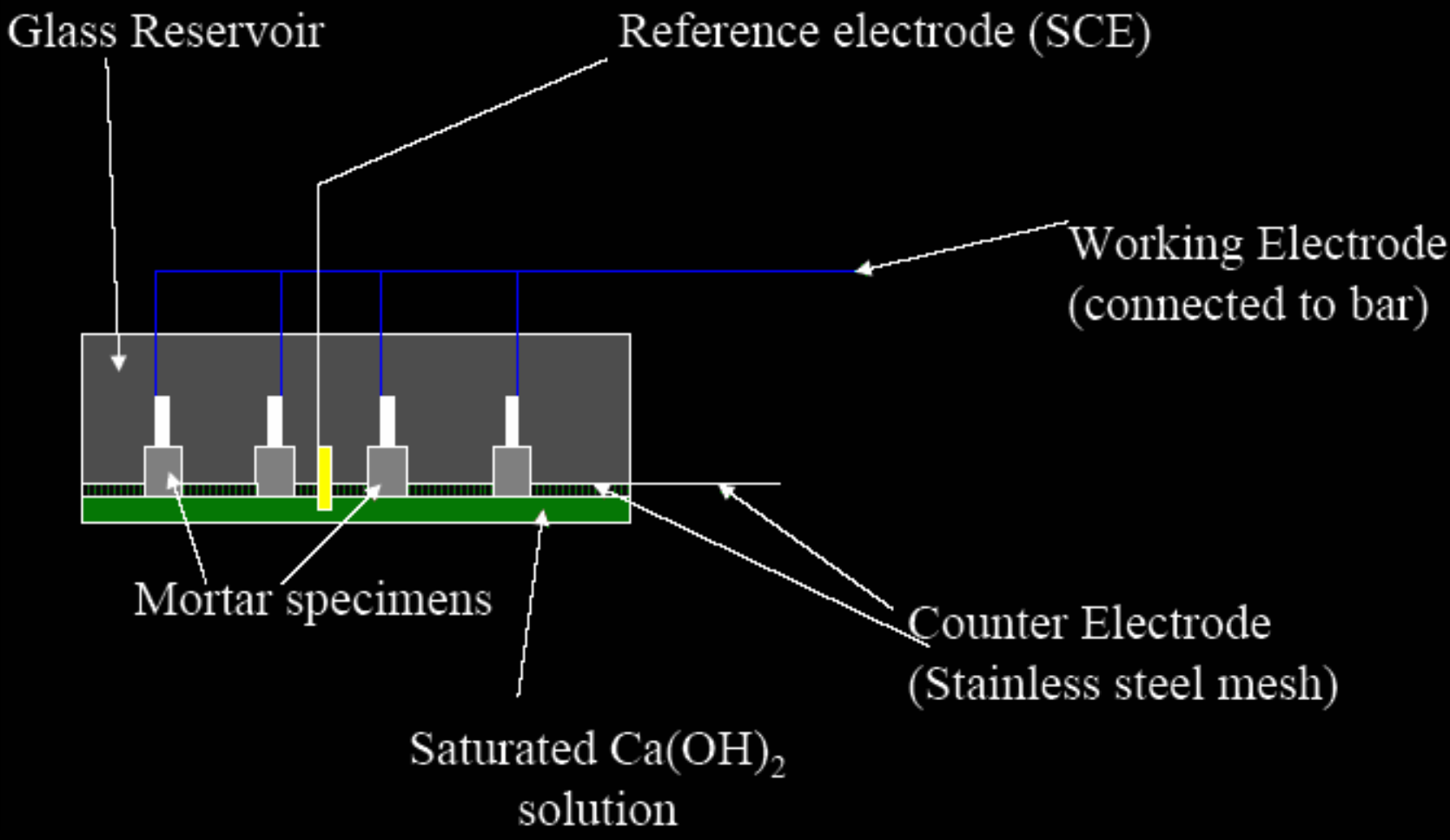
Corrosion Inhibitor Produced from AMD Sludge

- Powder is produced by firing calcium source and iron source at 1000°C
- RJ Lee Group has produced powder from samples of Brandy Camp sludge

