

Evaluation of Cadmium Replacement Alternatives for Aircraft

AeroMat 2002

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What's the problem with Cd?

- ❑ **Cd itself is toxic - heavy metal poison**
- ❑ **Intrinsic problem**
 - **Probable carcinogen**
 - **Causes lung and kidney damage**
 - **Process ESH issue for Cd workers**
 - **Life-cycle exposure**
 - ❑ **Leaches on washdown**
 - ❑ **Dust when sand surfaces for painting (aircraft)**
 - ❑ **Accumulates in food chain - especially fish**
- ❑ **However, it is about the most effective corrosion resistant surface there is**

Regulatory issues

- ❑ **Existing EPA and OSHA pel regulations**
- ❑ **European Commission proposal to remove Cd and Cr⁶⁺ from all electronic equipment**
 - **Note: this exempts applications for which there is no alternative, including aircraft - for now**
- ❑ **European end-of-life regulations for cars, aircraft, equipment of all types**
 - **Manufacturer are responsible for disposal of all items at end of life, so want to avoid toxic materials**
 - ❑ **Autos, aircraft, electronics are international businesses, so affects US manufacturers**

Drivers and barriers

Drivers

- ❑ **Environmental and worker safety**
- ❑ **Regulatory cost**
- ❑ **Legal risk**
- ❑ **Performance**
- ❑ **Life-cycle cost**

Barriers

- ❑ **Process cost**
- ❑ **Complexity**
- ❑ **Approval and adoption cost (esp. aerospace)**

The No-bull Prize

Environmental concern is
a driver for change

but when the chips are down

acceptance is driven by
cost
performance
reliability



What does Cd do?

- ❑ **Sacrificial coating**
 - **Galvanic cell with substrate corrodes coating**
 - **Protects even if scratched**
 - **Can be deposited by bath or brush plating**
 - **Must be chromated for aerospace use**
- ❑ **Therefore a simple barrier coating does not replace Cd**

General Cd coating requirements

- ❑ **Thin (<0.001"), smooth (no refinishing)**
- ❑ **Corrosion resistance B117 2,000 hrs**
- ❑ **Low fatigue**
- ❑ **Low embrittlement**
- ❑ **ODs and IDs**
- ❑ **Proper torque (fasteners)**
- ❑ **Low impedance (connectors)**
- ❑ **Good process control**
- ❑ **Fit with OEMs, depot and field repair**

Cadmium replacement requirements

Components

- ❑ The “cure-all” corrosion coating
- ❑ Good salt spray and scribed corrosion protection
- ❑ No hydrogen embrittlement or stress corrosion cracking
- ❑ ODs and IDs



Fasteners

- ❑ Correct lubricity (avoid changes to torque-tension specs)
- ❑ No hydrogen embrittlement
- ❑ Retain thread profile

