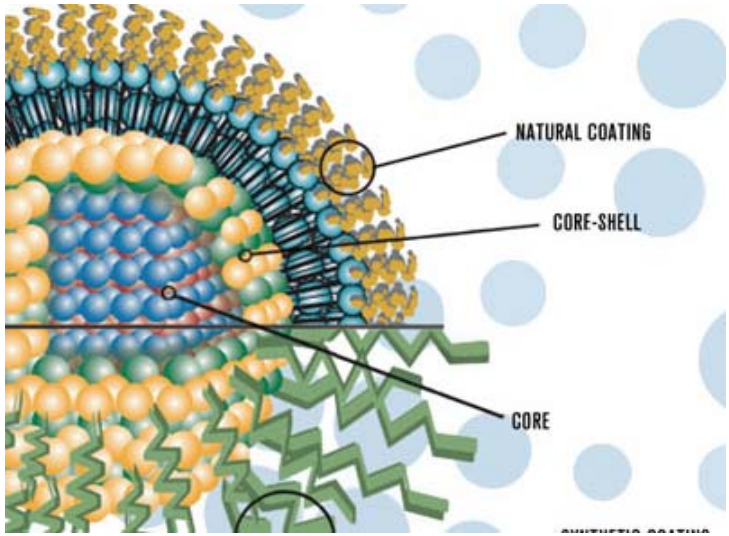

End-of-Life Heavymetal Release from Photovoltaic and Quantum Dot Enabled Panels

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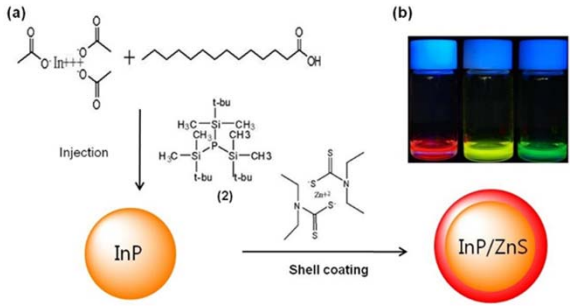
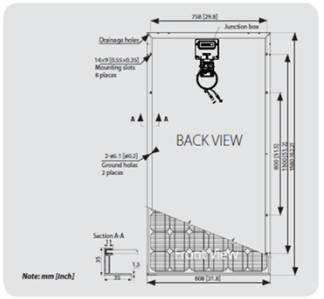
Introduction

- Photovoltaic panels (PVs) and quantum dot displays (QDD) are starting to see increases in commercial and consumer product use.
- Both utilize toxic and/or carcinogenic elements.
  - Cd, Cr, In, Se, Pb, Ag, Zn, Ni, Be…
- Next generation PVs and QDD may employ similar manufacturing process.
  - Use of similar materials
  - Need to protect solar cells/display films leads to product encapsulation
    - Can impact the mobility of elements in both panels and displays





Current-Voltage & Power-Voltage Curve (170W)

Mechanical Characteristics

Solar Cell	Mono-crystalline 125×125mm (5inch)
No. of Cells	72 (6×12)
Dimensions	1580×808×35mm (62.2×31.8×1.4inch)
Weight	15.5kg (34.1lbs.)
Front Glass	3.2 mm (0.13inch) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP65 rated
Output Cables	AIW (12AWG), asymmetrical lengths (-) 1200mm (47.2inch) and (+) 800mm (31.5inch), MC Plug Type IV connectors

Temperature Coefficients

Nominal Operating Cell Temperature (NOCT)	45℃±2℃
Temperature Coefficient of Pmax	-0.48 %/℃
Temperature Coefficient of Voc	-0.34 %/℃
Temperature Coefficient of Isc	0.017 %/℃

Temperature Dependence of Isc, Voc, Pmax

Open Questions and Concerns

- 1st generation products are nearing end of expected life span.
  - Lack of waste classification data.
    - Little information on leachate contaminant concentrations.
    - No USEPA classification as Solid or Hazardous waste per 40 CFR 261.24 subpart D.
- Recycling/reuse options limited.
  - Burgeoning waste stream with little preexisting recycling options.
    - What materials are recoverable?
    - What is the monetary value and does it offset recycling costs?
  - Most PVs are decommissioned once actual power output falls below 80% of rate power output.
    - Are the any applications for PVs after reduction in power output?
  - Why recycle/reuse?
    - Unlike EU, EPA does not regulate PV waste.
    - No regulation > No disposal fine > Low disposal cost > No incentive to recycle
- Lack of environmental impact data.
  - Are contaminant concentrations/mobility sufficiently high to leach into environment if improperly disposed?
    - How is proper disposal dictated without waste classification?
- Next generations of PVs anticipated to be nano-enabled.
  - What can we learn from existing PV and nano-enabled technology about End-of-Life?

LC nano

Goal

- Through End-of-Life (EoL) heavy metal release analysis we hope to:
  - Use QD EoL studies to forecast potential environmental impacts of subsequent generations of PVP
  - Evaluate concerns for Hazardous waste classification
  - Examine if RCRA Land Disposal Restrictions (LDR) Rule may apply

- **Underlying question**: Should we worry that next generation QD enabled PVs could be considered RCRA hazardous waste?