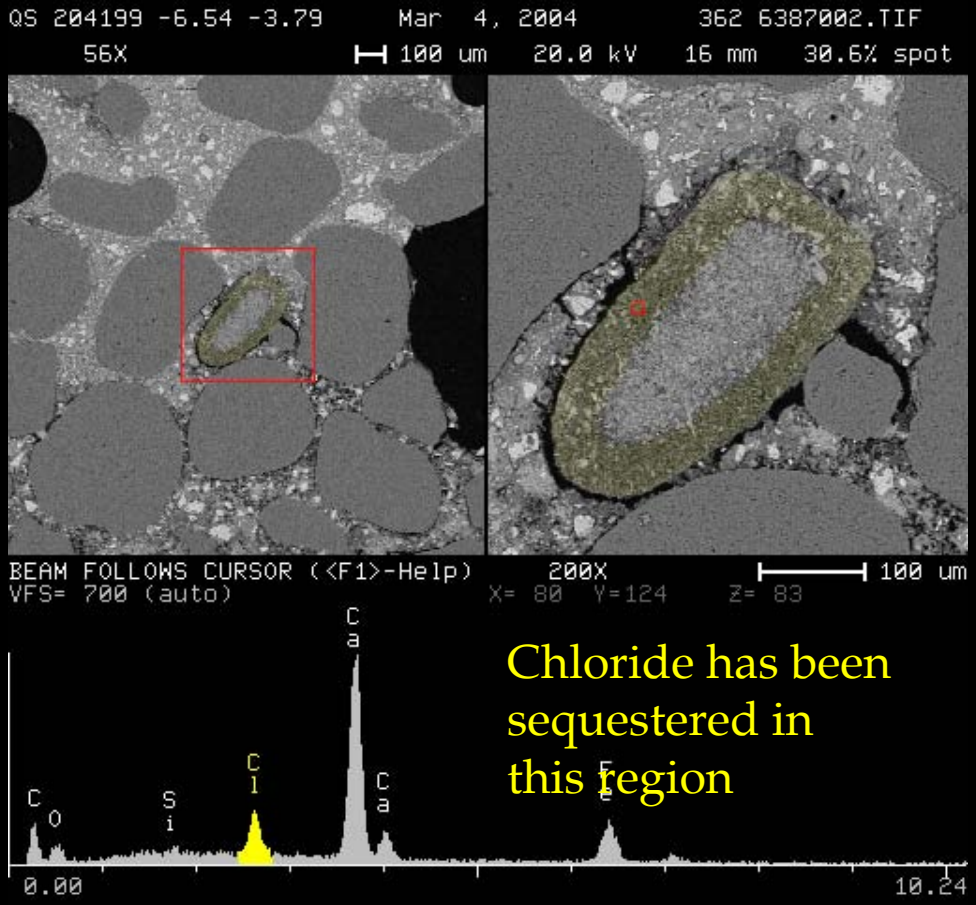
Corrosion Testing



Corrosion Testing



Powder Added to Mortar Mixture