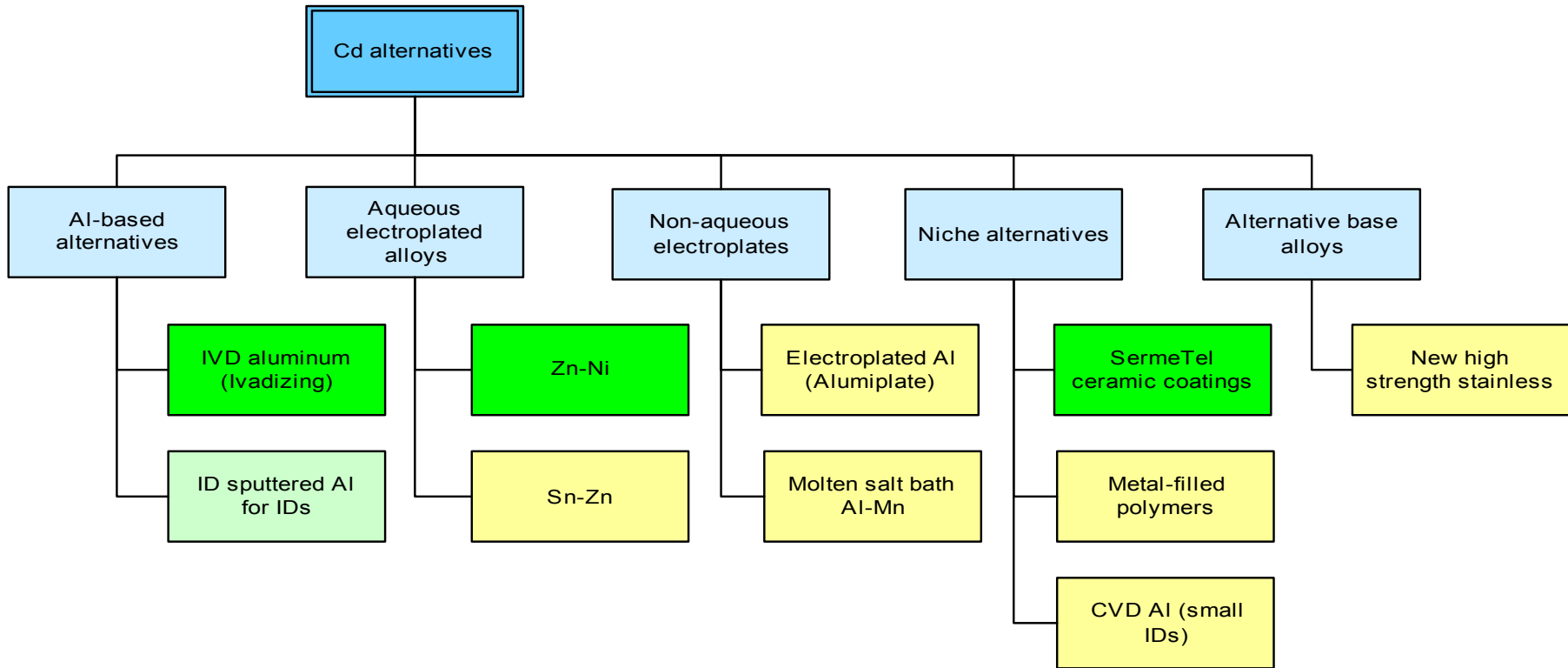


Connectors

- ❑ For electrical equipment
- ❑ Solderable
- ❑ Low contact resistance
- ❑ Non-insulating corrosion products



Cad alternatives



**Al is the only “global” replacement
Almost everything needs chromate conversion**

Aqueous electroplates - Zn-Ni, Sn-Zn

❑ Pros

- Tank methods
 - ❑ **Closest to drop-ins**
 - ❑ Large body of available data
 - ❑ Currently under some of the most serious evaluation - Boeing
 - ❑ WR-ALC has replaced Cd with Zn-Ni and IVD
 - ❑ Good throwing power
- Usually less expensive than dry methods
- Can be brush plated
- Can be done on ODs and IDs

❑ Cons

- Larger waste volumes than dry methods
- Alloy plating can be tricky since chemistry usually depends on solution chemistry and current density

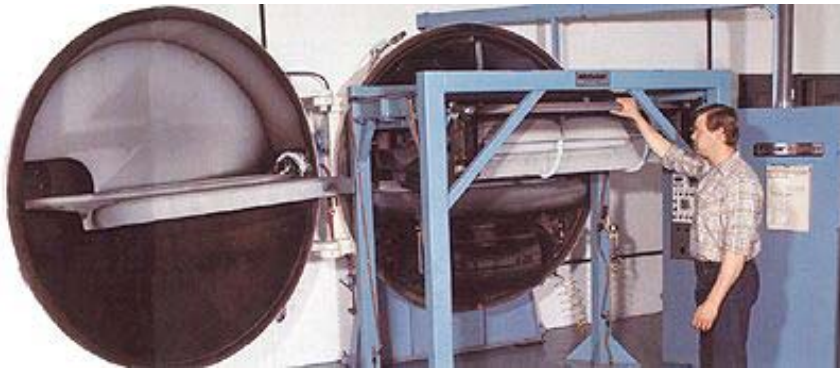
❑ Status

- Zn-Ni already in use
 - ❑ Boeing Pat # 4,765,871
- Sn-Zn being sold for brush plating