Methodology

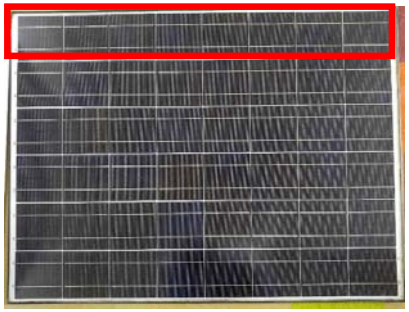
- 3 test methods were used to determine and compare leachable and total contaminant concentrations.
  - USEPA SW846 method 1311, Toxicity Characteristic Leaching Procedure (TCLP).
  - 22 CCR Appendix II (f), Waste Extraction Testing (WET)
    - PVs only
  - USEPA SW846 method 3050,
- TCLP and WET both use weak acid extraction fluids.
  - TCLP- Glacial acetic acid/Sodium Hydroxide (pH~4.93±0.05)
  - WET- Citric acid/Sodium hydroxide (pH~5.0±0.1)
- TCLP/WET procedure are similar with slight variations.
- Analysis performed via Inductively Couple Plasma; OES (PVP), MS (QDD)

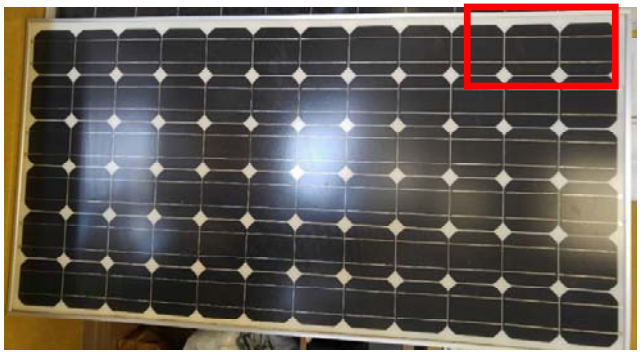
	TCLP	WET
EF to Waste ratio (m/m)	20:1	10:1
Minimum sample size (g)	100	50
Agitation duration (hrs.)	18 ± 2	~48
Filter size	0.7 µm	0.45 µm
Sample purge	yes	no

