Replacement of Cadmium and Hexavalent Chrome in DoD Ground Systems

Clean Coatings for Common Hardware & Corrosion Control

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ASETS Defense 2018

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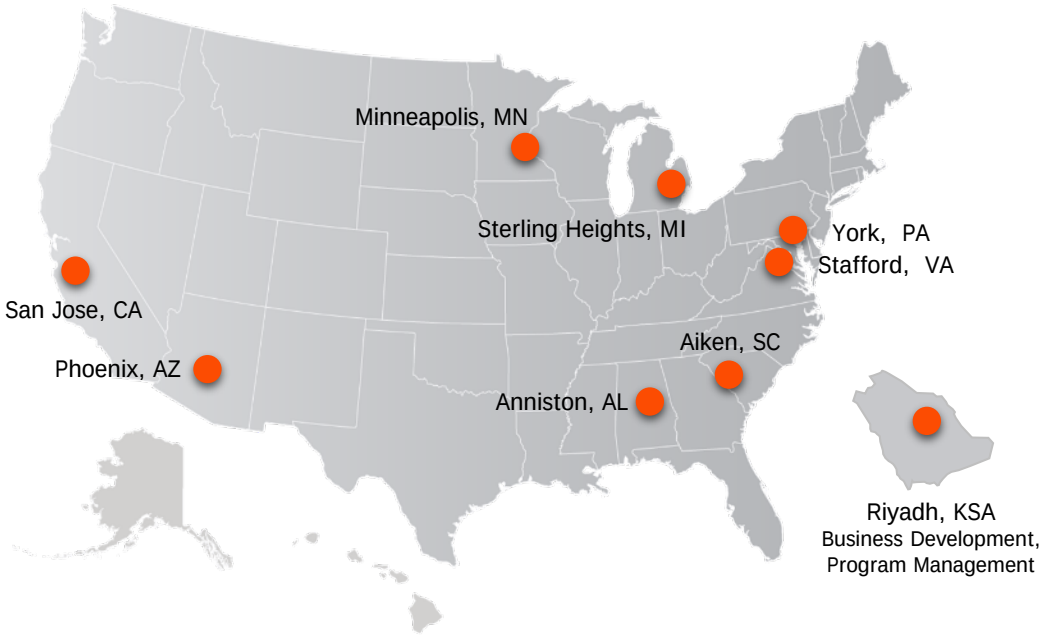
Platforms & Services – **Combat Vehicles (US, A&I)**



Primarily tracked and amphibious vehicle market serving U.S. and international customers

Consists of amphibious programs, core of United States Army Armored Brigade Combat Team (ABCT) portfolio, personnel armor, and aviation seating programs.

An Introduction to Cadmium & Hexavalent Chrome
Hazardous Materials & Surface Finishes

The successful fabrication, integration, and sustainment of armored fighting vehicles (AFVs) requires a wide breadth of manufactured products, joining technologies, and protective coatings.

- Material selection reduced due to identification of hazardous materials *OSHA 29 CFR 1910.1200(c)*
- Additional "prohibited materials" defined per program contract.
- Cd & Cr^{+6} included in IARC Group 1 compounds.

Structure Corrosion on Aluminum

Torsion Bar Failure Caused by Corrosion

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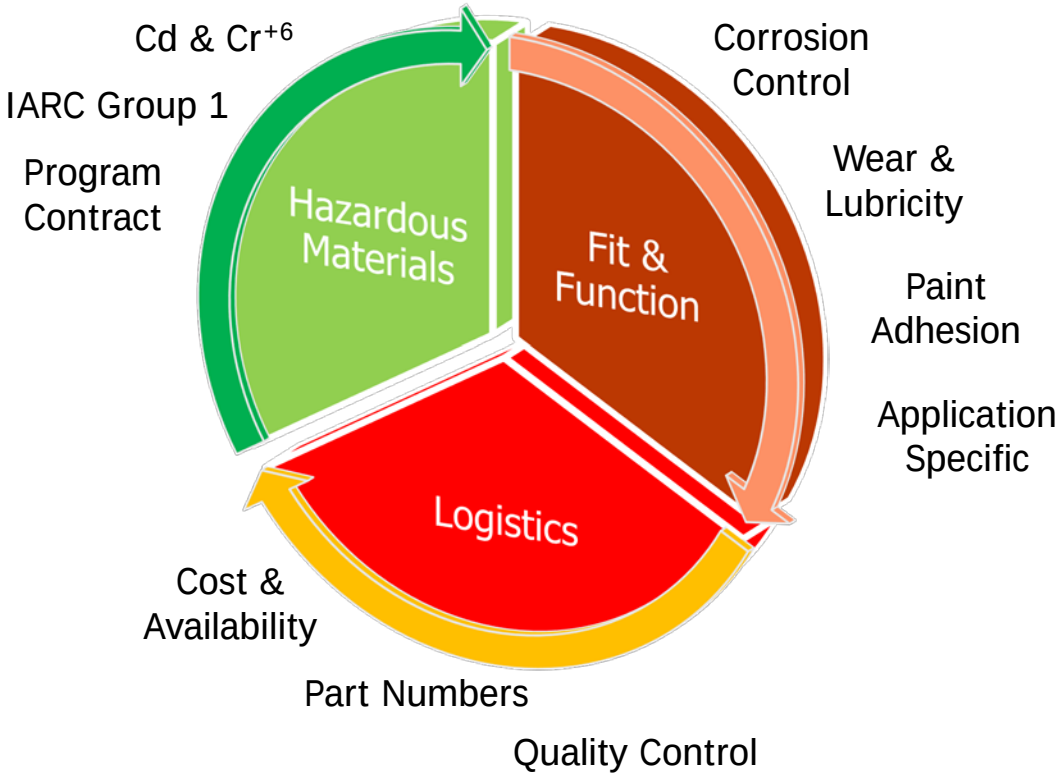
Eliminating Cd & Cr^{+6} from Ground Systems
The Problem with Cleaning Up

Cadmium is the most hazardous chemical used in, and applied to, Army weapon systems and components. The potential liability and environmental costs associated with cadmium warrant an assertive effort to reduce the Army's usage. (1)

James H. Sullivan
Director, Army Acquisition (1996)
Pollution Prevention Support Office



Why aren't DoD ground systems "clean"?