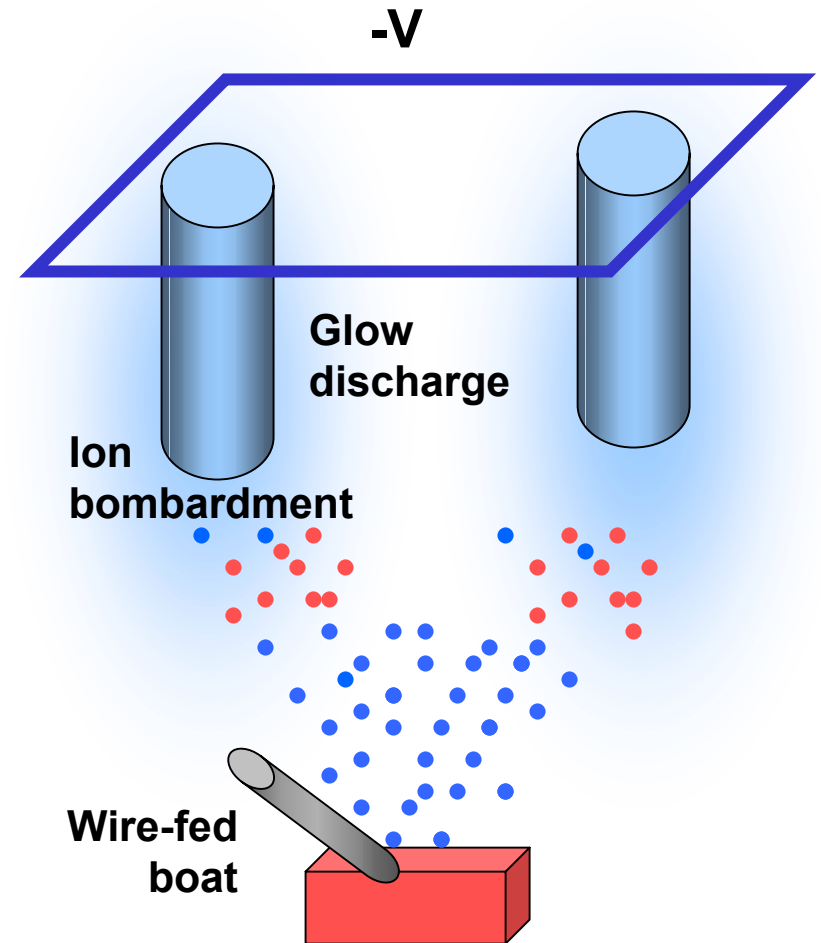
Aluminum coatings

**Al is the closest thing to a “drop-in”
material alternative to Cd**

IVD Aluminum



- ❑ **Developed by McDonnell in 60's**
 - now sold by Abar Ipsen
- ❑ **70+ installations worldwide**
- ❑ **Aerospace qualified:**
 - MIL-DTL-83488
 - Douglas DPS9.22
 - McDonnell Douglas PS 13143
 - Bombardier MPS 160-43
 - SAE AMS 2427



IVD Aluminum

❑ Process

- Plasma sputter clean
- Vacuum evaporate
- **Bead blast to densify**
- **Chromate convert** for best corrosion resistance (MIL-C-83488 Type II)

❑ Pros

- Clean - no wastewater
 - ❑ except aqueous cleaning and chromating
- Years of successful use
 - ❑ primarily for components, not fasteners, connectors