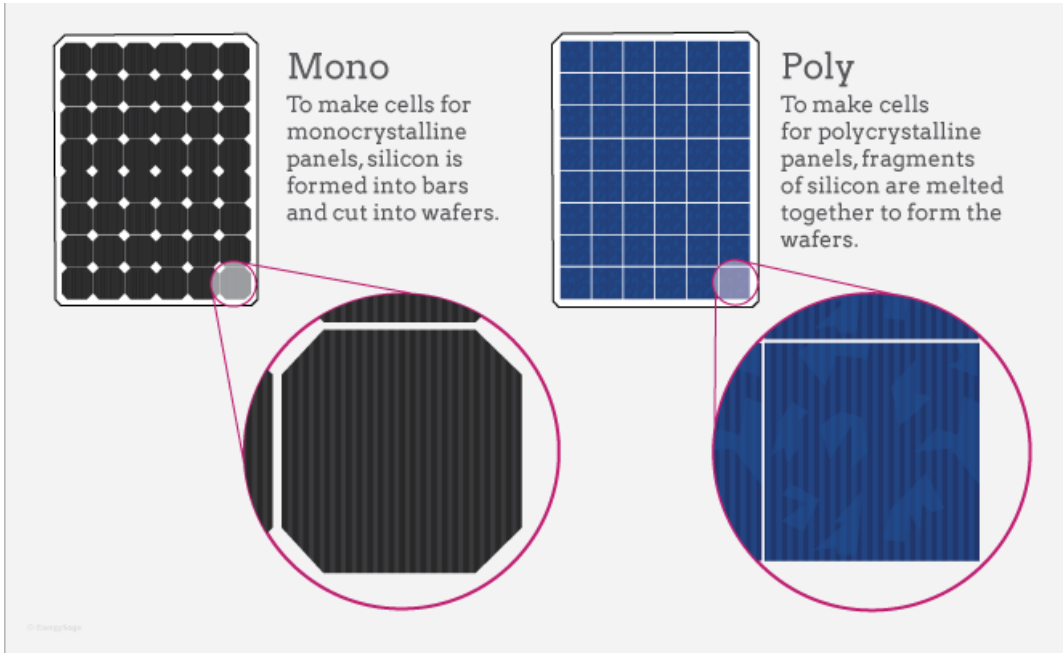
Methodology
PV PANELS

Sharp ND u1673A

Polycrystalline







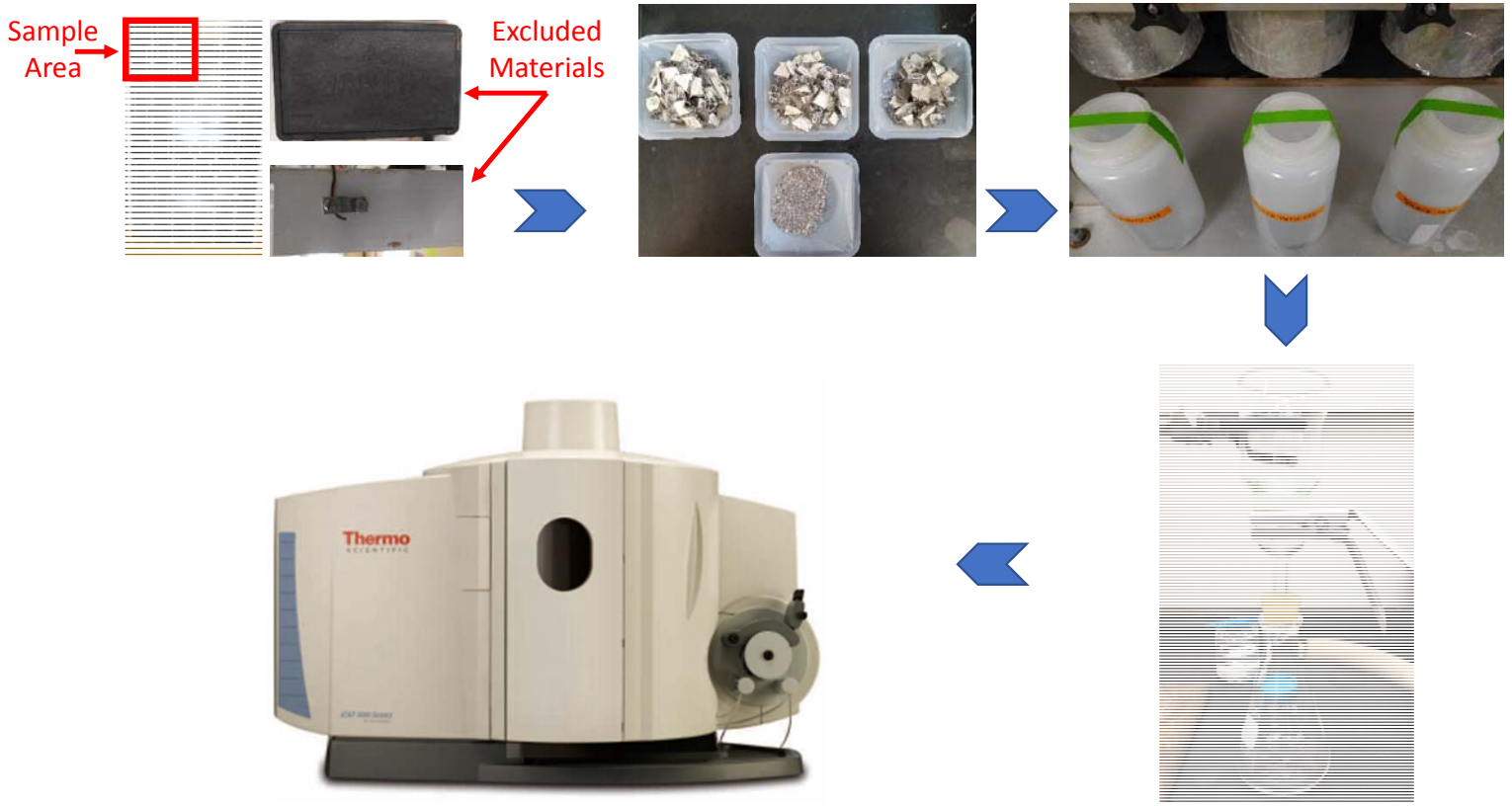
From https://www.energysage.com/solar/101/monocrystalline-vs-polycrystalline-solar-panels/

Sharp NT 175U1

Monocrystalline

Canadian Solar - monocrystalline
Sharp ND167U - polycrystalline
Sharp NE170U - polycrystalline
Sharp NT175 - monocrystalline
Suntech - monocrystalline

Methodology – Leaching and Analysis PV



http://www.nbg.kiev.ua/upload/image/scea/iCAP.pdf

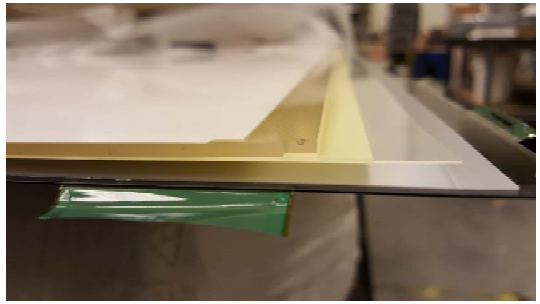
- Determine area/parts for representative sample
  - PV cells, tempered glass, back mounting material
- Sample preparation
  - Particle reduction/solid-liquid separation if needed
  - Needed due to surface to mass ratio < $3.1\ \frac{cm^2}{g}$
- Sample agitation
- Sample filtration and preservation
- Sample Analysis
  - ICP-OES

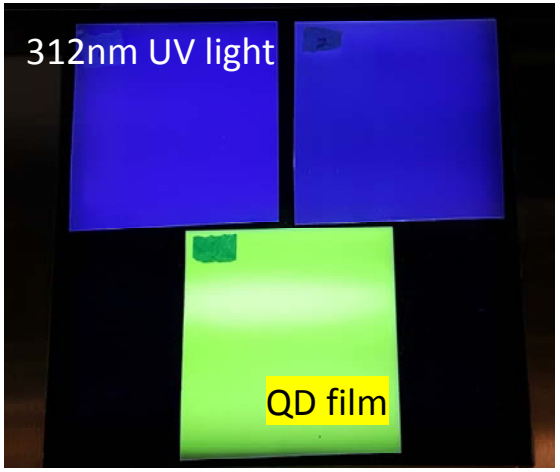
Methodology - QD Displays

Amazon Kindle Fire HDX 7

Both LCD displays use **on-surface QD display technology**, where sheets of QD films cover the entire display area.

