

Review of Cadmium Alternatives

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Background of the work

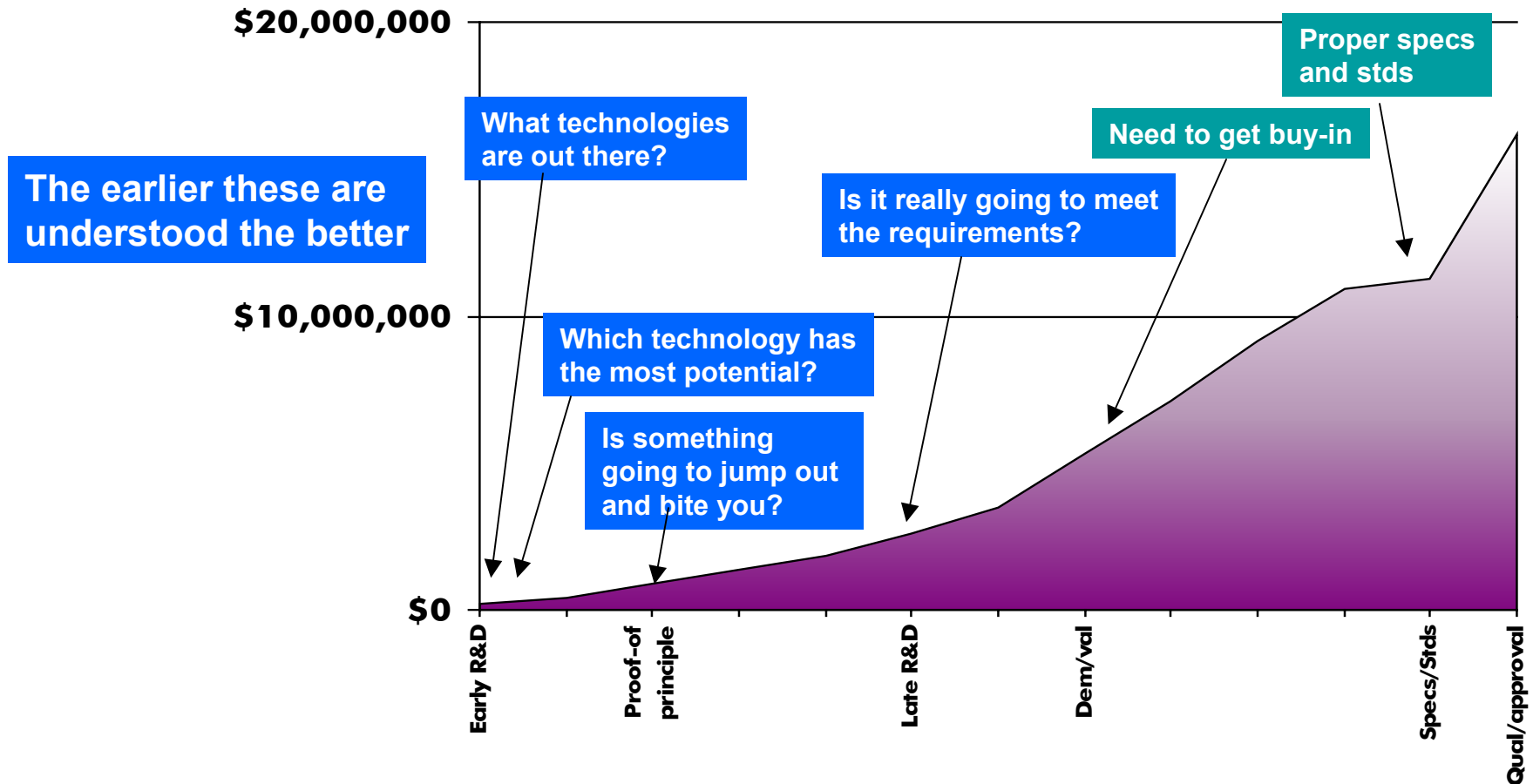
- ❑ **Funding source - JSF IPT, NADEP Jacksonville**
- ❑ **Concern is to avoid Cd, Cr, VOCs on the JSF**
 - **only possible if there are viable alternatives**
- ❑ **Follows from prior work on ID chrome alternatives**
 - **Current SERDP projects on plasma spray, electrospark deposition, non-Ni nanocrystalline electroplates**
- ❑ **Purpose is to make recommendations on most viable alternatives based on existing data and current work**
- ❑ **Work is in progress**