1. *Few new-build/design programs. Programs will not finance complete update and refurbishment of existing, functional weapons systems.*
2. *"Cleaning up" is complicated – need to balance "cleanliness" with fit/function and logistics.*
3. *Every program is different in how they prioritize hazardous material elimination.*

Eliminating Cd & Cr^{+6} from Ground Systems
The Problem with Cleaning Up

The Big Stuff

- Custom items based on engineering drawings.
  - Hull structures (pre-treatments for corrosion and paint adhesion).
  - Large component parts (suspension, towing hooks, powertrain components, etc,).
  - Brackets & stowage.

The Small Stuff

- Commodity or specification controlled items.
  - Threaded & non-threaded fasteners.
  - Pins & springs.
  - Electrical connectors.

Eliminating Cd & Cr^{+6} from Ground Systems
Fixing the "Big Stuff"

Heat Exchanger, treated Type 2 MIL-DTL-5541

Much easier to eliminate hazardous materials from "big stuff" as these parts are custom made and controlled directly by procuring activity.

- Lots of clean coating options: If you can buy it, you can use it.
- Exceptions and special performance requirements can be specified when needed.
- Barrier to use of clean coatings is primarily an engineering issue.

Category	Specification	Clean Classifications
Pretreatment or Bare Metal	MIL-DTL-5541	Type 2
	MIL-A-8625	Prohibit Chromate Seal
	AMS 2700	Method 1 Type 5 thru 8, Method 2
	TT-C-490	Multiple
Electrodeposited Coatings	ASTM B633	Type V and VI
	ASTM B841	Prohibit Chromate Conversion Coating
Organic Coatings	ASTM F2833	-
	MIL-DTL-53022	-
	MIL-DTL-53030	-

Eliminating Cd & Cr^{+6} from Ground Systems
Fixing the "Small Stuff"

Very difficult to eliminate hazardous materials from small, common, "commodity" parts. The primary deal breaker is often due to logistics and procurement, not engineering.

- "Small Stuff" is supplied as a commodity/COTS product.
- OEM does not have control over commercial hardware.
- No consensus on common solution at customer-level.
- **Major need for a common, clean hardware solution for DoD ground systems.**

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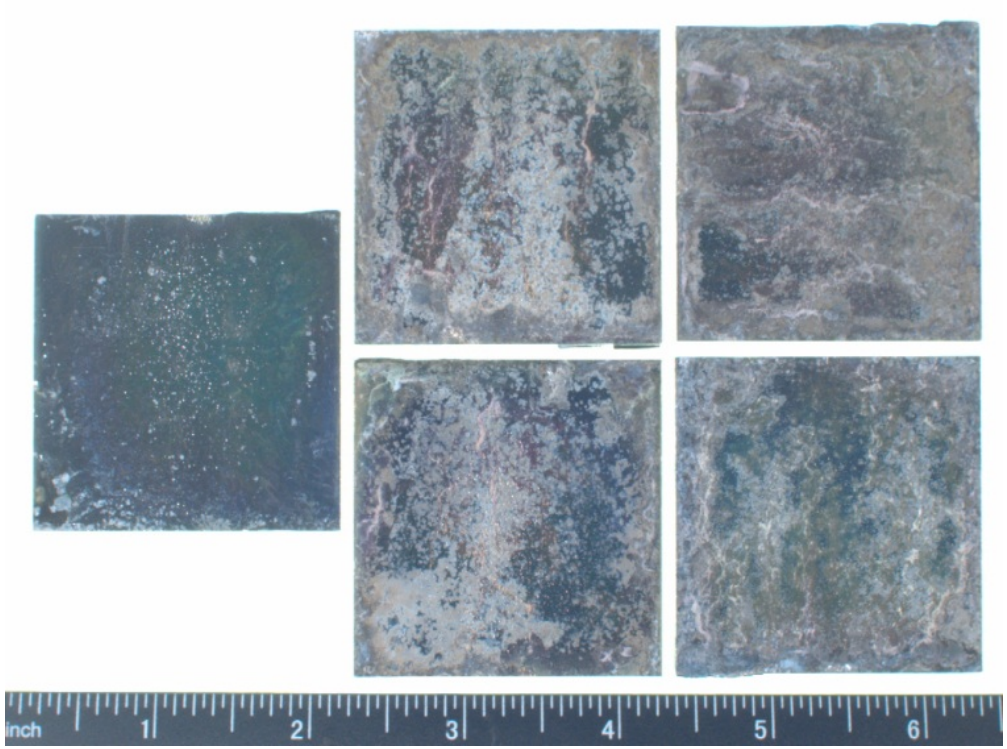
Clean Hardware
Requirements for Ground Vehicle Programs

- Must not contain IARC Group I (Carcinogens) compounds including Cd or Cr^{+6}.
- “Drop-in compatible” with existing hardware on most programs.
- Must be readily procurable, available, proven history of success (COTS preferred).
- Must meet minimum program corrosion requirements (20+ years, 1,000 hours ASTM B117).
- Desirable to have a single solution within ABCT visually distinguishable from legacy hardware.

