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Health Risk Assessment for Steel Slag, Future Strategies

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September 2024

Presentation Overview

I. Published Health Risk Assessment for Residential Exposure for EAF slag

II. Responding to the Challenges Posed by National Academies of Science Engineering and Medicine Report

III. Cumulative Impact Assessments

IV. Future Strategies for Risk Assessment Work

DOI: 10.1111/risa.14309

ORIGINAL ARTICLE

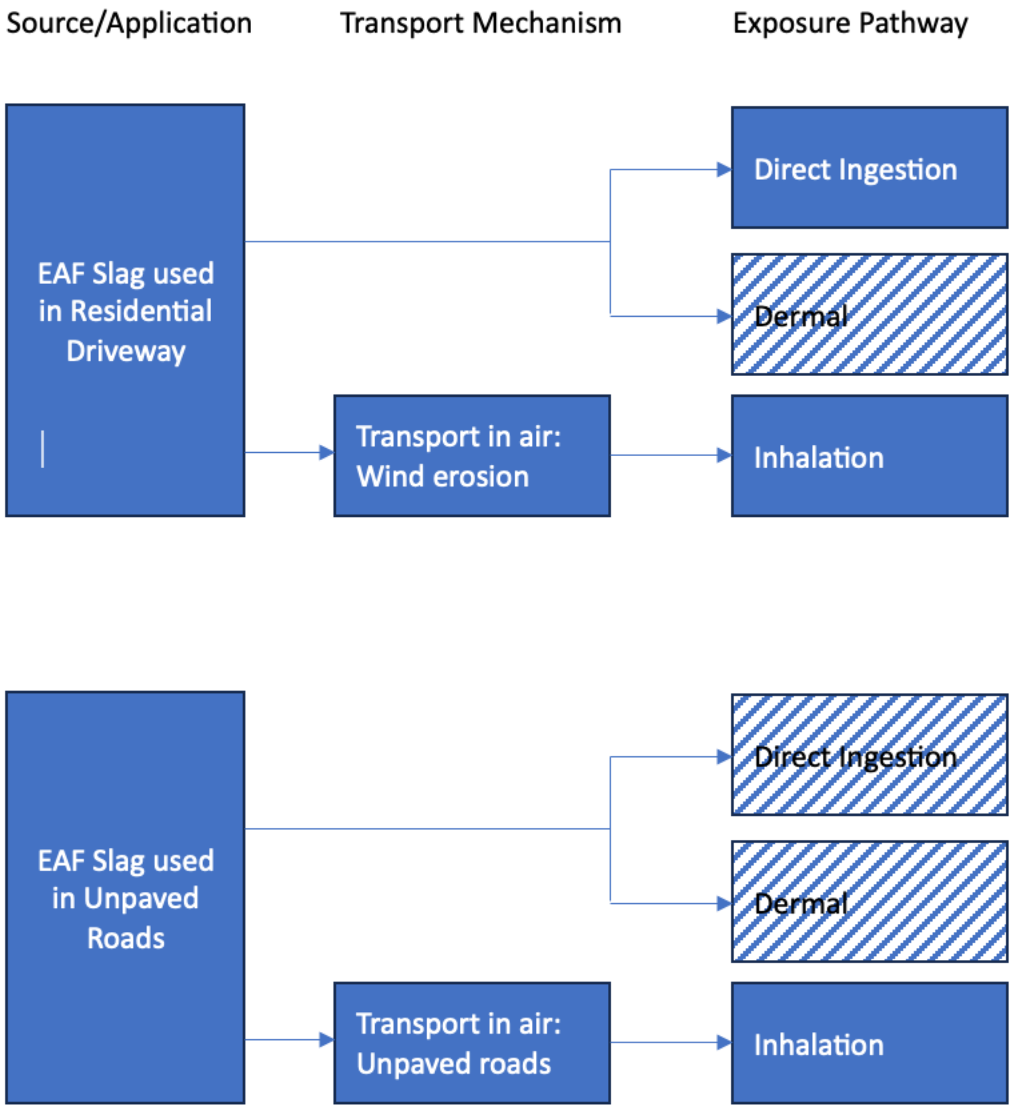
Probabilistic risk assessment of residential exposure to electric arc furnace steel slag using Bayesian model of relative bioavailability and PBPK modeling of manganese