Cadmium replacement teams/programs

- ❑ **Boeing JG-APP**
- ❑ **(Michael Kane, NAWC) Joint Cadmium Alternatives Team, Al-Mn**
- ❑ **Canadian Cadmium Replacement Program (CCRP)**
- ❑ **REFOCUS Program (AEA Technology, European)**

FYI

Getting technology from lab to life



Technology Analysis

❑ Technology analysis

- Review work currently under way
- Identify alternatives
 - ❑ including alternatives not currently being considered
 - at various stages in the development cycle
- Assess status using **Technology Assessment Matrix** method
- Evaluate suitability and fit for OEM and O&R based on data and requirements

❑ Various options will be discussed at this meeting, especially electroplating methods

- Rather than repeat we will concentrate on less well-known options for this paper

Technologies examined

❑ **Electroplating methods**

Electroplates

- **Zn-Ni (acid and alkaline)**
- **Sn-Zn**
- **Al-Mn**
- **Electroplated Aluminum (Alumiplate)**

❑ **Dry coating methods**

Everything else

- **IVD Aluminum and other PVD methods**
- **CVD aluminum**
- **Thermal spray aluminum**
- **SermeTels (Al-ceramics in binders)**
- **Metal-filled polymers**

❑ **New stainless steels**

Assessment of development status

- ❑ **Looks at all requirements for successful application and ranks by development stage**
 - **Raw materials**
 - ❑ availability, production
 - **Production equipment**
 - ❑ availability, capacity
 - **Production methods**
 - ❑ preparation, processing, finishing
 - **Materials**
 - ❑ definition, properties, performance
 - **Production system**
 - ❑ design, methods
 - **Market penetration**

Note: This says how well developed it is, not how well it works

Same approach being adopted for ranking fit and function

Technology Assessment Matrix - definitions

Rank	Description	Specific milestones
0	Not possible with reasonable manufacturing approach	Fundamental reason why it cannot be done
1	Initial concept	Initial concept with backup reasoning
2	Early R&D - basic methods and properties developed	Demonstrated lab production, initial data
3	Proof-of-principle	Demonstrated lab production - equipment design viable, performance requirements appear attainable
4	Late R&D - advanced methods and performance measured	Demonstrated lab scale; acceptable performance in most critical areas; no show stoppers
5	Production demonstration/validation	Demo'd full scale; full data sets obtained; acceptable performance in all critical areas
6	Specifications and standards issued - general or specific (e.g. Boeing)	General specs or standards issued (AMS, ASTM, etc.) or commercial specs (Boeing, GE, etc.)
7	Qualification/approval	Approved for production
8	Early commercial (< approx 20 part production)	Commercial production of a few (<~20) different items
9	Market penetration	<~10% of market for item
10	Market acceptance	>10% of general market, or well-defined niche

❑ To be adjusted for assessment of critical applications

- **airframe**
- **fasteners**
- **electrical connectors**

Electroplates

❑ Pros

- **Tank methods**
 - ❑ Closest to drop-ins
 - ❑ Large body of available data
 - ❑ Currently under some of the most serious evaluation
 - ❑ Good throwing power
 - ❑ “Fire and forget”
- **Usually less expensive than dry methods**

❑ Cons

- **Larger waste volumes than dry methods**
- **Alloy plating can be tricky since chemistry usually depends on solution chemistry and current density**
- **Non-aqueous methods (Al, Al-Mn) highly reactive with water**
 - ❑ require enclosed, load-locked baths for production

IVD and other PVD methods

❑ Pros

- IVD is a fully commercial process
- Long history of successful use
 - ❑ airframe parts
- Clean process
- High volume chamber (up to 5'x1.5'x15' load)
- Available at many