Samsung 60" 4K SUHD TV





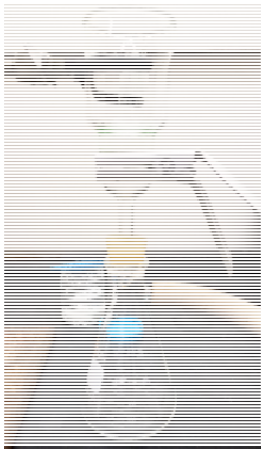
QD enhancement film is identified based on **Fluorescence Properties** under UV light .

Methodology – Leaching & Analysis QD Displays

S1

S2

S3

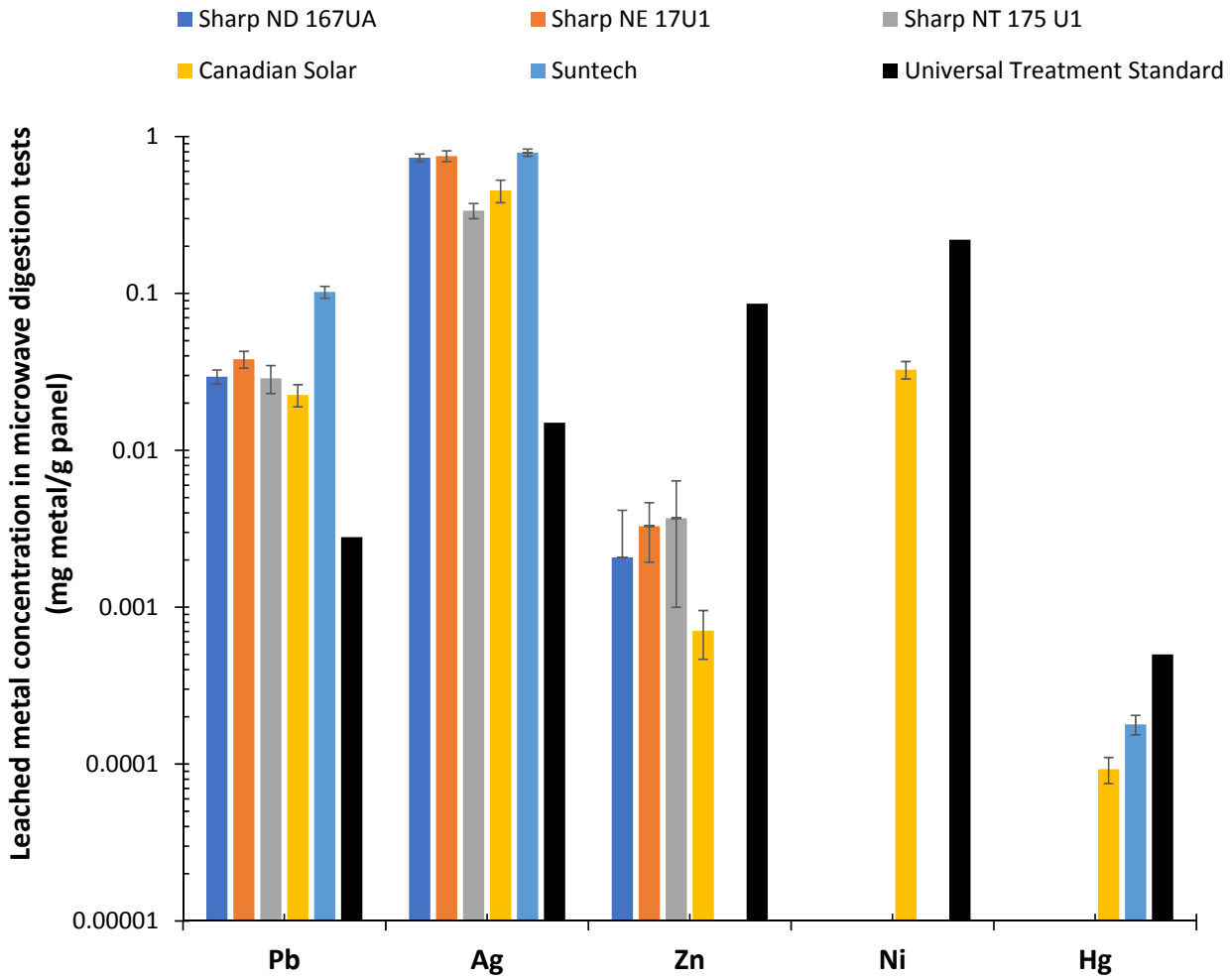


- Determine area/parts for representative sample
  - Set 1 – Film only
  - Set 2 – Digitizer & display
  - Set 3 – Remaining components
- Sample preparation
  - Particle reduction/solid-liquid separation if needed
- Sample agitation
- Sample filtration and preservation
- Sample Analysis
  - ICP-MS