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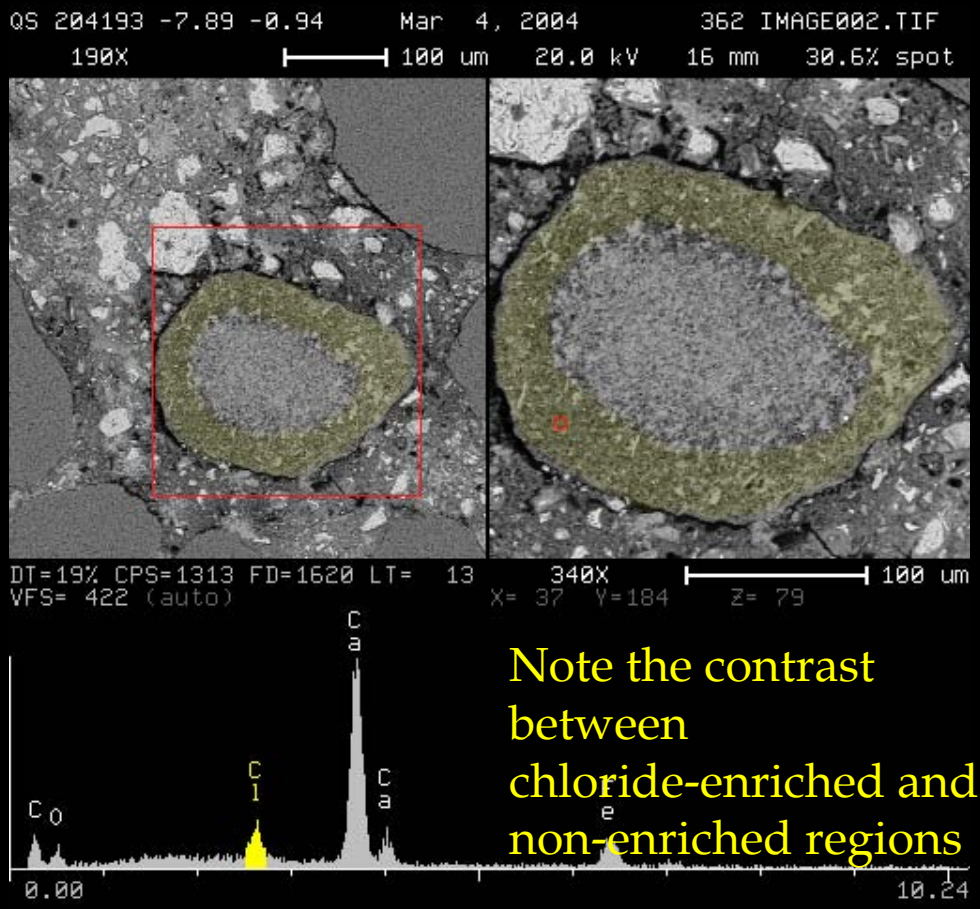
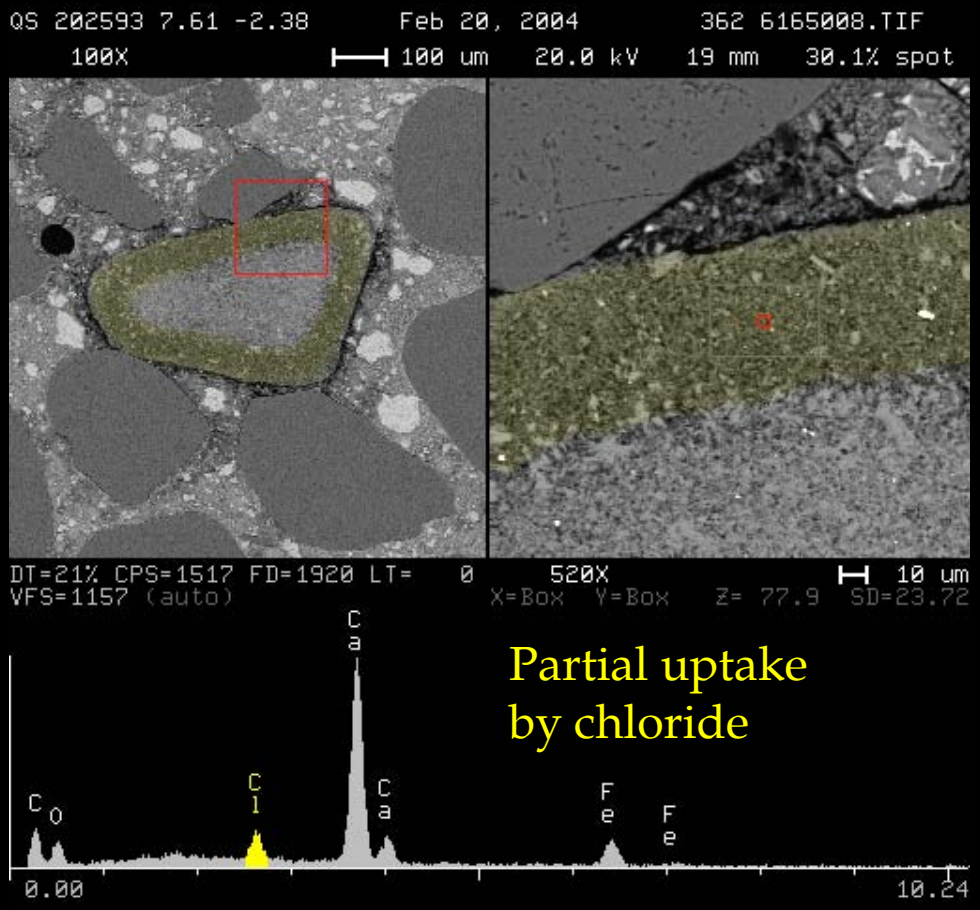