Abar Ipsen Ivadizer

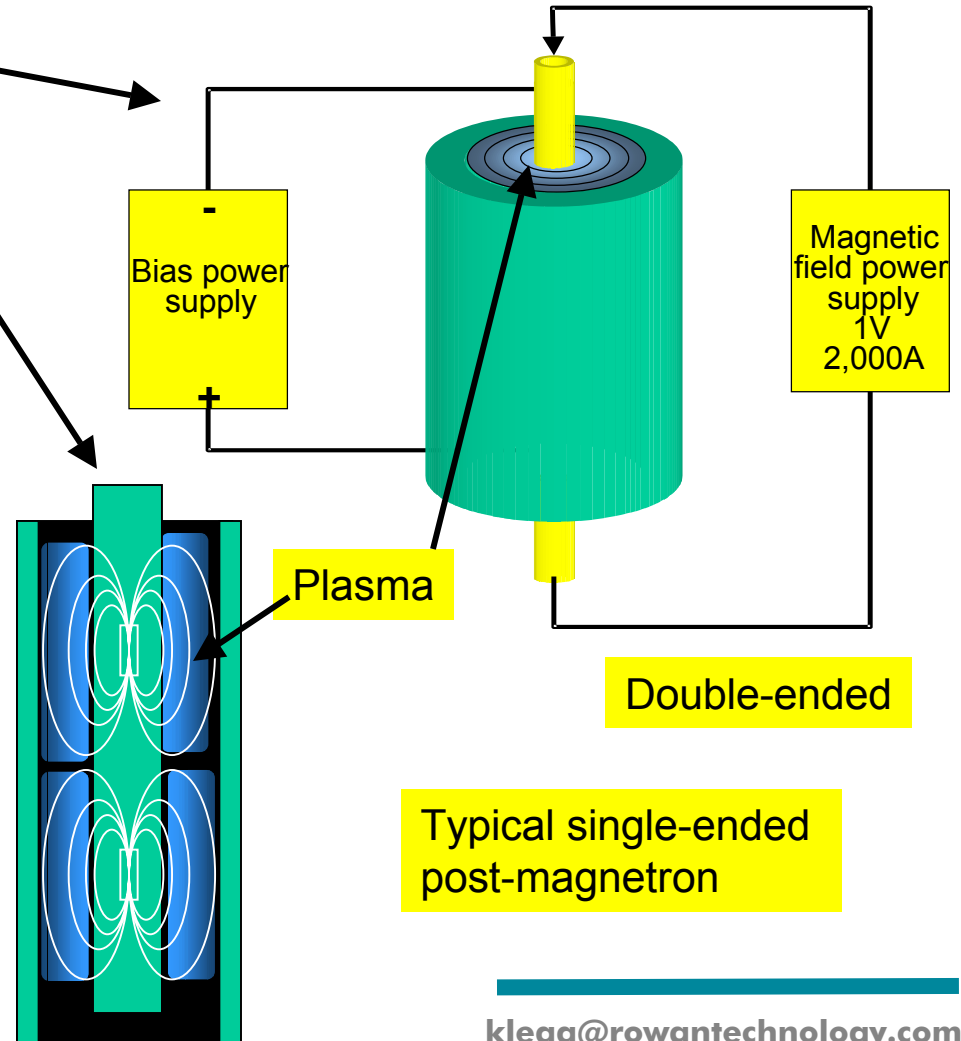
❑ Vacuum processes

- Cost is a primary issue
- ❑ IVD requires shot blasting and chromate conversion
- ❑ Poor throwing power (especially in holes)
- ❑ Solid lubricant for torque-tension
 - must be reliable, reproducible
- ❑ Limited data on some applications
 - electrical connectors
 - fasteners

Sputtered aluminum for IVDs

- ❑ **Green gun barrel (Benet)**
- ❑ **Currently under demo at Boeing, St Louis**
- ❑ **New types of magnetron equipment (rod magnetron, Plug & Coat)**
- ❑ **Better coating quality than IVD**
 - **higher plasma density**
 - **lower porosity**
 - ❑ **no need for shot blast**
 - ❑ **may be able to get away without chromating**