❑ Cons

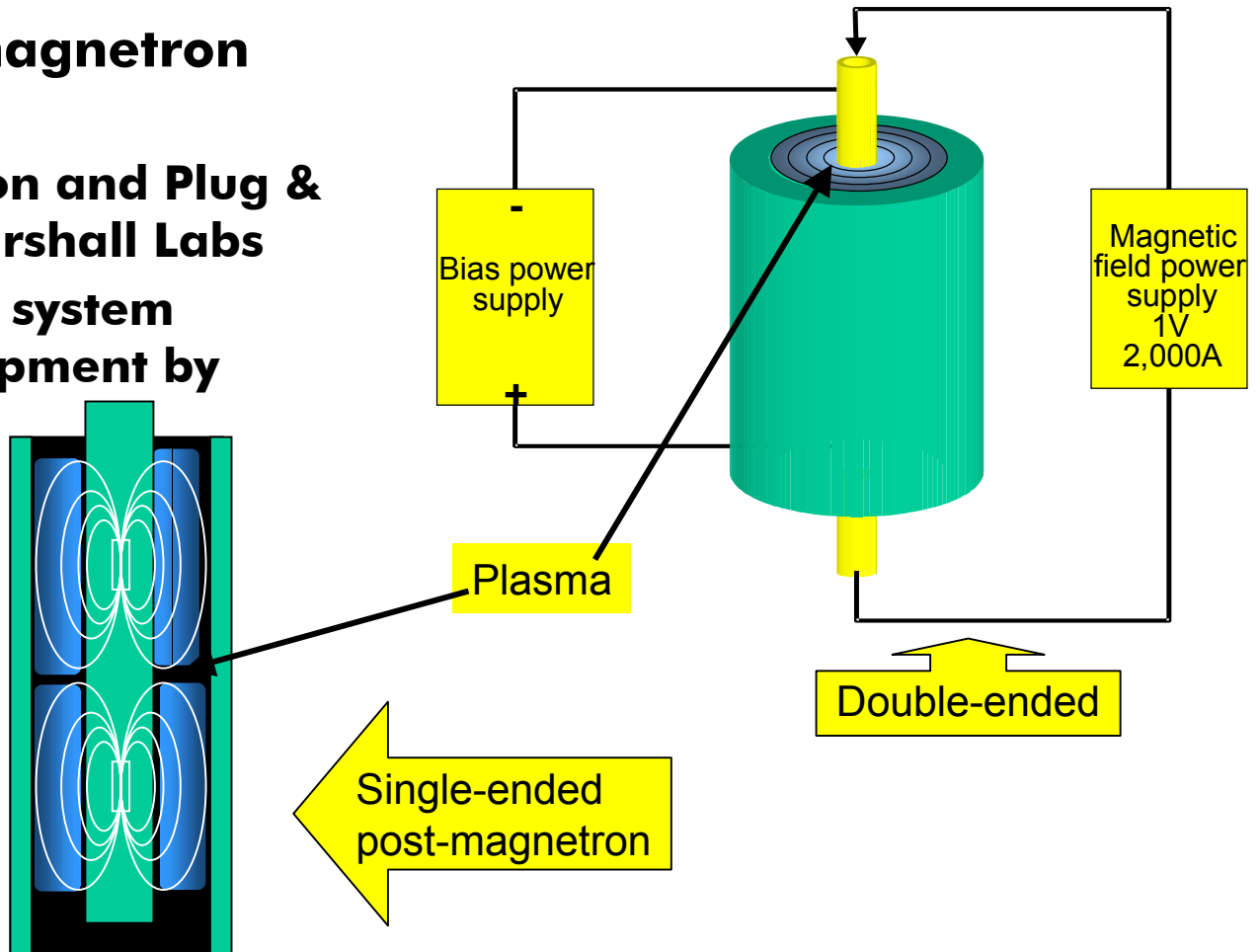
- Vacuum process
 - ❑ always relatively complicated and expensive
- Poor throwing power
 - ❑ not good for IDs
- Connectors
 - ❑ difficult to solder
- Fasteners
 - ❑ needs solid lubricant

❑ Status

- Commercially available
- Aerospace qualified

Recent improvements Sputtered aluminum for IDs

- ❑ **New types of magnetron equipment**
 - **rod magnetron and Plug & Coat from Marshall Labs**
 - **external field system under development by Cametoid**