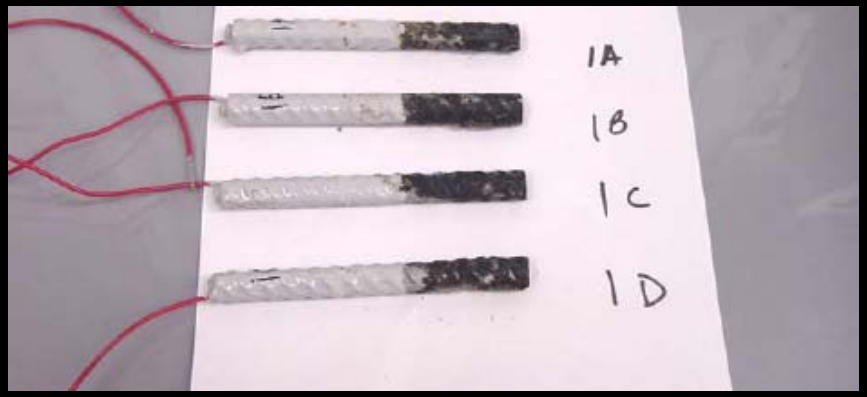
Note the contrast between chloride-enriched and non-enriched regions

Powder Added to Mortar Mixture



Results of Corrosion Testing