Surface Solutions,
Benet Labs



Sputtered and arc deposited Al for ODs

❑ Sputtering

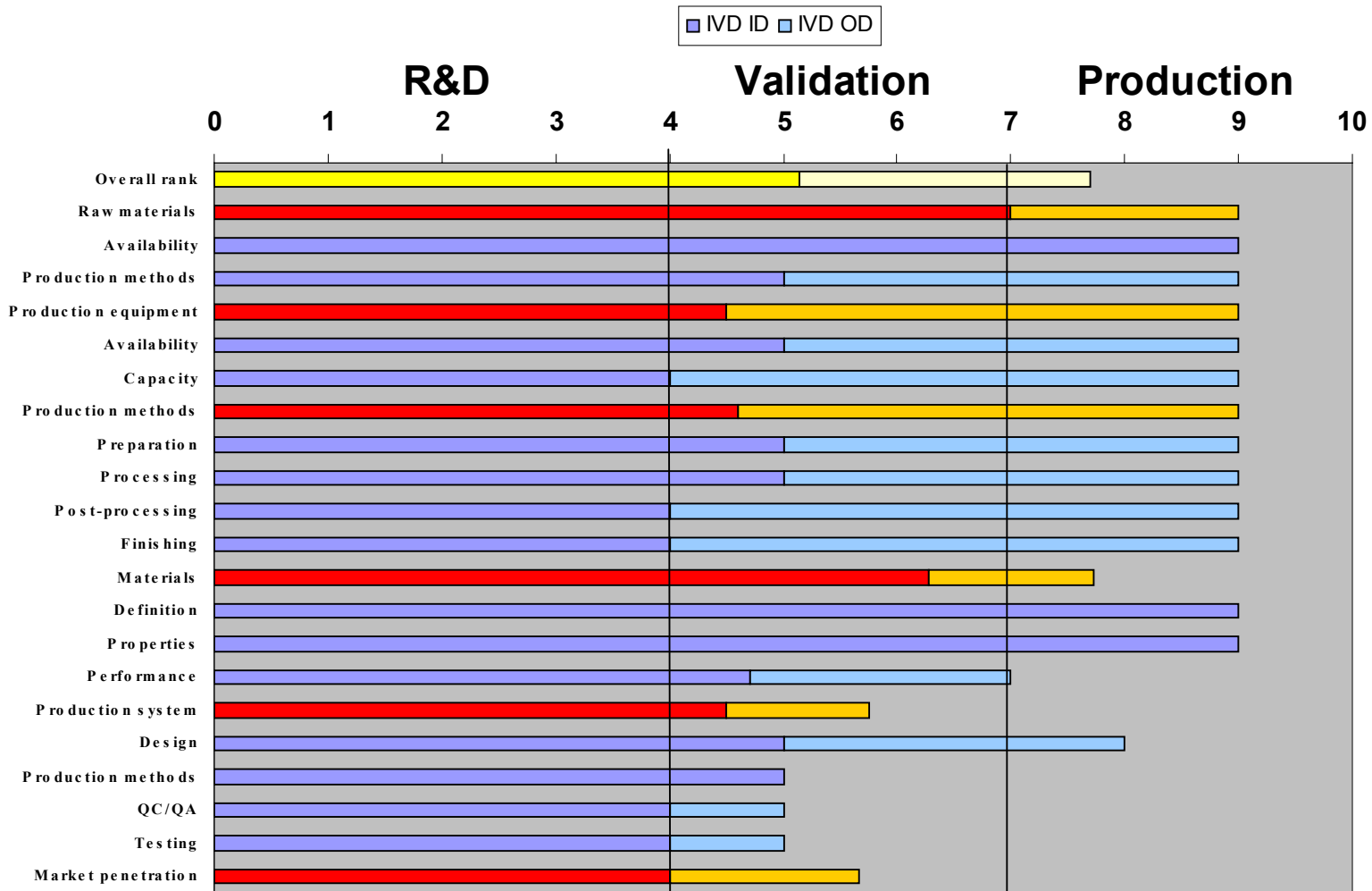
- **Vacuum coating**
- **Highest quality coating**
- **Lowest deposition rate of commonly-used PVD methods**
 - ❑ **most expensive**
- **Low plasma density**
- **Difficult to fill large chamber with plasma, even with unbalance**
 - ❑ **likely to have poor quality coating on large objects**

❑ Arc

- **Vacuum coating**
- **Method used for tools in 1-2 m chambers**
- **Not commercially developed for Al**
- **High quality possible**
- **High deposition rate**
- **High plasma density**
 - ❑ **more likely to fill chamber if properly controlled**