Liz Mittal[1] | Camarie S. Perry[1] | Alexander D. Blanchette[2] | Deborah M. Proctor[3]

- ❖ Published the study in 2024 in *Risk Analysis* as Open Access
- ❖ Timeline allowed us to respond to challenges identified by NASEM Report

Update of the EAF Slag Risk Assessment

- Probabilistic Risk Assessment (PRA) to calculate excess risk and hazard quotients for all Constituents of Interest (COIs)
- Used New Model of Mn Relative Bioavailability
- Used New PBPK model for Mn to evaluate potential accumulation of Mn in the brain



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Results

Metals Concentrations in EAF Slag Current Study

Metal	Detection Frequency	KM Mean (mg/kg)	95 UCL (mg/kg)	Maximum (mg/kg)	EPA RSL (mg/kg)
Aluminum	100%	25,400	28,104	63,000	77,000
Antimony	**67%**	**14.9**	**19.02**	**79**	**31**
Arsenic	**36%**	**2.24**	**2.806**	**7.3**	**0.68**
Barium	100%	600	661.2	1,200	15,000
Beryllium	97%	2.54	2.776	4.6	160
Cadmium	69%	0.812	0.96	2.2	7.1
Calcium	100%	193,000	204,631	320,000	NA
Chromium	100%	3,320	3,733	7,700	120,000
CrVI	**90%**	**9.30**	**24.68**	**104**	**0.30**
Cobalt	62%	4.33	5.206	15	23
Copper	100%	166	191.8	415	3,100
Iron	**100%**	**182,000**	**196,904**	**315,000**	**55,000**
Lead	82%	14.6	17.61	160	400
Magnesium	100%	54,600	57,335	80,000	NA
Manganese	**100%**	**32,900**	**34,952**	**49,000**	**1,800**
Nickel	92%	55.9	89.28	515	1,500
Potassium	10%	73.4	85.84	160	NA
Selenium	82%	11.9	13.14	24	390
Silver	72%	5.21	5.863	11	390
Sodium	64%	227	261.5	690	NA
Thallium	0%	<1.1	--	0.51	0.78
Vanadium	**100%**	**626**	**678.8**	**1,200**	**390**
Zinc	100%	257	398.5	2,100	23,000
Mercury	41%	0.00714	0.00845	0.031	11

Calculations from EPA ProUCL

- Constituents of Interest measured above residential RSLs are bolded
- Cr(VI) analyzed by 3060A/7199
- Results for As and Tl analyzed by EPA **method 6020**, all others by method 6010

Presence of and levels of CrVI in EAF slag were higher than in earlier assessments

- Higher detection frequency and concentrations measured in 2019 than in previous assessments
- Crushing samples prior to analysis may have resulted in oxidation of CrIII to CrVI in digestion.

2021 Bioaccessibility Data

- Bioaccessibility (BA) testing using EPA Method 1340 conducted on 5 representative EAF slag samples
- Samples were crushed in the lab to prepare samples of <150 µm for analysis—expected to increase solubility of metals due to effect on particle surface chemistry
- CrVI was not tested because previous studies have shown that all results will be non-detect due to reduction to trivalent chromium in the acidic extraction fluid.
  - ❖ Used data for total chromium as surrogate based on journal peer-review comments
  - ❖ Decrease in CrVI-related risks to < 1 in a million.
- For arsenic, EPA equation used to calculate RBA from IVBA
  - ❖ IVBA = 65%, Calculated RBA = 45% for arsenic in EAF Slag