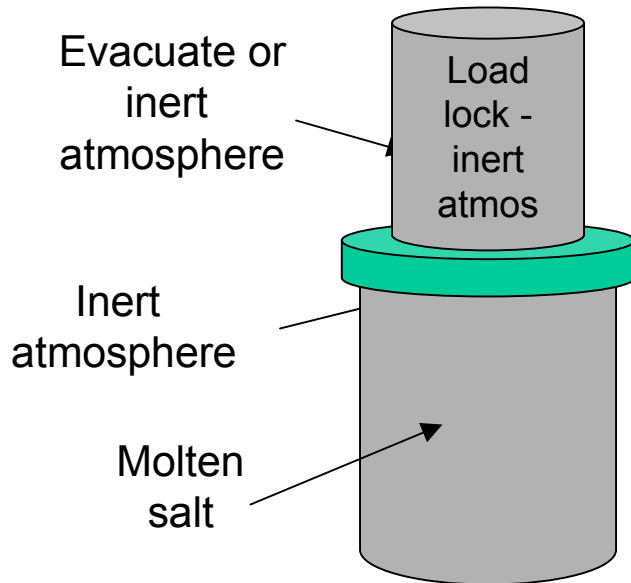


ID sputtering

- ❑ **Meets MIL-83488 (Report # BOEING-STL-01P0041)**
 - **Better coating quality than IVD**
 - **higher plasma density**
 - **lower porosity**
 - ❑ **no need for shot blast**
 - ❑ **may be able to get away without chromating**
 - **Only uncertainty is environmental embrittlement**
 - ❑ **testing issues**
 - ❑ **not part of MIL spec**
 - **All Al coatings require use of proper aqueous cleaners (avoid alkaline cleaners)**

- ❑ **Makes it possible to coat OD and ID simultaneously Plug & Coat**
 - **Add-on to existing IVD chamber**
 - **available to DoD and contractors from Steve Gaydos, Boeing St Louis**
- ❑ **Being installed at Hill AFB**
- ❑ **Status**
 - **Just becoming commercially available**
 - **Meets MIL Spec.**

Non-aqueous electroplates - molten salt bath Al-Mn



Pros:

- Good corrosion resistance
- No H embrittlement

Cons:

- Requires enclosed tank
- Temperature too high for Al alloys (including Al connector shells)
- Residual salts can cause environmental H embrittlement
- Plating chemistry uniformity

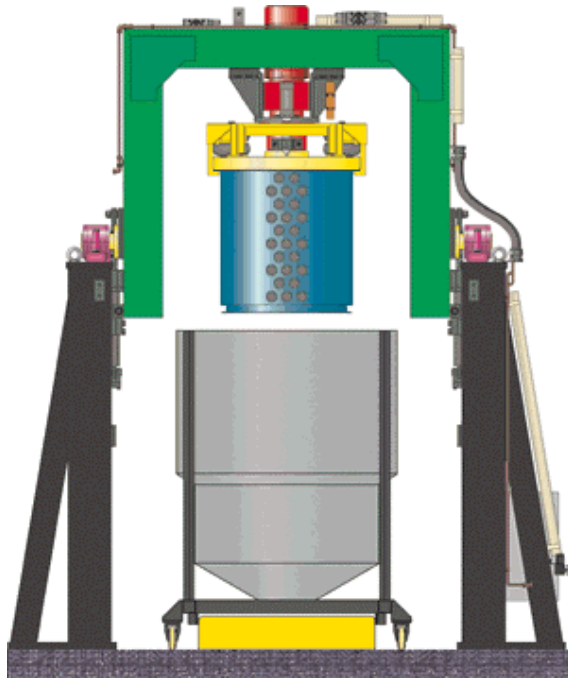
Electroplating from molten AlCl_3 ,
 MnCl_3 bath 350 F

NAVAIR-PAX

Stage of development:
Dem/val (ESTCP program)

Non-AI methods

Metal-filled polymers for fasteners



Dip-spin or spray
Al- or Zn-filled PTFE or epoxy

Many vendors

Pros:

Inexpensive
Wide automotive use
No embrittlement
Fared very well in TACOM tests

Cons:

Process control
Tends to fill threads
What about lightning strikes?

Stage of development:

Commercial
Wide automotive use

**Works like washing
machine/spin-drier**

Niche processes

❑ Al-filled ceramics (SermeTels)

- **Used in aircraft engines, some usage on landing gear**
- **Used for Cd alternative on F-22**
- **Expensive, sole supplier**
- **Requires heat treatment**
- **Some issues with embrittlement with recent formulations**

❑ Thermal spray Al, Zn, Al-Zn

- **Widely used for bridges radar/radio towers, infrastructure**
- **Small usage as Cd alternative for landing gear**
- **Coatings thick and rough**

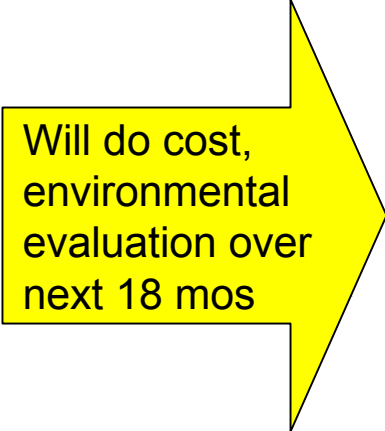
Forget all this coating stuff - just use a better alloy