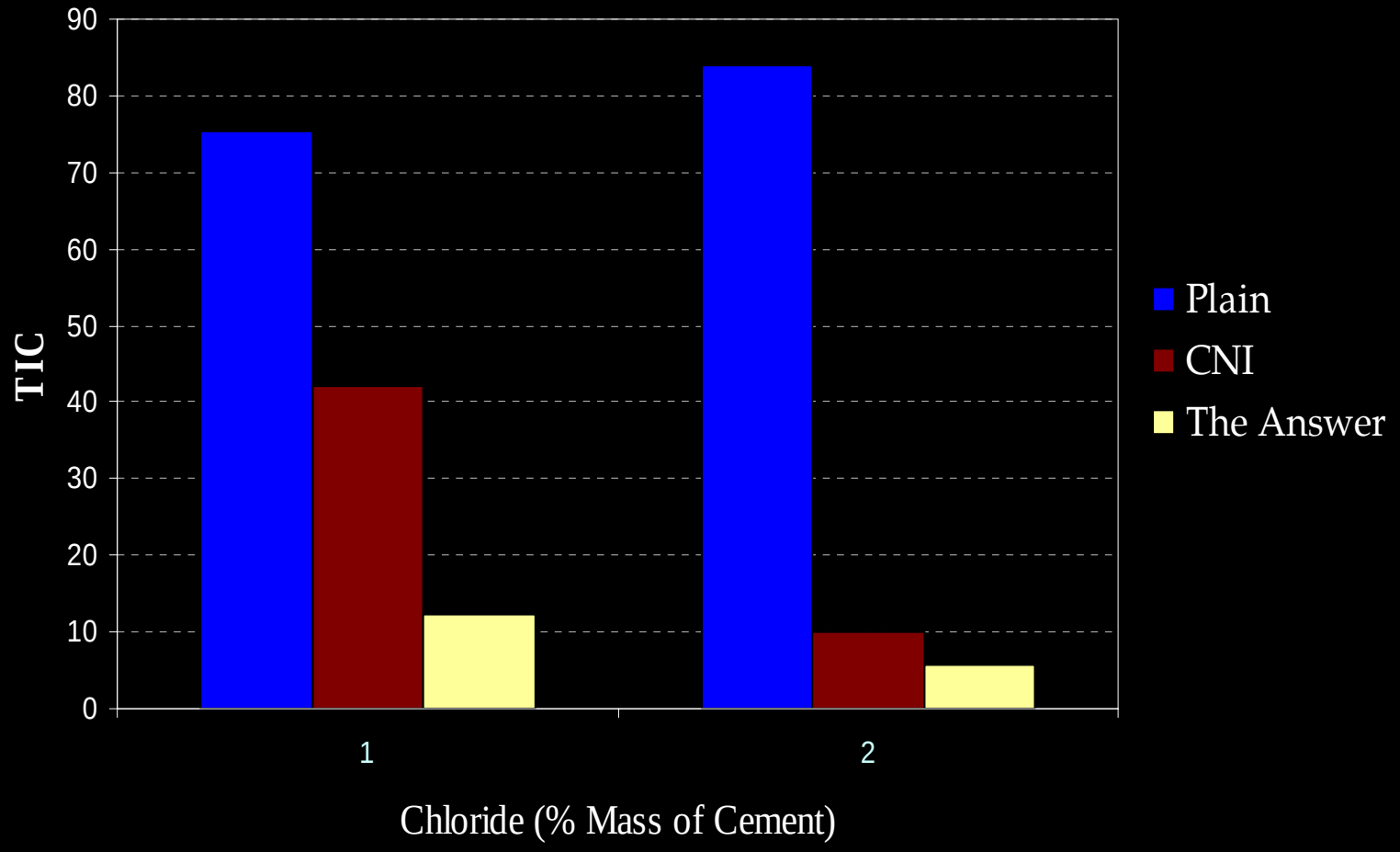
Plain Cement Paste



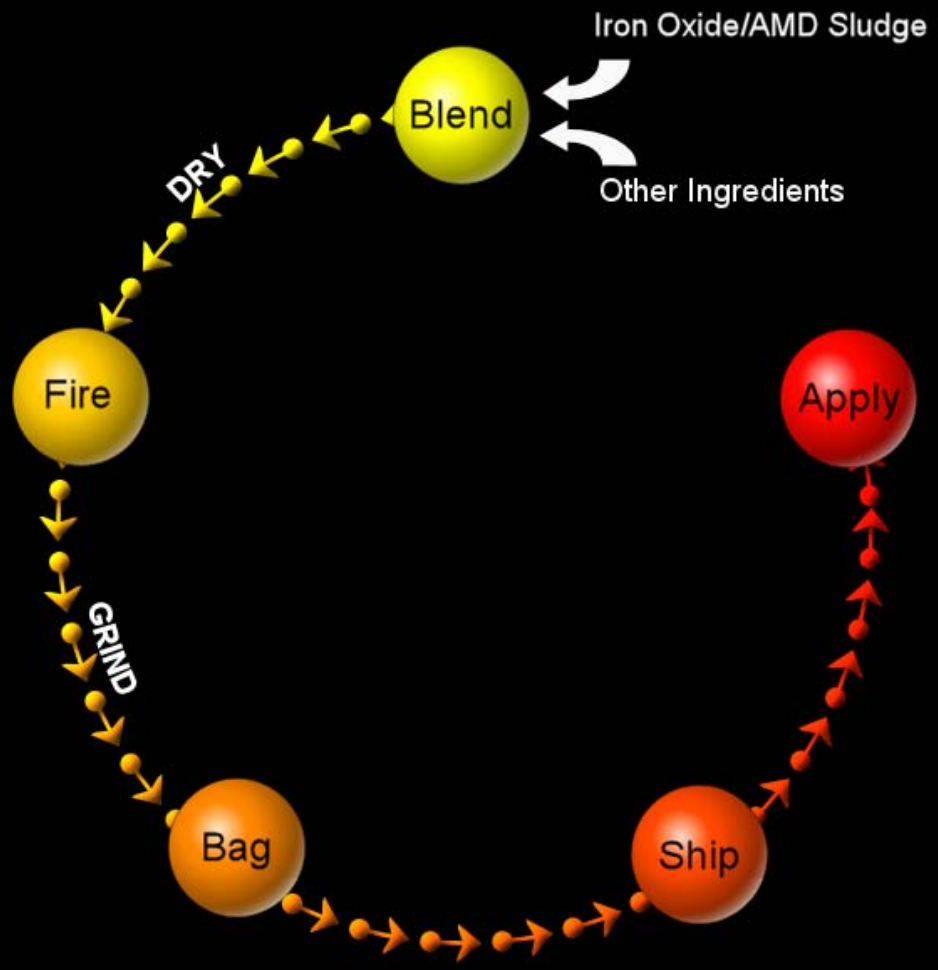
Calcium Nitrite

The Answer

Average Total Induced Current (TIC)