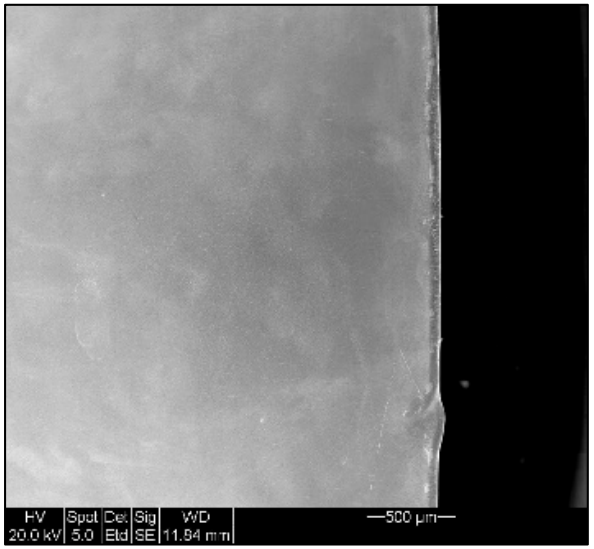
Coating	K-Factor	Corrosion Performance	Prohibited Materials	Sole Source?
Zn-Ni	⊘	✓	✓	No
Zn-TCP	?	⊘	✓	No
Zn-CCC	✓	⊘	⊘	No
Cd-CCC	✓	?	⊘	No
HP Aluminum	⊘	✓	✓	Yes
Organic	✓	✓	✓	Yes, Multiple Vendors

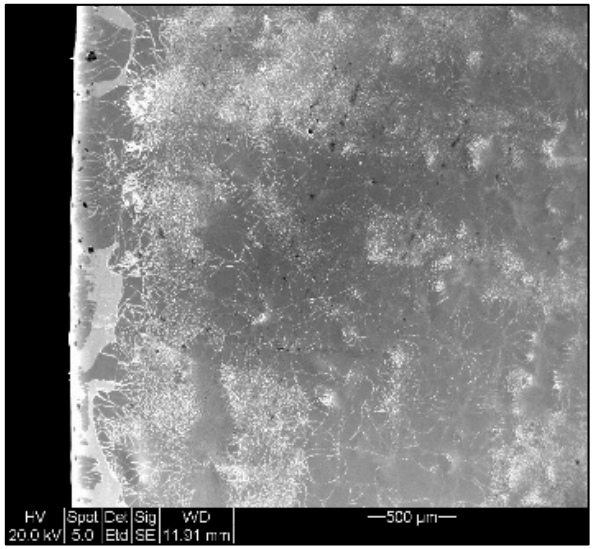
Clean Hardware
Cleaning Up Electrodeposited Zinc

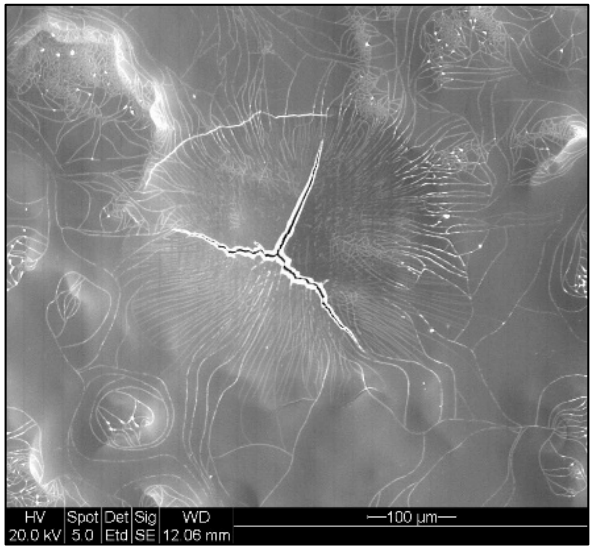
- Can existing chromate containing hardware be “cleaned up”?
  - Thermal conversion of hexavalent chrome is possible. (2,3)
  - Would allow use of existing Zn-CCC hardware stock as clean solution.
- Results:
  - Samples passed ASTM D6492 indication test post processing.
  - Will not reliably pass 96 hour salt spray requirement (Type II, ASTM B633).