- ❑ Traditional alloy design very slow and expensive
- ❑ New computational method (QuesTek Innovations, LLC)
 - Materials by Design approach
 - Designing stainless steel with essentially the same mechanical properties as 300M
 - ❑ Drop-in replacement
 - Designer alloys can be made quickly and efficiently (months instead of years)
 - ❑ Greatly reduced time-to-market and cost for design
- ❑ New stainless landing gear steel being developed under SERDP and ALGLE funding
 - **Properties in 300M envelope**
- ❑ More efficient steels
 - Lower alloying (Cr) and carbon percentages
 - Designed properties for better performance
- ❑ Reduce or eliminate hydrogen embrittlement and stress corrosion cracking
 - **Primary landing gear failure mechanism**

Modern methods may make designer steels cost-effective even for niche applications

New steels - on the other hand

- ❑ **Previous stainless steels suffered pitting corrosion**
 - **Not yet known whether these will do same**
 - ❑ **Initial data suggest not**
- ❑ **Will corrode Al alloys**
- ❑ **Cost of qualification may be higher than for a coating**
 - **To be determined**
 - **Designers/users must feel comfortable with the steel itself**
 - ❑ **On other hand, if bulk properties look good, avoidance of coatings could reduce testing**



Will do cost, environmental evaluation over next 18 mos

- ❑ **Makes sense for new designs - what about legacy systems?**
 - **Landing gear O&R appear willing to replace existing 300M gear**
 - ❑ **avoids scc - major failure mechanism**
 - ❑ **probably better damage tolerance**
- True drop-in would presumably be acceptable for other components**
 - ❑ **likely to be used mainly for b.e.r. items (if it ain't broke, don't fix it)**

Decision metrics - the Technology Assessment Matrix

- ❑ **Technology Assessment Matrix method developed for Joint Strike Fighter program**
 - **What technology alternatives are out there?**
 - **What will make technical and logistical sense?**
 - **Which options are close enough to production either**
 - ❑ **for OEM use?**
 - ❑ **for MRO use a few years down the road?**
 - **What are the **critical gaps****
 - ❑ **What time, money, resources will it take to bring to production?**
- ❑ **Method can be applied to any technology, material, etc., - even software**
- ❑ **Purpose is to replace hand-waving and intuition with quantitative logic**

Choosing the best option for the application

- Technology Assessment Matrix

What are the engineering and fit requirements?

How well does the new process meet these requirements?

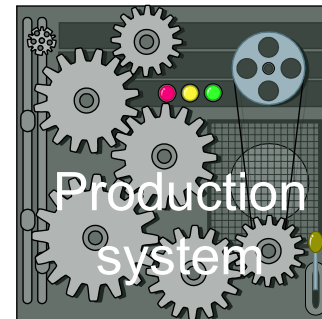
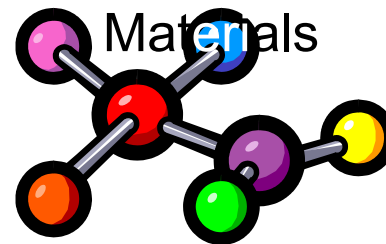
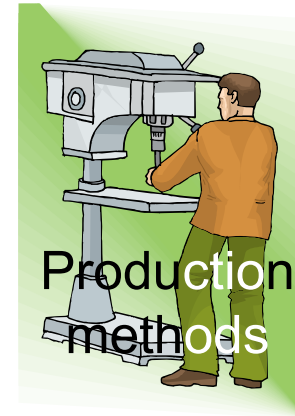
What are the production steps in the new process?

How well developed is each production step?

Where are the gaps?

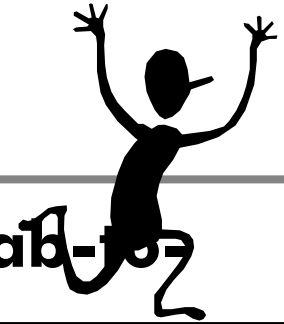
What are the costs to production?