Toxicity Criteria

Metal	Comment
Antimony	Noncarcinogen—RfC and RfD based on current USEPA IRIS values
Arsenic	Carcinogenic and Noncarcinogenic criteria based on current USEPA IRIS values ❖ Arsenic cancer potency estimates to be updated by EPA in the near future
Hexavalent Chromium	Carcinogenic and Noncarcinogenic—EPA RfD and inhalation cancer slope factor from 2022 EPA Draft IRIS file were used ❖ EPA Assessment is now Final (August 2024) ❖ EPA Final Oral cancer slope factor decreased decreased 3-fold so updated analysis would result in lower risk estimates for CrVI for the Driveway scenario
Iron	Only toxicity criteria is oral PPRTV RfD
Manganese	Noncarcinogenic—EPA and ATSDR toxicity were used ❖ Journal peer-reviewers requested including less restrictive criteria from peer-reviewed literature, so discussion was expanded. ❖ NASEM panel called for EPA to update its IRIS Mn criteria
Vanadium	Noncarcinogen—RfC and RfD based on current USEPA IRIS values Assumed that Vanadium in EAF slag is unlikely to be in pentoxide form

Residential Driveway/Landscape Scenario for upper 95th percentile exposure

	Cancer Risk Target ≤ 1E-06	Hazard Index – Child Target ≤ 1	Hazard Index – Adult Target ≤ 1
Constituent of Interest	95th Percentile	95th Percentile	95th Percentile
Antimony	--	2E-02	2E-03
Arsenic	1E-06	3E-03	3E-03
Hexavalent Chromium	7E-07	3E-03	2E-03
Iron	--	3E-02	3E-02
Manganese[1] (RfD = 0.024 mg/kg-day)	--	**2E+00**	2E-01
Manganese[2] (RfD = 0.071 mg/kg-day)	--	7E-01	7E-02
Vanadium	--	7E-01	6E-02

Manganese RfD 1 is corrected for background diet and includes 3-fold modifying factor
Manganese RfD 2 is corrected for background diet

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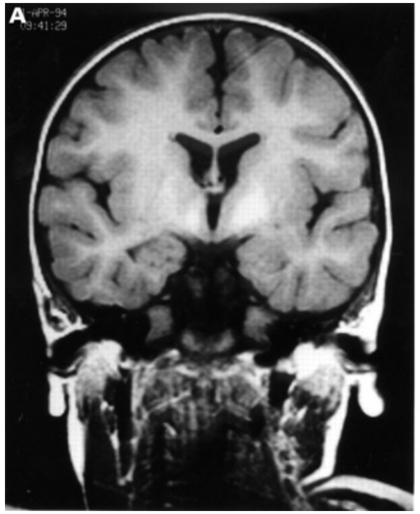
PBPK Modeling of Mn
Residential Exposure Scenarios