Clean Hardware
Cleaning Up Electrodeposited Zinc



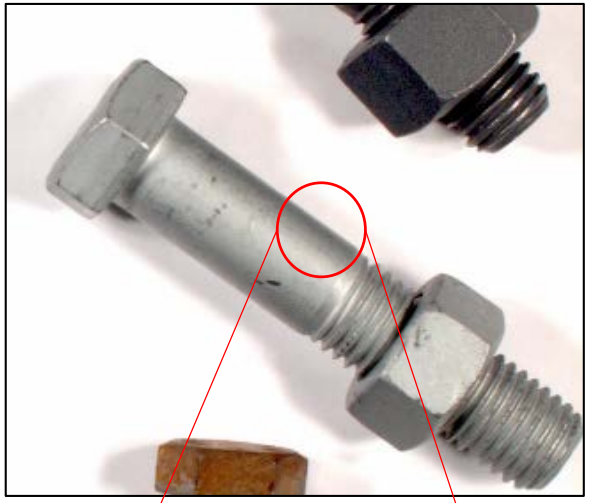


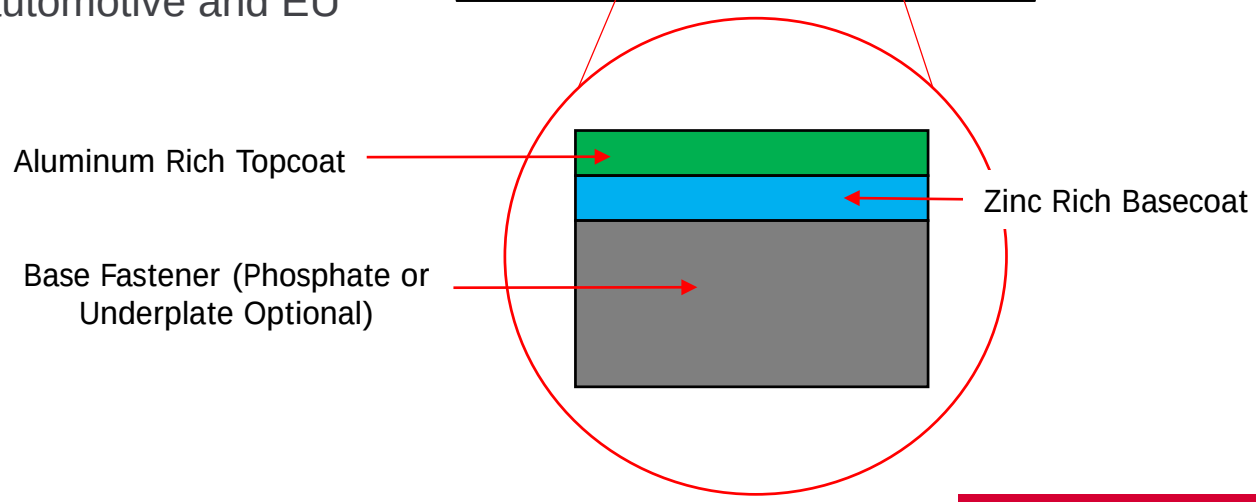


- Can CCC hardware be “cleaned up? Not without loss of corrosion protection.
- Trivalent chrome passivates are feasible alternative.
  - Until 2015, no ASME B18 pin codes to support.
  - Type VI coatings may be okay for some programs (will not meet 1,000 hour salt spray).

Clean Hardware
Organic Coating Options

- Organic Coatings (Metal Flake)
  - Produced under different tradenames by different companies.
  - Can be produced with electrodeposited base coat or direct to metal.
  - Tailorable color, corrosion resistance, and k-factors.
  - Extensive use in automotive and EU markets.



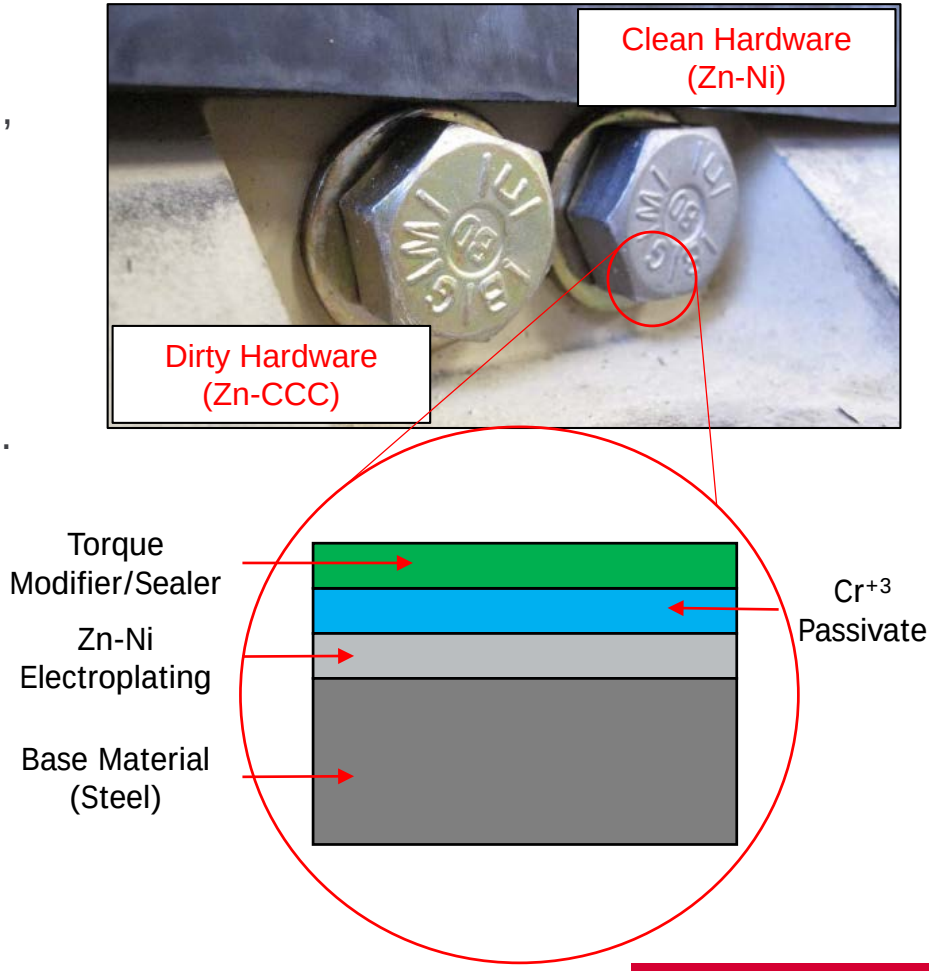


Clean Hardware
Organic Coating Options

- Pre-Production Validation
  - Passed k-factor in-lab testing.
  - Passed salt spray test, in-lab.
  - Visually distinct from “dirty” hardware.
- Production Lessons
  - 3 years in parking lot (not in service) resulted in coating failure.
  - Difficult to control thickness in-production.
  - Low durability compared to electrodeposited coatings.