Technology Assessment Matrix - Assessing a new technology

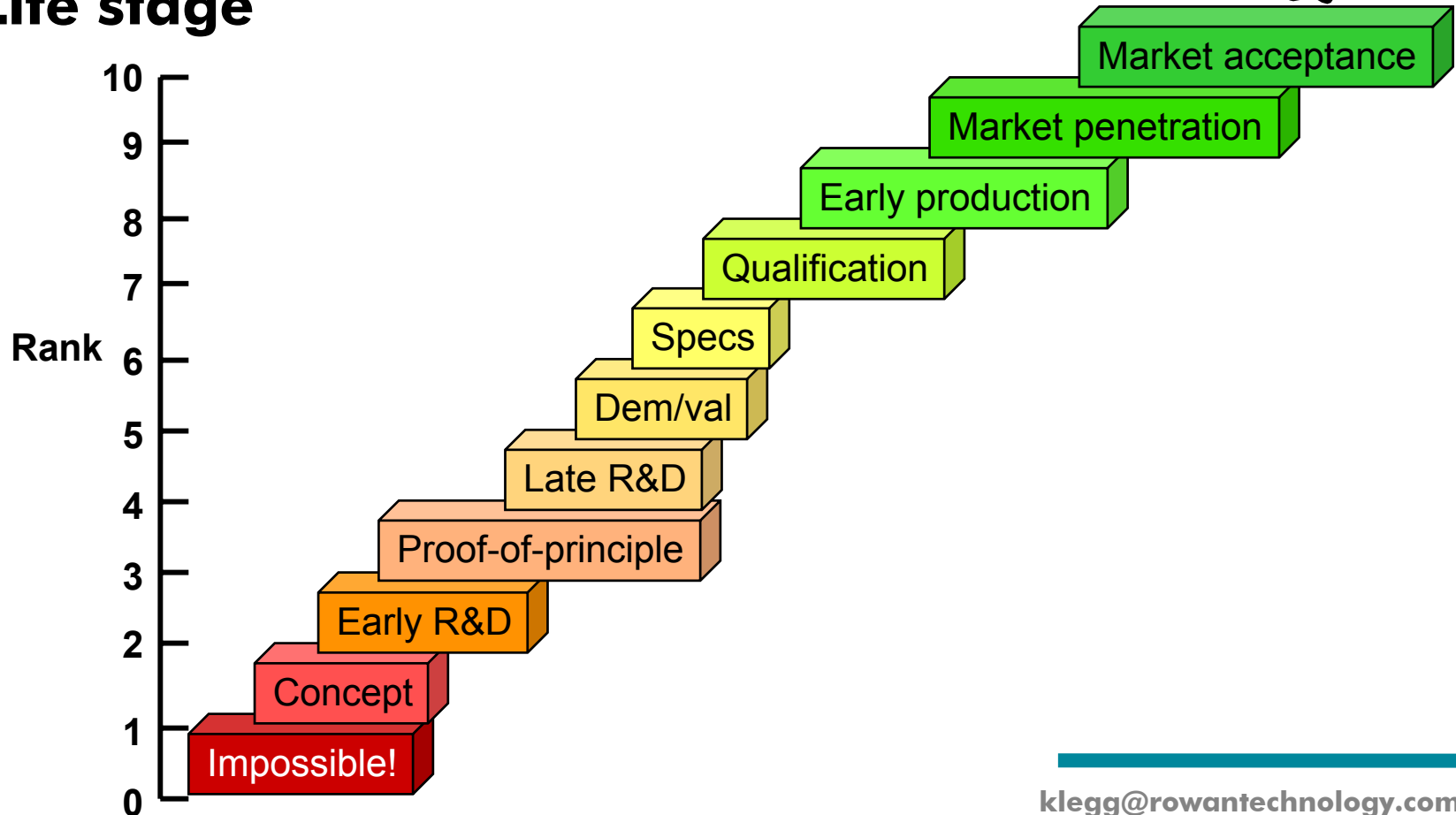


- ❑ What is critical to each process step?
- ❑ How advanced is the technology for each step?