Mn is paramagnetic and can be seen in an MRI

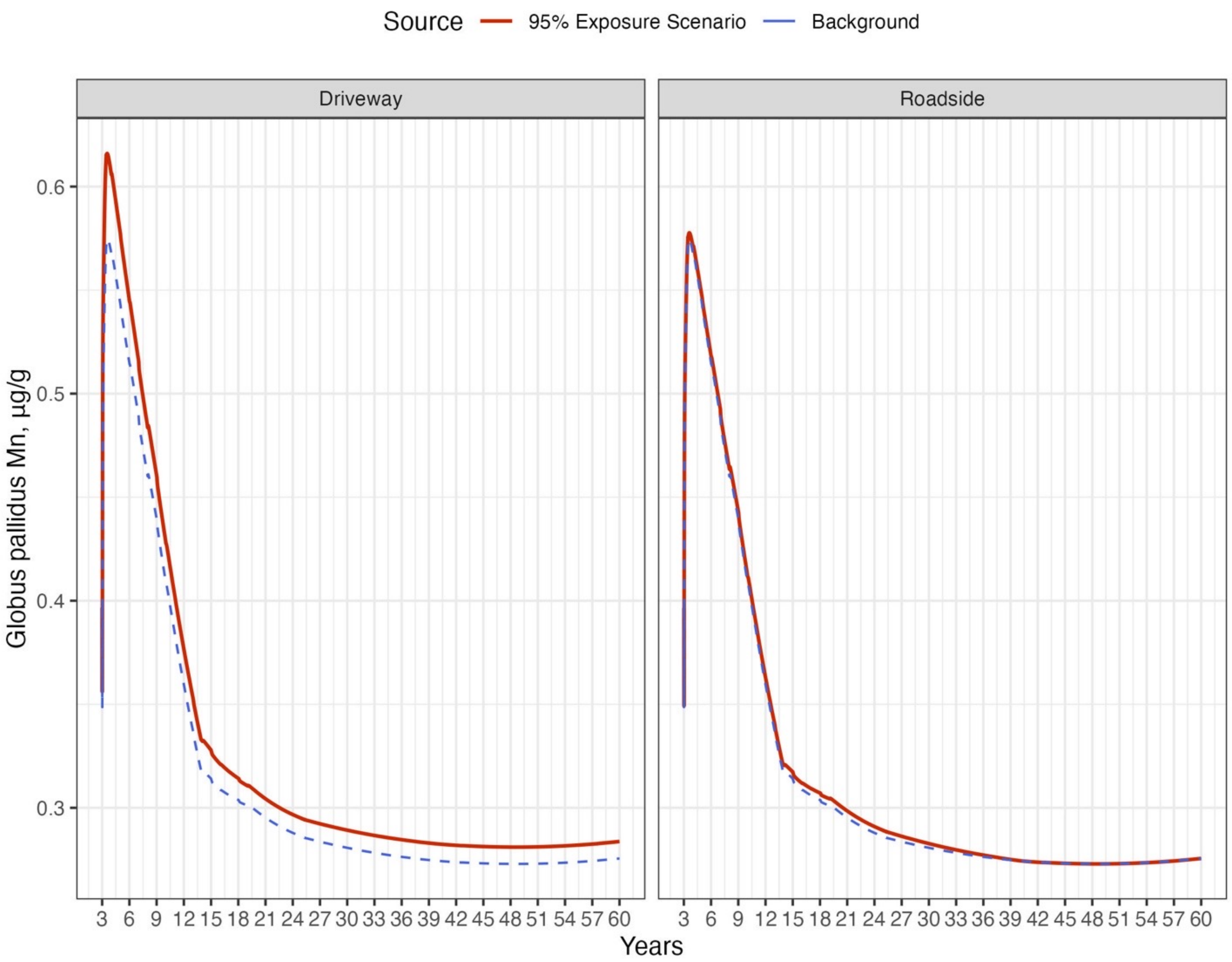
Newly Published Model Campbell et al. 2022

- Mn accumulation in Globus Pallidus of brain induces oxidative stress and neurodegenerative effects
- PBPK models exposure from ages 3-60 years
- New model includes transporter mediated rapid uptake and elimination

PBPK Model Predictions for Globus Pallidus for both scenarios at 95th percentile of exposure

Driveway includes ingestion, Roadway is only inhalation

Exposure (red) is slightly increased as compared to background (blue dashed) for driveway scenario



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Comparison of PBPK results with No Effect Levels

The PBPK model predictions for peak Mn in the globus pallidus were slightly increased (as high as 0.616 µg/g) for residential exposures compared to diet alone (0.58 µg/g) at age 3 years

At 7 µg/g, Mn in the globus pallidus causes neurodegenerative effects in animal studies

Predicted Mn concentrations were lower than published no effect levels (0.7-0.9 µg/g) reported in the literature from human and primate studies (Schroeter et al. 2012; Gentry et al. 2017).