Manufacturing Process

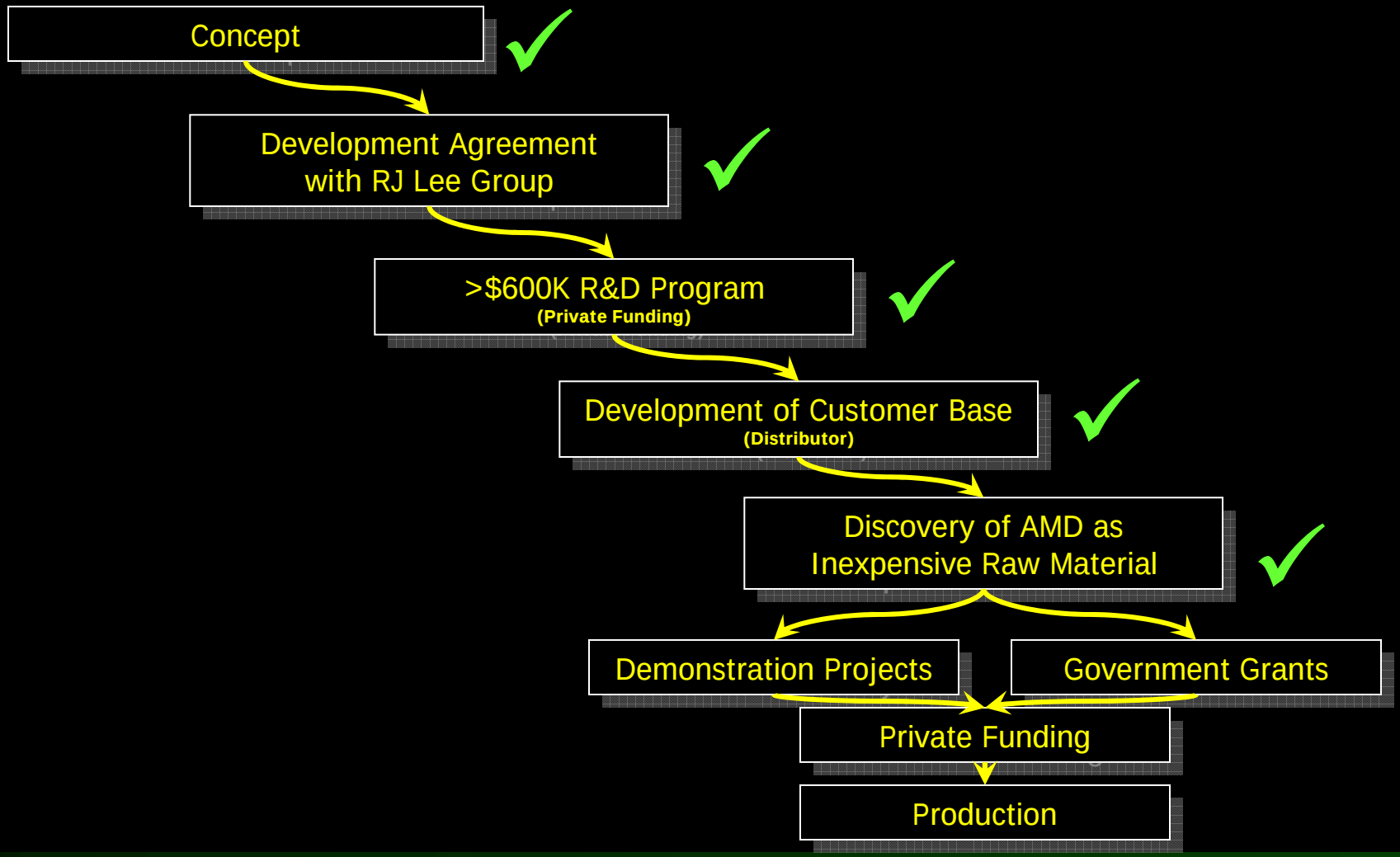


Concept to Reality

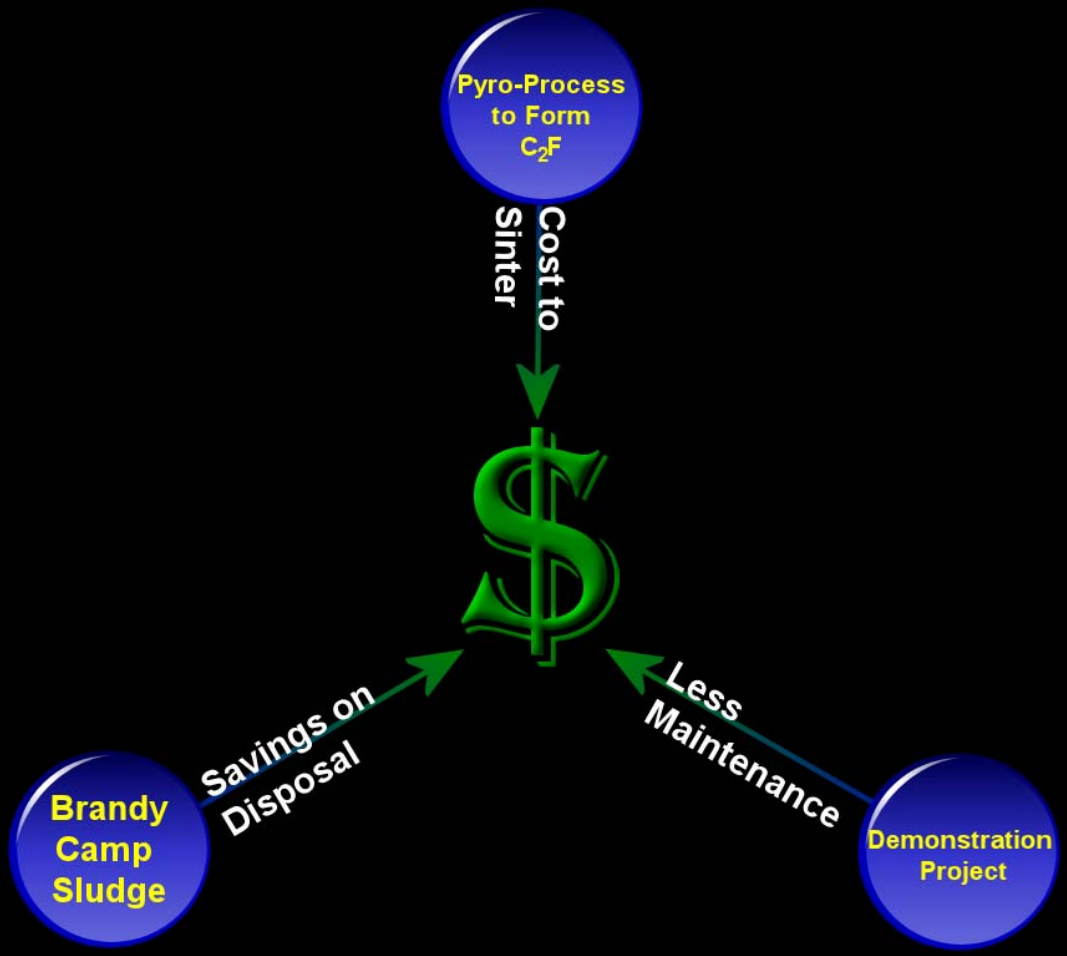
Concept

- Inventor conceived a new route to corrosion inhibition
- Patented by inventor
- Rights held by small company (inventor and wife)
- Reached development agreement with RJ Lee