Results
Total Heavy Metal Content
Microwave Digestion

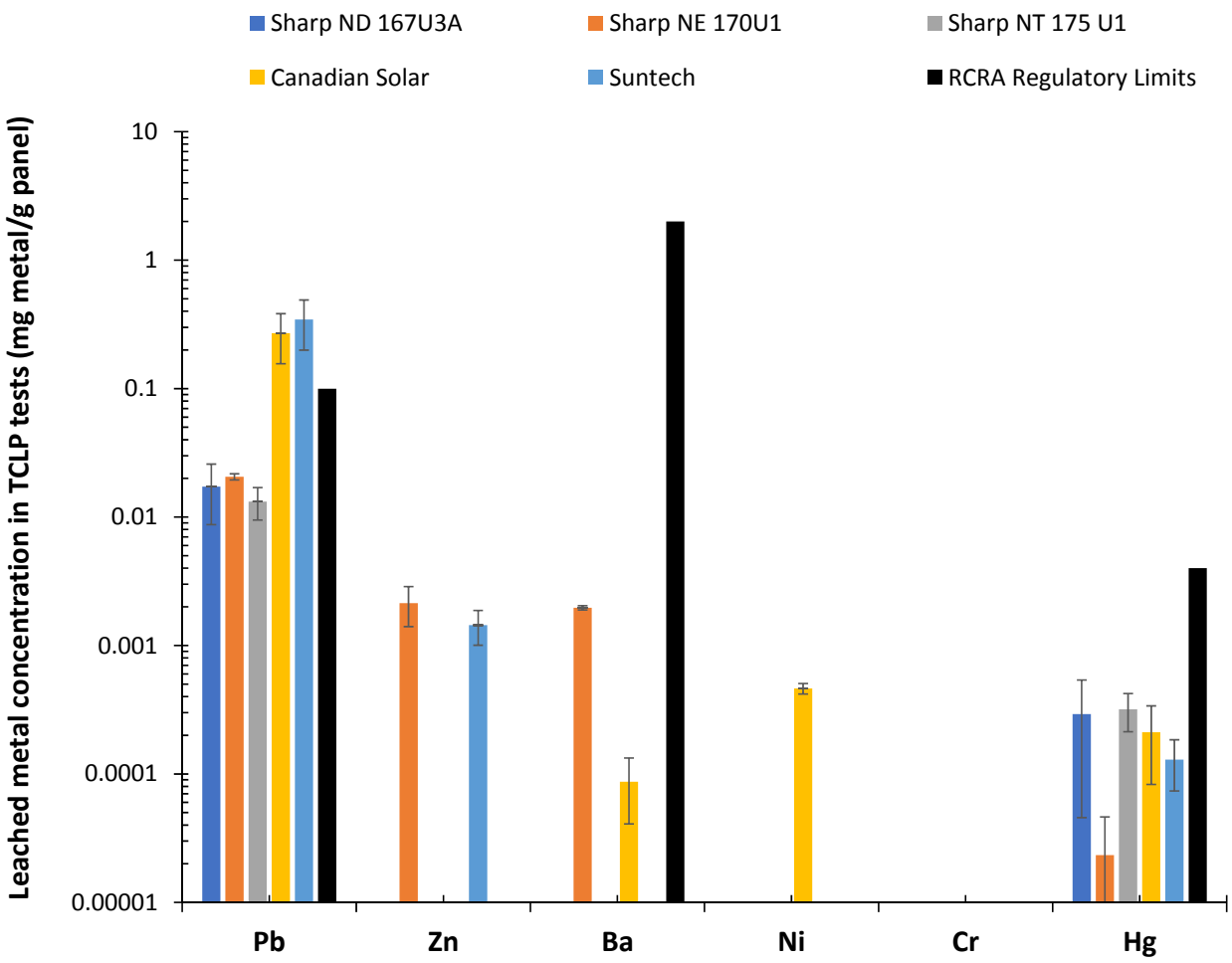
- Many RCRA Characteristic Hazardous waste metals potentially leachable.
  - D008 – Lead*
  - D009 – Mercury*
  - D011 – Silver

  * Possibility to exceed
- Universal treatment Standards
  - Nickel = 11 mg/L TCLP
  - Zinc = 4.3 mg/L TCLP