Most PVD methods coating quality, adhesion is temperature sensitive

Technology Assessment Matrix - IVD AI



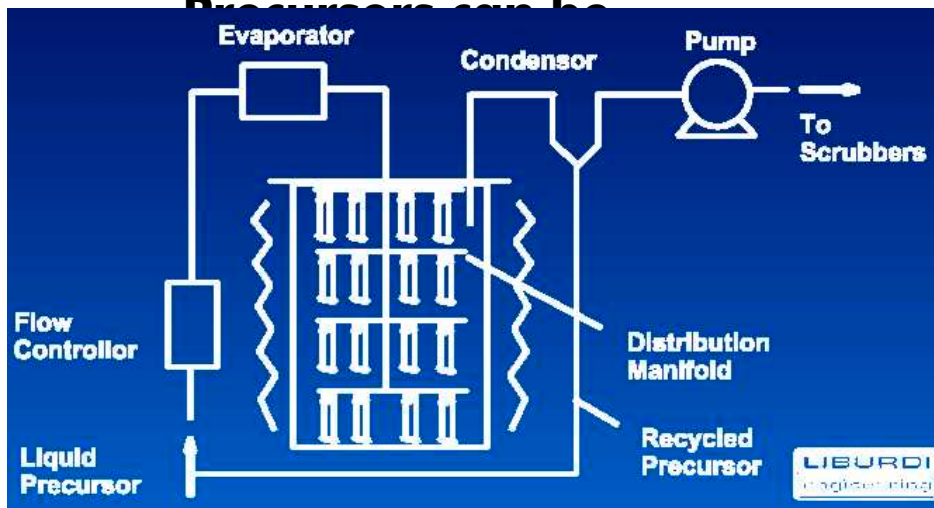
CVD aluminum - Liburdi Engineering

□ Pros

- Simple fixturing (no rotations, etc.)
- Very good throwing power
 - including deep holes
- Can coat with alloys

□ Cons

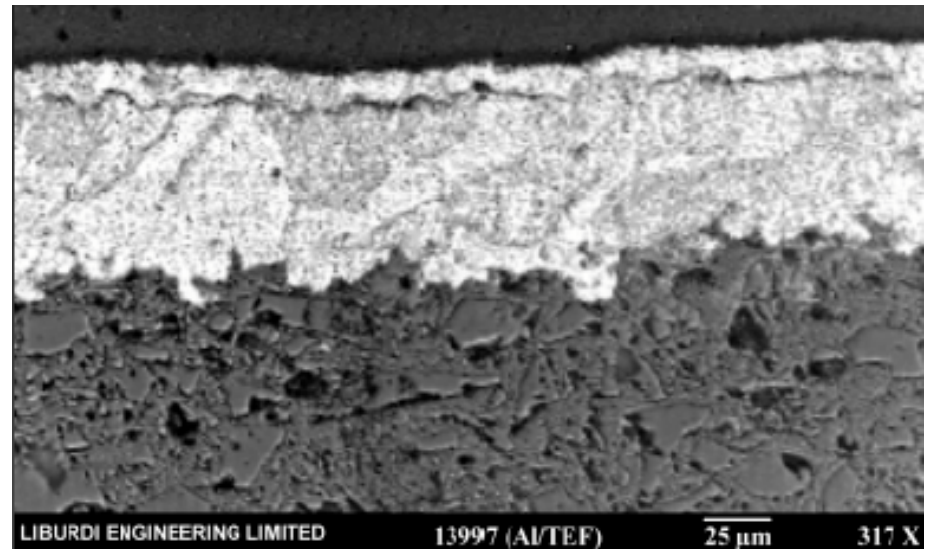
- Metalorganics
 - typically hazardous (flammable, poisonous)
- Relatively high temperatures (500F)
 - Can it be done effectively at 350F?
- Alloys - must balance kinetics