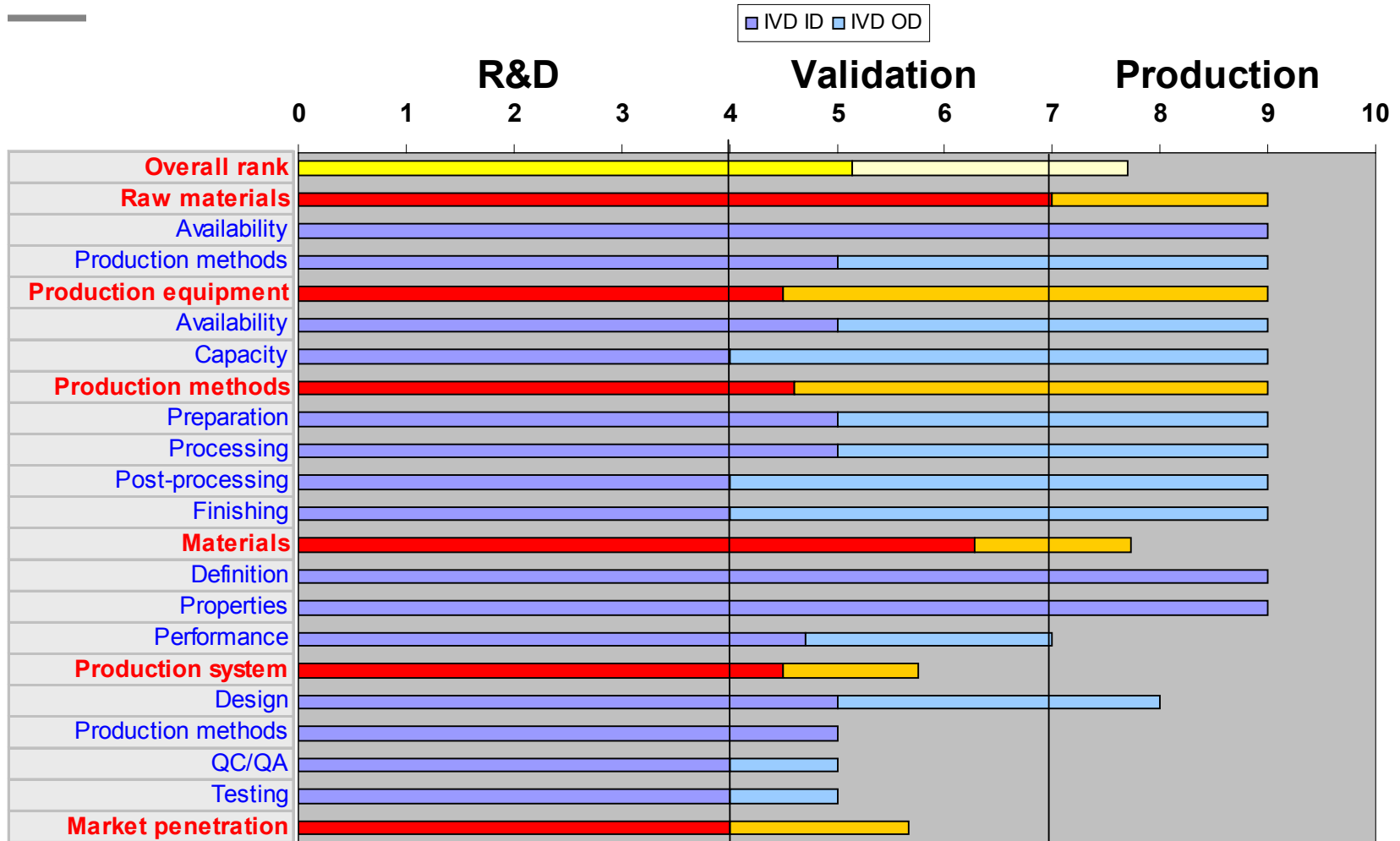
Technology Assessment Matrix - Semi-objective criteria



- Objective milestones used to decide on Lab-to-
Life stage



Technology Assessment Matrix - IVD AI



Summary

- ❑ **Al is “general alternative”**
- ❑ **Only methods widely and commercially available and approved right now are**
 - **IVD Al**
 - **SermeTel**
- ❑ **Zn-Ni and Sn-Zn electroplates are most developed of other alternatives**
- ❑ **Non-aqueous Al and Al-Mn**
 - **under development and test**
- ❑ **Niche options**
 - **thermal spray**
 - **metal-filled polymers**
 - **designer alloys**