- Incidental slag ingestion exposure was the primary exposure pathway, and inhalation contributed negligibly
- PBPK modeling results support lack of neurological hazard associated with residential exposures to EAF slag

Discussion Relative to NASEM Results

- NASEM's assessment was only screening level and indicated that several metals in EAF slag pose a ***potential*** hazard. Our risk assessment demonstrates that using advanced methods of evaluation, they do not.
- NASEM identified CrVI fate and bioavailability of CrVI as data gaps. We calculated margins of exposure of 140,000 and 24,000, based on bioavailability, relative to animal carcinogenicity data, indicating low potential to pose a hazard even data for CrVI.
- Panel concluded, **"Unless the reductive capacity is overwhelmed, there is minimal risk of hexavalent chromium-prompted disease burden."**
- NASEM recognized uncertainty in Mn toxicity criteria. We used PBPK model to address uncertainty and found no potential hazard, including among children.
- Further, RBA study in rats found that very high doses of Mn did not increase Mn in brain or lung tissue, supporting a protective role for iron.
- NASEM identified a lack of information regarding cumulative impacts in disadvantaged communities. We reported:
  - EPAs 2023 study of carbon and specialty EAF steel mills in US reported consistency in demographics for populations residing within 50 km of mills and US general population. Within 5 km, small differences in percent below poverty line and proportion minority populations were reported.
  - EPA 2023 rat bioassay of Mn drinking water, and induced stress, showed no effect from Mn alone, and Mn plus induced stress had a mitigating effect on cortisol levels relative to stress alone.

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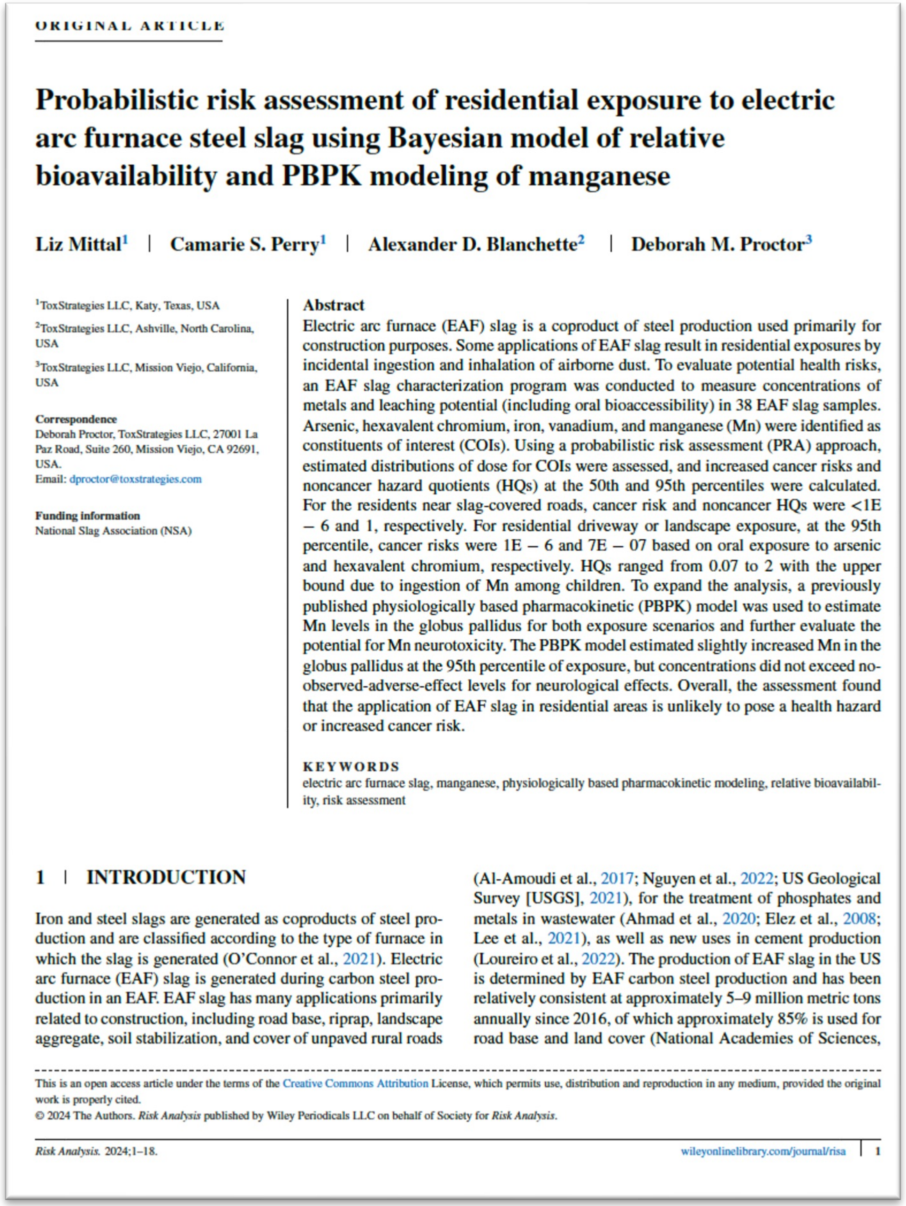
Risk Assessment Conclusions