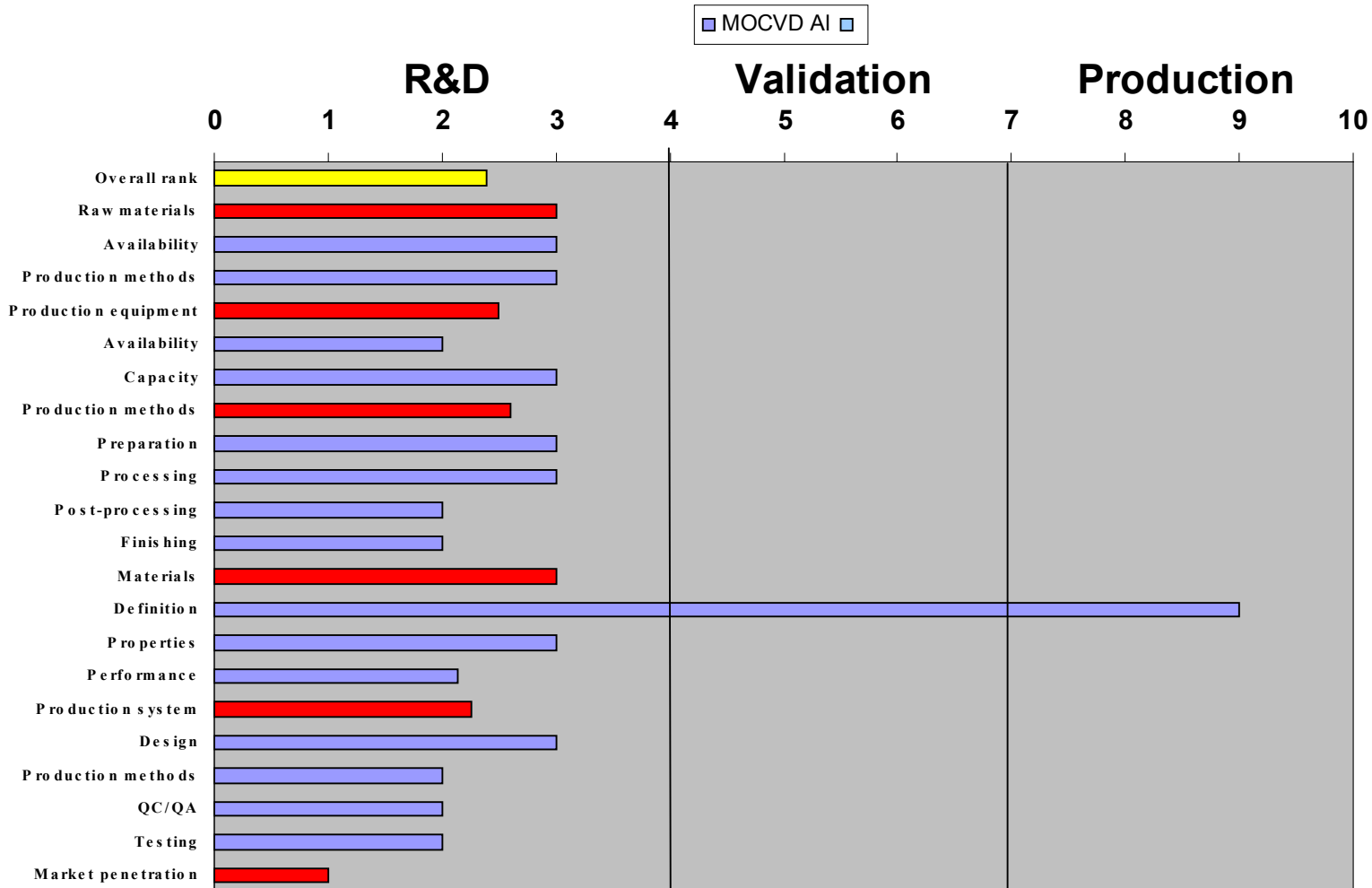
MOCVD Al performance

- ❑ **Very little data yet**
 - **Survived 600 hr B117 (unscribed)**
 - ❑ **Qualified for automotive**
- ❑ **Requires a great deal of data on process limits and performance**

MOCVD coating on Teflon



Technology Assessment Matrix - MOCVD Aluminum



Thermal sprayed Al and alloys

❑ Pros

- Arc and plasma sprayed Al, Al-Zn already used on some landing gear
 - ❑ also used for infrastructure (bridges, etc.) in Europe
- Commercially available
- In-air robotic
- Able to coat large areas

❑ Cons

- **Not for fasteners**
- **Electrical connectors?**
- **Quite thick coating (several mils)**
- **Line of sight**
- **Relatively porous coating**