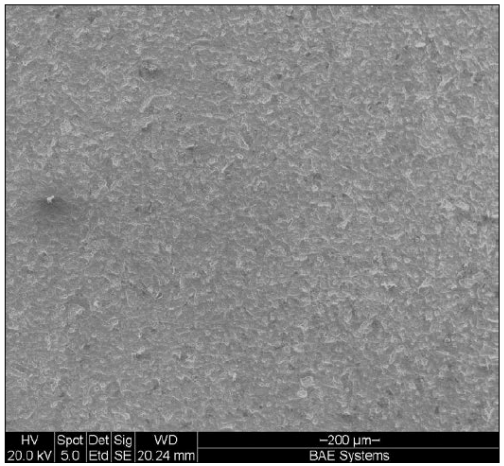
Clean Hardware
Electrodeposited Zn-Ni

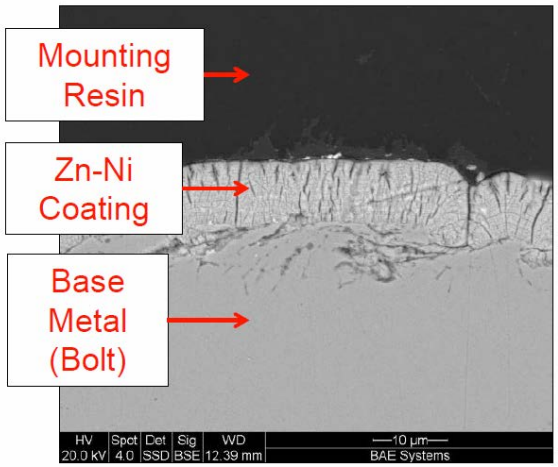
- Electrodeposited Zn-Ni
  - Ford (WSS-21P51), GM (GMW4700), and Boeing.
  - Originally considered as Cd replacement by FMC in 1990's.
  - Widely available, non-proprietary coating.
  - Visually distinct from "dirty" hardware.
  - High k-factors with wide spread (compared to Cd).
- Propose use of Zn-Ni based coating system with supplemental torque control.

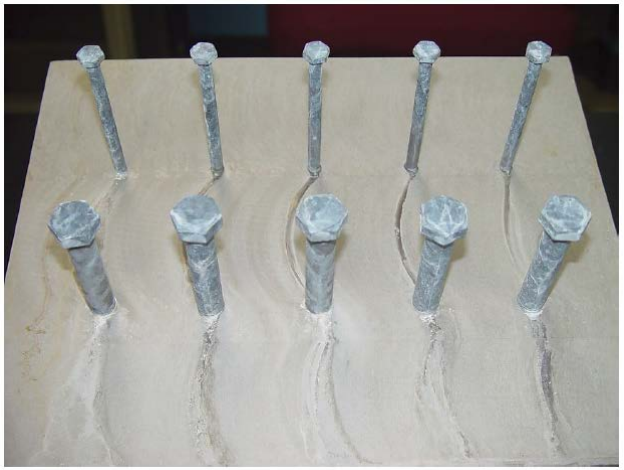


Electrodeposited Zn-Ni
Coating Quality and Corrosion Control

- Corrosion Requirements
  - Coating thickness 8µm minimum.
  - 12 – 18% Ni (by weight).
  - 240 hours to white corrosion, 960 hours to red rust (ASTM B117).
  - Use of hexavalent chrome prohibited.
- Specified in accordance with ASTM F1941/F1941M.

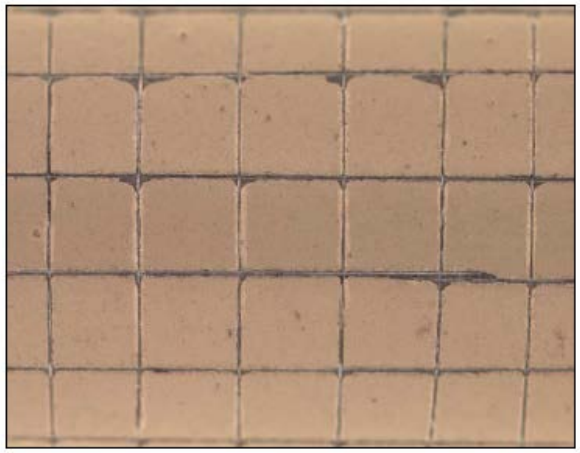




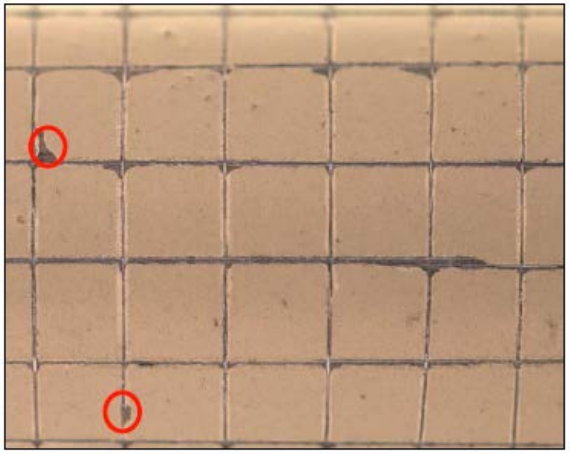


Electrodeposited Zn-Ni
Torque Modifiers and Finish Requirements

- Supplemental Requirements
  - Clear or blue finished allowable.
  - K-factors to be .18 - .22 (NASM 1312-15 or ISO 16047).
  - Torque modifiers and sealers shall not prevent paint adhesion.
  - Plating shops must pass initial qualification prior to start of production.