- **"Overall the assessment found that the application of EAF slag in residential areas is unlikely to pose a health hazard or increased cancer risk."**
- Current RBA study results support that accumulation of Mn in the brain or other tissues from EAF slag ingestion will not occur even at very high Mn doses. Homeostasis is not overwhelmed and iron in slag has a protective effect.
- The PBPK model provides additional support for findings because Mn levels in the globus pallidus do not exceed no effect levels for neurological effects published by others

❖ **This publication provides a peer-reviewed platform for risk assessment of other forms of steel slag**



ORIGINAL ARTICLE

Probabilistic risk assessment of residential exposure to electric arc furnace steel slag using Bayesian model of relative bioavailability and PBPK modeling of manganese

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Funding information
National Slag Association (NSA)

Abstract
Electric arc furnace (EAF) slag is a coproduct of steel production used primarily for construction purposes. Some applications of EAF slag result in residential exposures by incidental ingestion and inhalation of airborne dust. To evaluate potential health risks, an EAF slag characterization program was conducted to measure concentrations of metals and leaching potential (including oral bioaccessibility) in 38 EAF slag samples. Arsenic, hexavalent chromium, iron, vanadium, and manganese (Mn) were identified as constituents of interest (COIs). Using a probabilistic risk assessment (PRA) approach, estimated distributions of dose for COIs were assessed, and increased cancer risks and noncancer hazard quotients (HQs) at the 50th and 95th percentiles were calculated. For the residents near slag-covered roads, cancer risk and noncancer HQs were <1E − 6 and 1, respectively. For residential driveway or landscape exposure, at the 95th percentile, cancer risks were 1E − 6 and 7E − 07 based on oral exposure to arsenic and hexavalent chromium, respectively. HQs ranged from 0.07 to 2 with the upper bound due to ingestion of Mn among children. To expand the analysis, a previously published physiologically based pharmacokinetic (PBPK) model was used to estimate Mn levels in the globus pallidus for both exposure scenarios and further evaluate the potential for Mn neurotoxicity. The PBPK model estimated slightly increased Mn in the globus pallidus at the 95th percentile of exposure, but concentrations did not exceed no-observed-adverse-effect levels for neurological effects. Overall, the assessment found that the application of EAF slag in residential areas is unlikely to pose a health hazard or increased cancer risk.

KEYWORDS
electric arc furnace slag, manganese, physiologically based pharmacokinetic modeling, relative bioavailability, risk assessment

1 | INTRODUCTION

Iron and steel slags are generated as coproducts of steel production and are classified according to the type of furnace in which the slag is generated (O'Connor et al., 2021). Electric arc furnace (EAF) slag is generated during carbon steel production in an EAF. EAF slag has many applications primarily related to construction, including road base, riprap, landscape aggregate, soil stabilization, and cover of unpaved rural roads (Al-Amoudi et al., 2017; Nguyen et al., 2022; US Geological Survey [USGS], 2021), for the treatment of phosphates and metals in wastewater (Ahmad et al., 2020; Elez et al., 2008; Lee et al., 2021), as well as new uses in cement production (Loureiro et al., 2022). The production of EAF slag in the US is determined by EAF carbon steel production and has been relatively consistent at approximately 5–9 million metric tons annually since 2016, of which approximately 85% is used for road base and land cover (National Academies of Sciences,