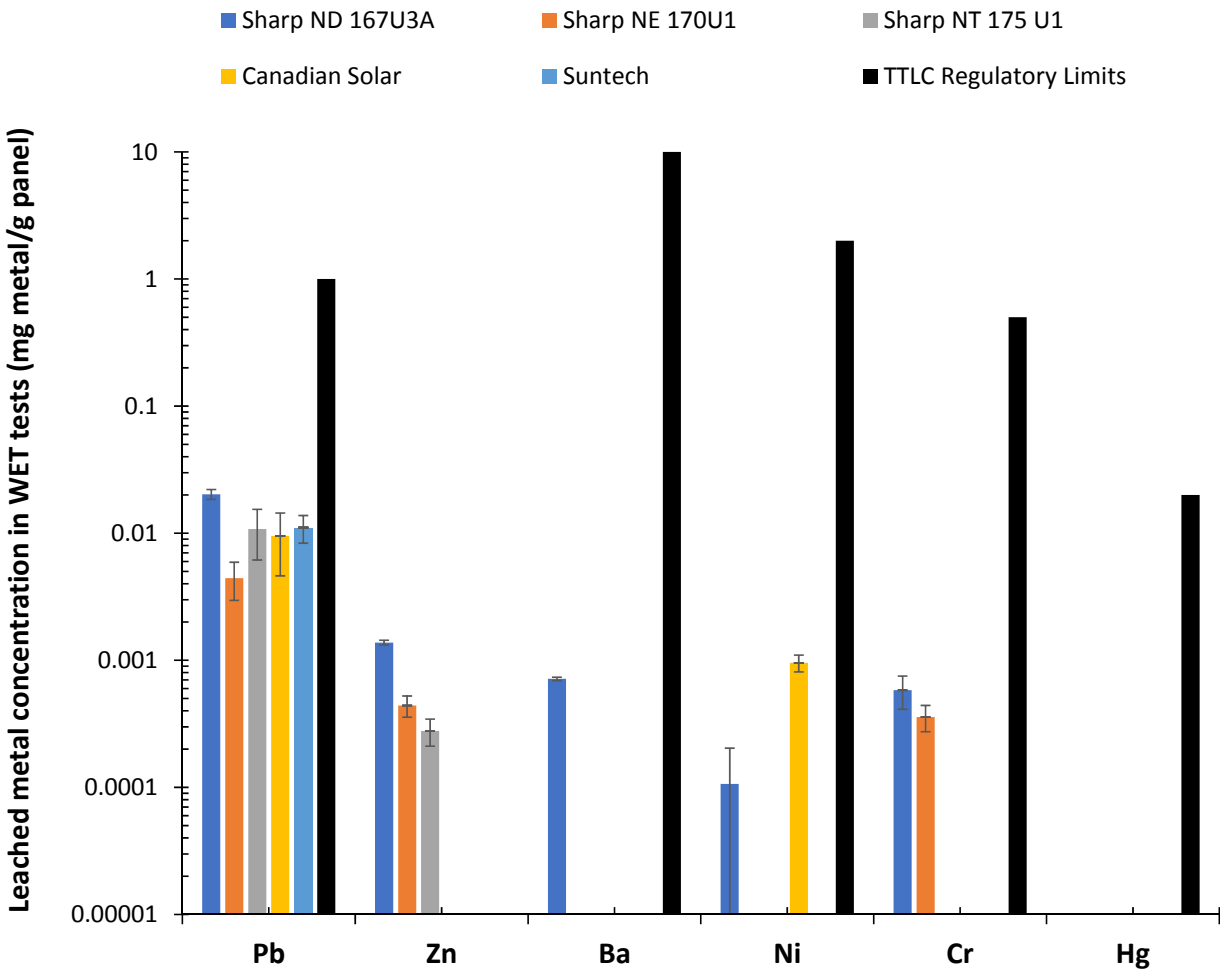
Results TCLP Leached Heavy Metal Content

- 34 elements analyzed,
- only 5 elements detected above MDLs
- Lead
  - only element found in concentrations that exceed RCRA regulatory limits
  - Possible source - soldering
- Nickel,
- Zinc,
- Mercury