Sample Condition prior to Adhesion Test



Sample Condition post Adhesion Test

Electrodeposited Zn-Ni
NASM 1312-15 Torque-Tension Data

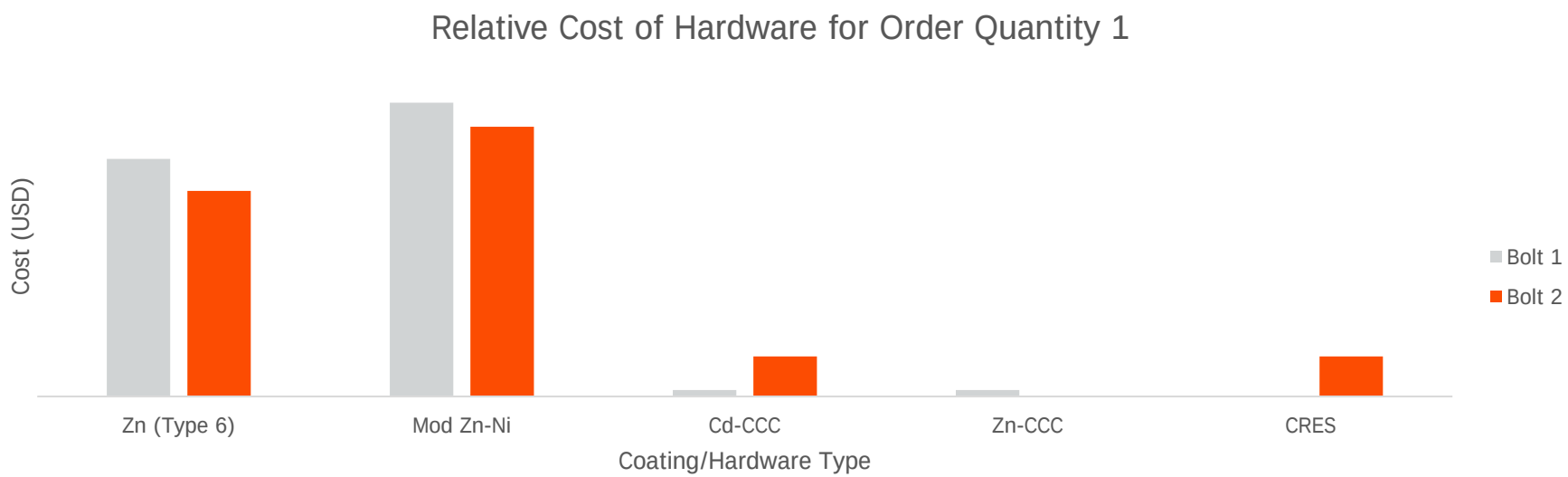
Bolt	Condition	Average K	Median K	Avg Range K	Std. Dev.
½”-13	Dry (Plain Zn-Ni)	.23	.23	.14	.06
	Oiled (Plain Zn-Ni)	.19	.19	.04	.02
	Loctite 242 (Plain Zn-Ni)	.21	.20	.03	.02
	Vendor 1 (Mod Zn-Ni)	.19	.19	.02	.01
	Vendor 2 (Mod Zn-Ni)	.18	.19	.04	.02
	Vendor 3 (Mod Zn-Ni)	.21	.21	.03	.01
¼”-28	Dry (Plain Zn-Ni)	.29	.30	.05	.04
	Oiled (Plain Zn-Ni)	.23	.22	.04	.03
	Loctite 242 (Plain Zn-Ni)	.19	.19	.03	.01
	Vendor 1 (Mod Zn-Ni)	.19	.18	.01	.01
	Vendor 2 (Mod Zn-Ni)	.19	.19	.03	.02
	Vendor 3 (Mod Zn-Ni)	.20	.20	.04	.03

Electrodeposited Zn-Ni
Vehicle-Level Test & Evaluation

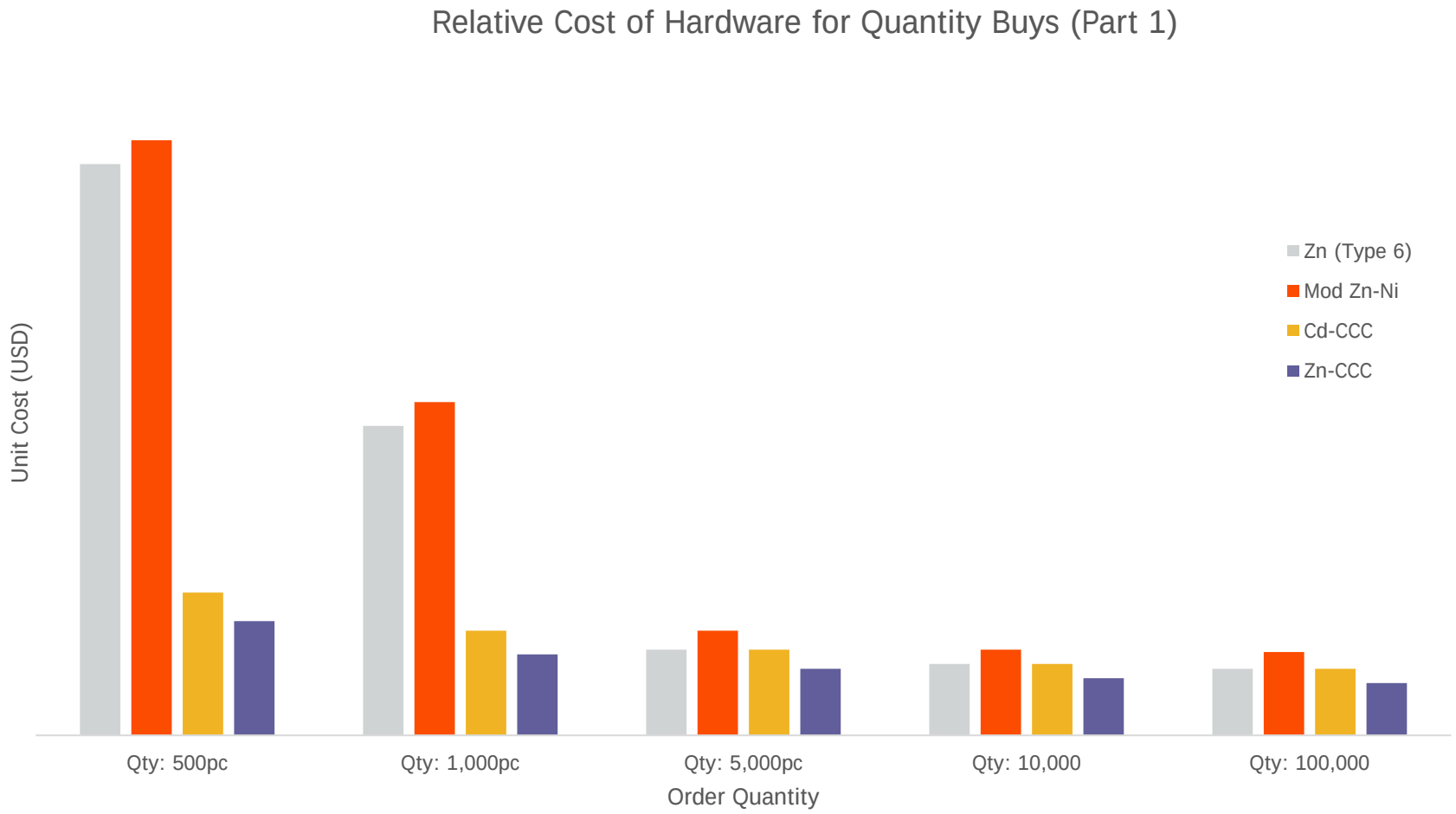
- Vehicle History on Zn-Ni Hardware
  - Evaluated in 1990's at FMC on Bradley Fight Vehicle.
  - 12 vehicles with installed hardware.
    - Cumulative > 19,000 miles logged.
    - Individual vehicles > 3,000 miles logged.
    - On-vehicle time > 2 years.
  - No issues with loss of torque or corrosion in steel and aluminum assemblies.
- Planned for Accelerated Corrosion Durability Testing (ACDT) in 2018/2019.