Risk Analysis. 2024;1–18. wileyonlinelibrary.com/journal/risa | 1

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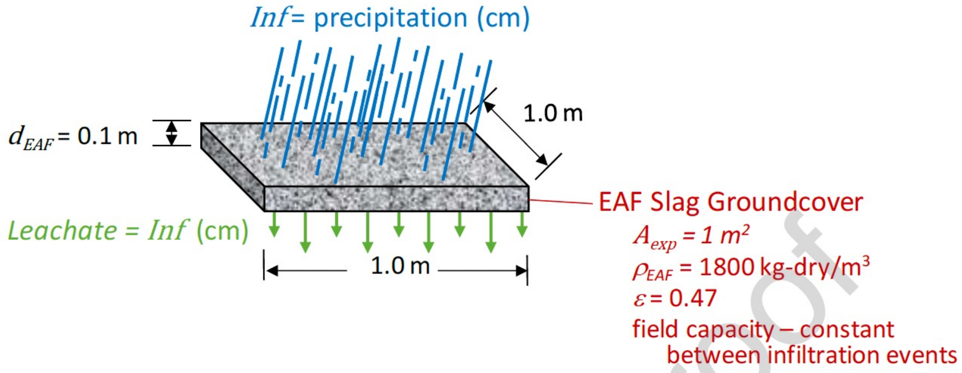
Vanderbilt/EPA EAF Slag LEAF leaching study has been published



- **Yu et al. 2024a and 2024b. From leaching data to release estimates: Screening and Scenario assessments of EAD slag under unencapsulated use. *Journal of Hazardous Materials and Journal of Environmental Management (in review)*.**
  - Screening identified 11 of 20 constituents requiring further assessment, scenario-based assessments conducted to evaluate total mass and time-depending projections of leaching over 30 years
    - 3 Fresh slag from Colorado steel mil and 2 field aged slag from residential properties, particle size reduced to <300 um and <2 mm.
  - Leaching of Al, Cr, Co, Mn and Se did not deplete with time, but leaching of As, Ba, Mo and V were depleted.
  - Aging decreased Si release and increased Cr, Co, Mn and Tl release (slightly)
  - Field aged slag pH ~9 and that of fresh slag was 13
  - At natural pH, only total Cr (not CrVI) and Al showed assessment ratios >1
  - For driveway scenario, only Al and Mn had assessment ratios >10—**still very conservative!**
- **Overall results are not highly concerning but could be misinterpreted**
- **These data would be critical for geochemical modeling of leachate for slag application scenarios, has been considered a potentially important next step for risk assessment**

Cumulative Impact Assessments: Coming to a location near you soon

Screening level evaluations were included in NASEM report for Pueblo, CO, and Allegheny County, PA

Why cumulative impact assessment?

- Disadvantaged and underserved communities are exposed to numerous chemical and non-chemical stressors from a wide array of sources through multiple pathways.

- The combined exposures to these stressors (i.e., cumulative impacts) may increase the exposed community's vulnerability and susceptibility to environmental hazards, resulting in exacerbated and disproportionate health impacts and thus environmental injustice.