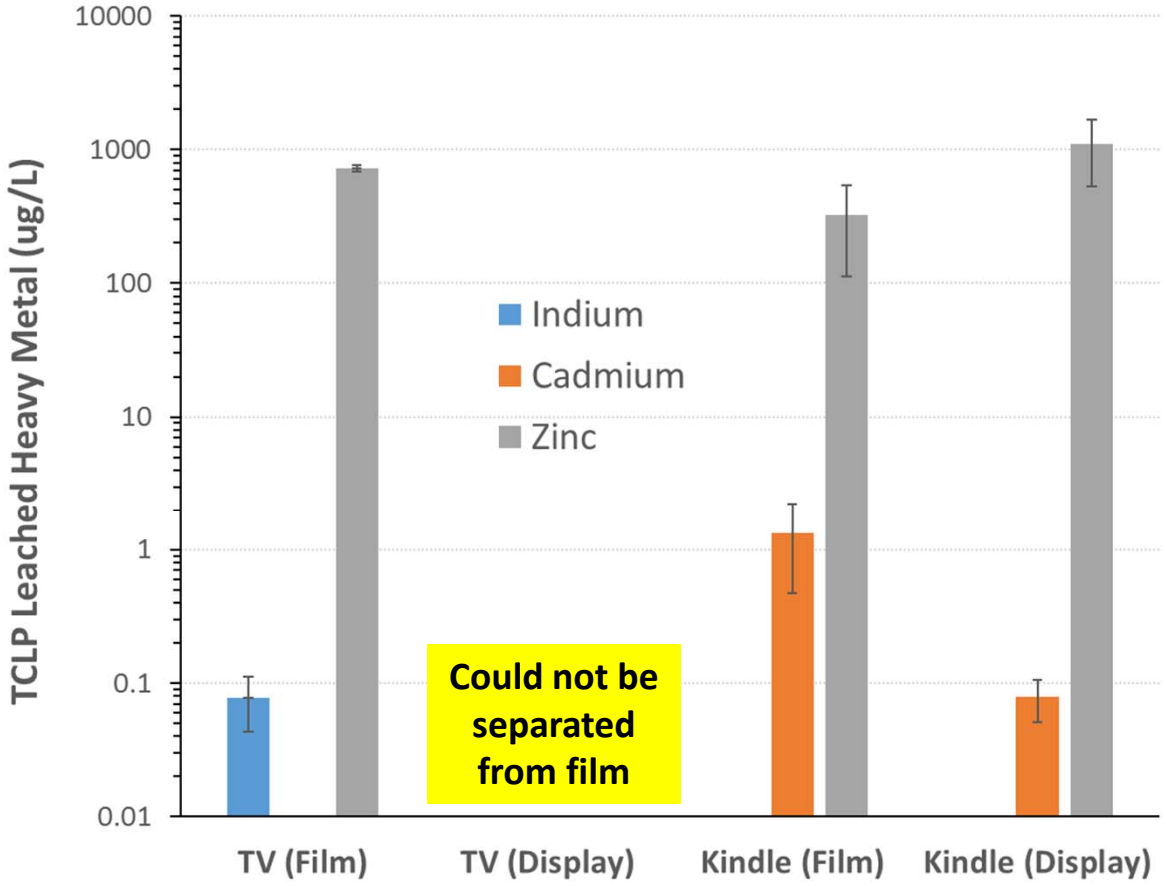
Results
WET Leached Heavy Metal Content

- Qualitative results similar to those found from TCLP
  - Lead dominant element
  - Detectable levels of Chromium
    - below California's regulatory limits.
- PV Crystallinity does not have significant effect on release of heavy metals



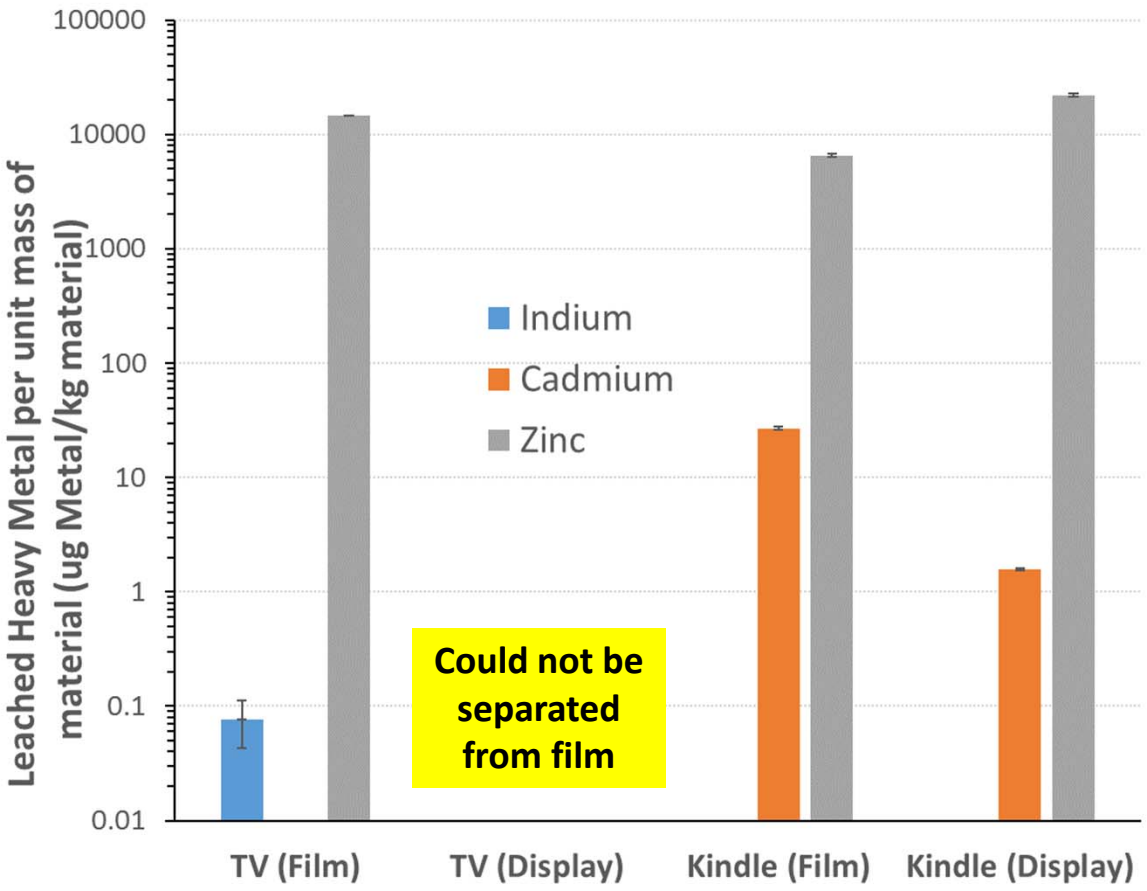
TCLP Heavy Metals of Concern Leached from QDs

- RCRA Regulatory Level
  - D006 = 1000 µg/L
  - Far below regulatory Limit.
- 40 FCR 268.48 Universal treatment standards
  - Cd: 110 µg/L
  - Zn: 4,300 µg/L
  - Far below regulatory Limit.