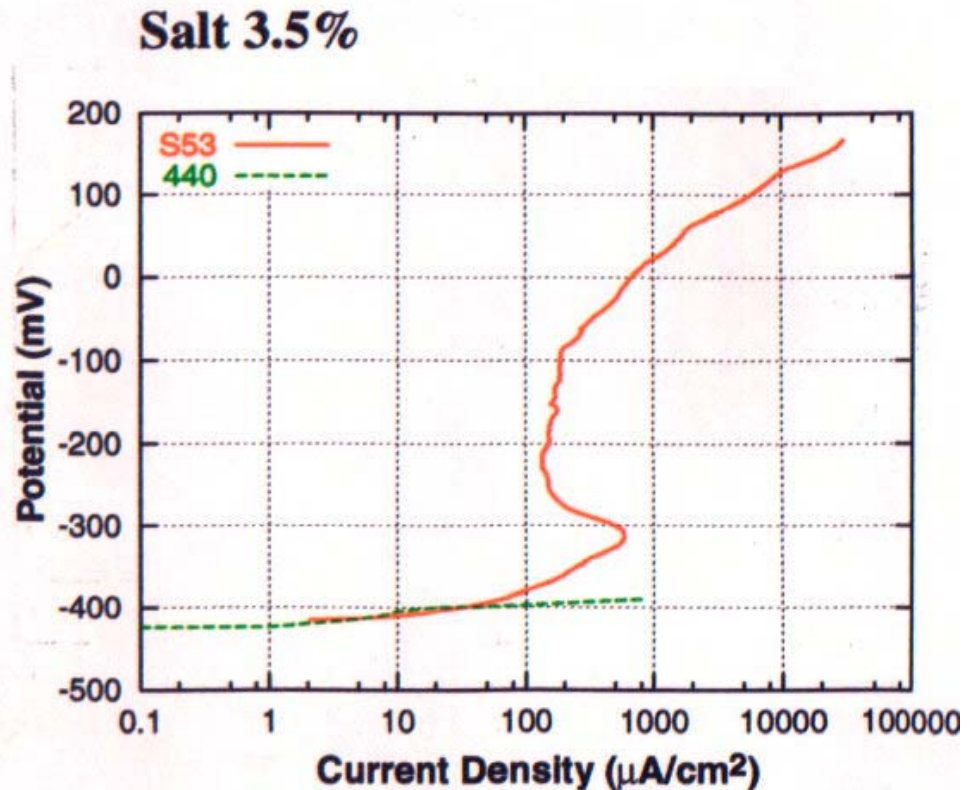
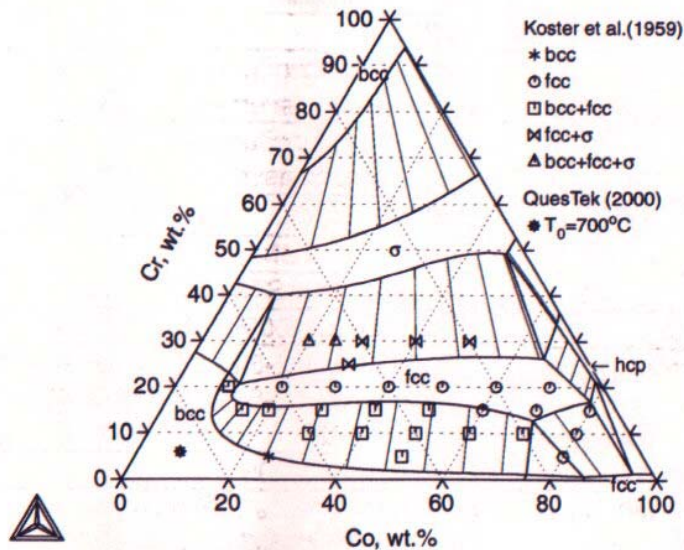
Forget all this coating stuff - just use a decent steel

- ❑ **New computational method (QuesTek Innovations, LLC)**
 - **Materials by Design approach**
 - **Appears possible to design 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**
- ❑ **More efficient steels**
 - **Lower alloying (Cr) and carbon percentages**
 - **Designed properties for better performance**
- ❑ **Reduce or eliminate hydrogen embrittlement and stress corrosion cracking**
 - **Primary failure mechanism for landing gear**

New steels - on the other hand

- ❑ **Previous stainless steels suffered pitting corrosion**
 - **Not yet known whether these will do same**
 - ❑ **Initial data suggest not**
- ❑ **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, provided bulk properties look good, avoidance of coatings could reduce testing significantly**
- ❑ **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)**

New landing gear steel design



Initial design

- Mechanical properties close to 300M
- Passivation (corrosion) looks good

Conclusion

- ❑ **As with Cr, no single solution**
- ❑ **Aqueous electroplates and IVD are furthest along**
 - **new IVD ID methods look promising**
- ❑ **Non-aqueous electroplates**
 - **attractive properties, but much more difficult production**
- ❑ **Thermal spray methods in limited production**
 - **may be viable for wider range of applications**
- ❑ **MOCVD attractive for IDs**
 - **concern over OSH and temperature**
 - **likely to be a niche product**
- ❑ **High strength stainless steel**
 - **out-of-the-box approach to eliminate Cd and SCC**
 - **does not solve parts refurbishment**