Electrodeposited Zn-Ni
Logistics & Cost Analysis

- Logistics is the single largest barrier to implementation of clean hardware on ground vehicles.
- Part numbers? Unit costs? Lead times?



Electrodeposited Zn-Ni
Logistics & Cost Analysis



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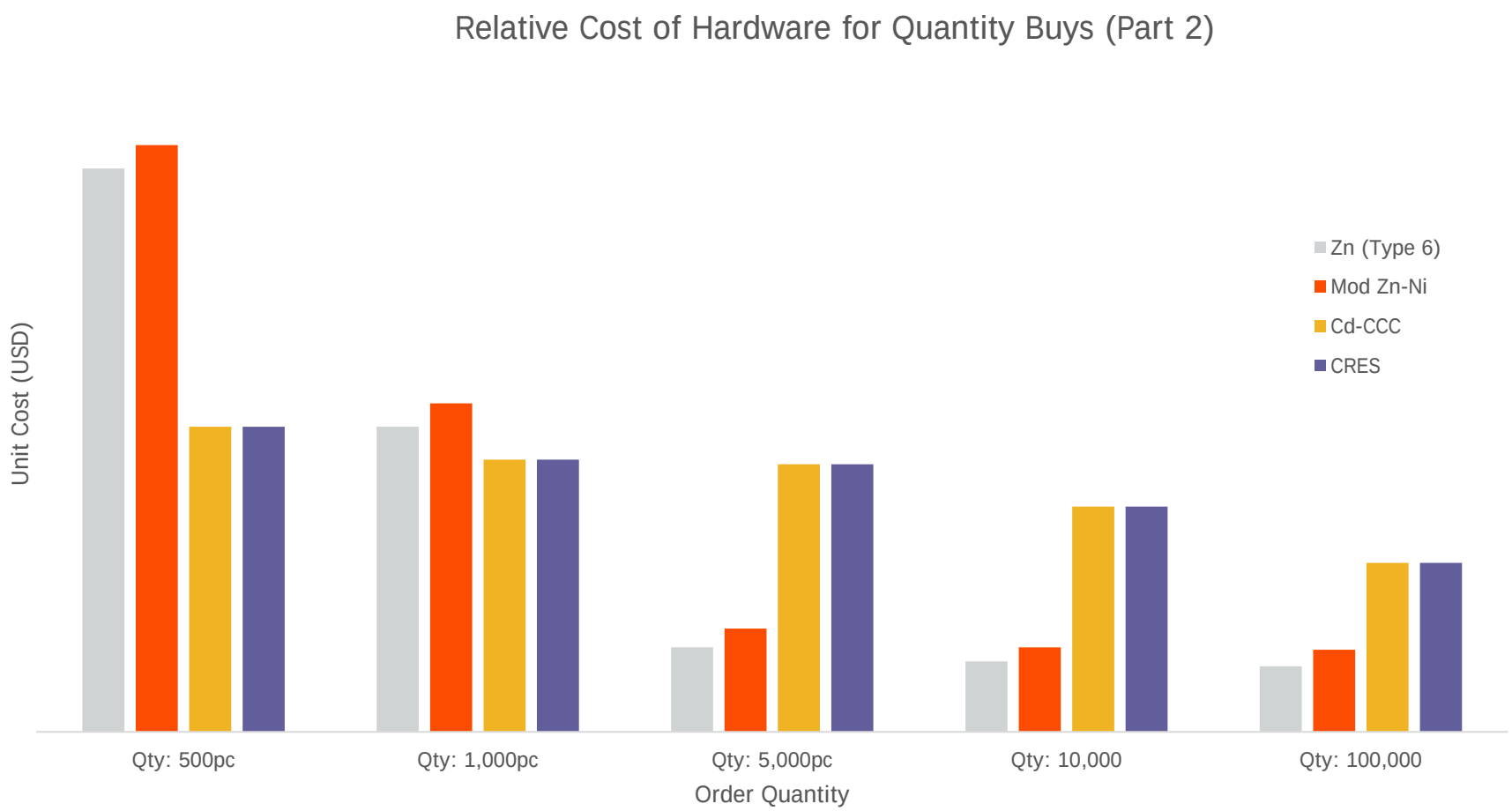
Electrodeposited Zn-Ni
Logistics & Cost Analysis