Concept to Reality



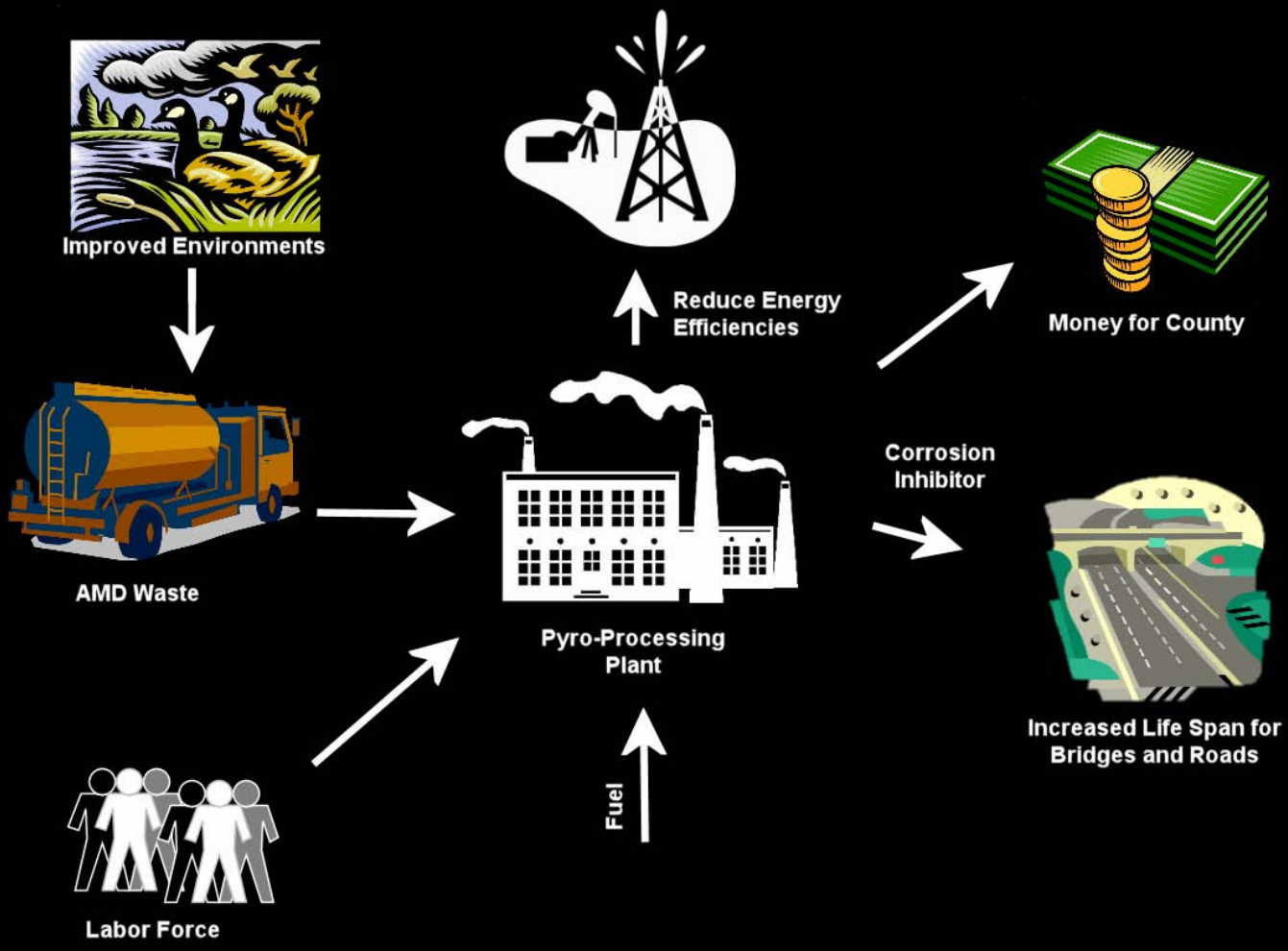
Economic, Engineering and Environmental Partnership



Effect on Treatment Costs

- Current
  - Construction
  - Operating
  - Trucking
  - Disposal
- Future
  - Same
  - Same or less
  - Similar or less
  - Less or zero

Bringing It All Together



Estimated Financial Benefits

- Reduction or Elimination of AMD Sludge Disposal Costs (*$2.3 to $23 million*)
- Environmental Cleanup of Streams (*not quantified*)
- Extended Infrastructure Service Life of all Bridges Funded (*$90 to $150 million*)
- Job Creation (*$6 to $12 million*)
- Increased State Revenues from Collection of Taxes on Processing Facilities in Operation (*$1.8 to $2.4 million*)

Total Combined Benefit: $100 to $185 Million

Cost of Repairing All Bridge Deficiencies in PA: ~$7 Billion

Advantages

- Increased Service Life
  - Including Epoxy Coated
- Lower Cost
- Applicable to Repair and Rehabilitation

Questions?