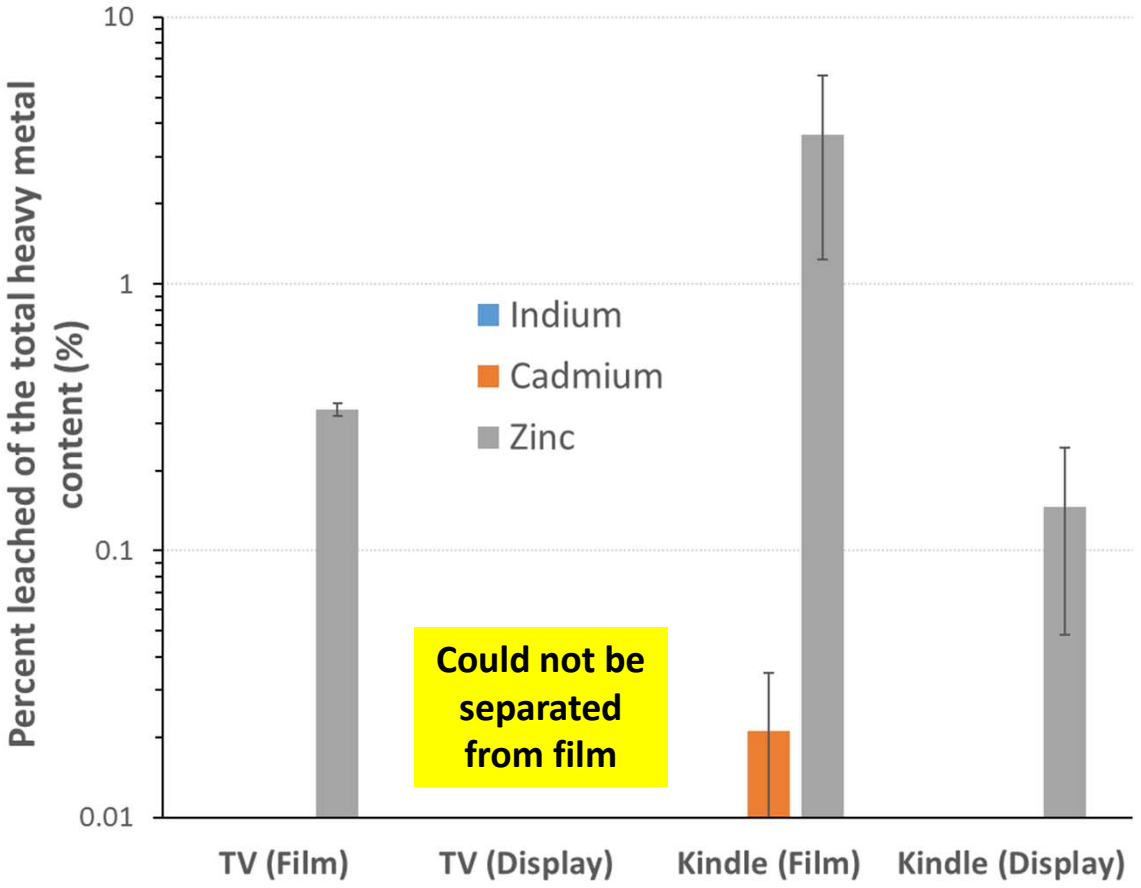
Leached Heavy Metals from QDs per mass of material

- High Zn content in:
  - Film material
  - Total Display
  - From electronics and ZnS?
- Indium content
  - Negligible
- Cadmium content
  - 10 – 50 ug/kg
  - Much higher CdSe QD content than InP QD



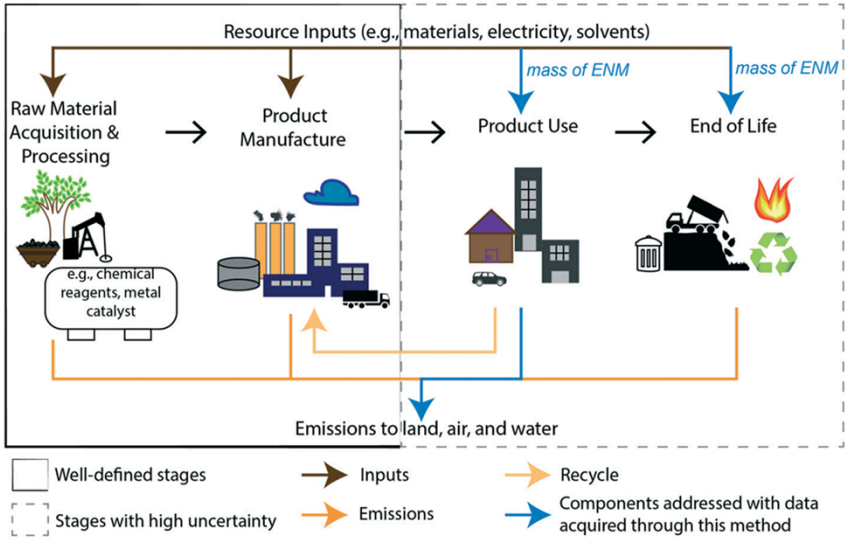
Percent leached of the total heavy metal content

- Generally heavy metal leaching
  - **< 1 %**
- Except Zn from film
  - 1% - 7%
- Not a concern but…
- Potential implications for
  - Release
  - Landfilling
  - Incineration



Implications for LCA

- PV cells and DQ film will likely maintain their integrity at the EoL
  - Due to encapsulation by glass, casing, film layers, etc.
- Exposure likely to increase only with handling (production) and recycling (EoL).
- Given low leachate contaminant concentrations,
  - EoL environmental impact should be insignificant.
- Probability for hazardous waste classification is low,
- **CAVEAT**:
  - PVs and next generations may not met LDR requirements as a result of Zn or similar element leaching.



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