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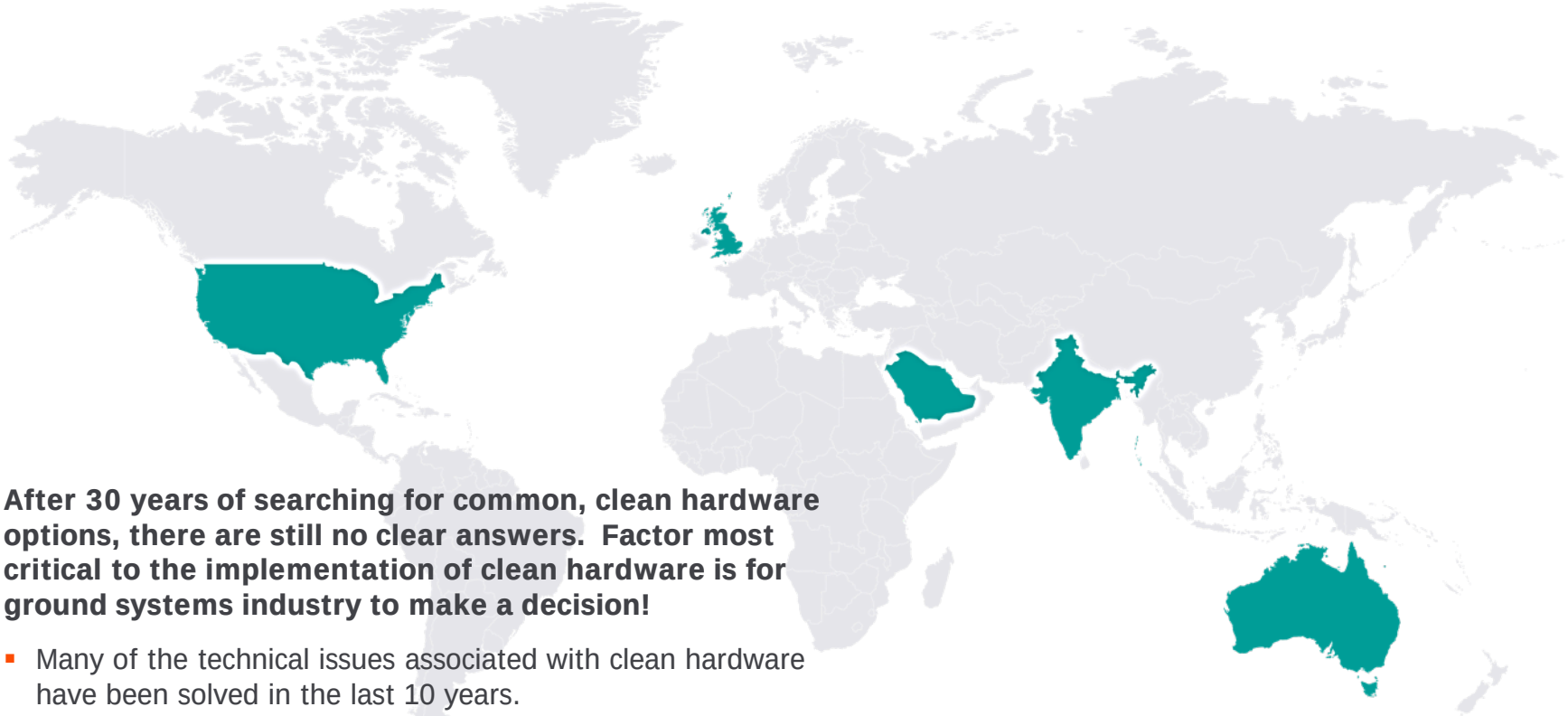
Electrodeposited Zn-Ni
Logistics & Cost Analysis

- BAE Systems, Combat Vehicles (US, A&I) has generated a clean, Zn-Ni hardware library for use across all ground systems platforms.
  - 19207-12578628
  - Hardware library currently “program owned”.
- Electrodeposited Zn-Ni is becoming the industry standard for clean hardware coatings for fasteners.
  - Automotive
    - Ford
    - General Motors
  - USAF (NASM 9928)
  - Commercial Aerospace (Boeing)
  - USN

Clean Common Hardware
Wrapping Things Up…



After 30 years of searching for common, clean hardware options, there are still no clear answers. Factor most critical to the implementation of clean hardware is for ground systems industry to make a decision!

- Many of the technical issues associated with clean hardware have been solved in the last 10 years.
- Commercial standards are still catching up (ASME/NASM).
- Success of “clean hardware” for ground systems is contingent upon unified standard between OEMs and USG.

Clean Hardware
Electrodeposited Zn-Ni

1. **U.S. Army Acquisition Pollution Prevention Support Office.** *Guidance for Eliminating Cadmium from U.S. Army Weapon Systems.* S.l. : U.S. Army, 1996.
2. **Laget, V., et al.** *Thermal Stability and Aging Characteristics of Chromate Conversion Coatings on Aluminum Alloy 2024-T3.* s.l. : OSTI, 2000. BNL 67060.
3. *Effect of Temperature, Ionic Strength, Background Electrolytes, and Fe(III) on the Reduction of Hexavalent Chromium by Soil Humic Substances.* **Wittbrodt, Paul R. and Palmer, Carl D.** 8, s.l. : Environmental Science & Technology, 1996, Vol. 30.