- **Cumulative Impact Assessment (CIA) is meant to address the total burden from all chemical stressors and non-chemical stressors on health, well-being, and quality of life in these communities**

Regulatory Drivers for Cumulative Impact Assessment (CIA)

- Required by multiple Executive Orders
- EPA has asserted authority to require consideration of cumulative impacts as basis for environmental decisions
    - Communities with environmental justice concerns and underserved communities where there are "disparate impacts"
    - *EPA Legal Tools to Advance Environmental Justice: Cumulative Impacts Addendum. January 2023. Office of General Counsel, U.S. Environmental Protection Agency*
- Recent NEPA Phase 2 rule (July) - directs agencies to consider "disproportionate and adverse effects on communities with environmental justice concerns"
- Incorporated into numerous federal agency plans
- Several recent State EJ plans and a few State laws (e.g., NJ)
- Action to date focused on:
    - Air permitting
    - Siting
    - TSCA high-priority existing chemicals risk evaluations
    - New Coal Combustion Residuals Management Unit rules will require EJ assessments (undefined)
    - Title VI Civil Rights Act pressure on state agencies to require CIA – being litigated

Elements of a Cumulative Impact Assessment

1. **Identify and characterize communities** with EJ concerns and underserved communities that are within the exposure area
2. With input from stakeholders, **develop a problem formulation framework** to visualize within the decision context the potential cumulative impacts based on the place, people, stressors, and their interactions
3. **Define unique exposure scenarios** for the exposed community, including cultural influences
4. **Estimate cumulative chemical stressor exposures**, including background source exposures
5. I**ncorporate important non-chemical stressors**
6. **Incorporate important background physical and biological stressors**
7. **Incorporate background pre-existing health conditions, life-stage exposures, and generational exposures**
8. **Consider effects of intrinsic genetic/epigenetic/biological dose-response and health-impact modifiers**

Elements of a Cumulative Impact Assessment

9. Include **climate and ecosystem services impacts** on health
10. **Quantify relationships** among chemical stressors, non-chemical stressors, and health impacts
11. Use qualitative and/or quantitative methods to **combine chemical and non-chemical stressor impacts** to characterize cumulative impacts
12. Identify how the impacts are influenced by changes in certain variables and assumptions used in developing the CIA, including **consideration of uncertainty**
13. **Consider net impacts**, positive and negative
14. **Determine which impacts are disproportionate**
15. **Identify effective interventions** for reducing disproportionate impacts and improving health, well-being, and quality of life

ToxStrategies review report prepared for the American Chemistry Counsel (ACC) is available on their website. Comprehensive Review of Frameworks, Methods, and Metrics for Cumulative Impact Assessment of Vulnerable Communities: A Science Perspective - American Chemistry Council.

State of Science

Current scientific understanding of the causal relationships of individual and community health impacts from cumulative exposures to chemical and non-chemical stressors is incomplete, uncertain, and variable.

- How the interaction of these factors affects susceptibility
- Relative contributions of chemical and non-chemical stressors to health impacts

Non-chemical stressors are at least as important as chemical stressors in affecting vulnerable community health

Observational epidemiological (statistical association) studies provide the predominant evidence base for the contribution of non-chemical stressors to increased susceptibility

Very few of these studies have been systematically evaluated for their quality or scrutinized using established causality assessment frameworks

Research and development needed before CIA can be implemented quantitatively with scientific credibility

CIA not recommended as the primary basis for enforcement, standard-setting, or determining compliance

This is not to say CIAs should not be attempted

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The Big Picture

Cumulative Impact Assessment can identify multiple ways for the community to improve health and achieve equitable risk

This can be achieved by interventions that address
- Both chemical and non-chemical stressors
- Changes to the built, natural, and social environments

If federal and state environmental agencies focus only on what is within their jurisdiction, they may omit consideration of interventions that may be more effective in improving health

The proper balance between interventions aimed at non-chemical and chemical stressors should be determined by the scientific evidence for their independent and joint impacts, not on which government agency is involved.

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Future Risk Assessment Projects

1. Conduct 'mini' risk assessment for other forms of slag (BF, BOF, Ladle, etc) based on published methods from EAF Risk Assessment

2. Prepare white sheets to readily communicate risk assessment findings to non-technical stake holders
   - Relative bioavailability of Mn
   - Response to NASEM
   - Analysis of Vanderbilt study results

3. Geochemical modeling of realistic slag application scenarios

4. Cumulative Impact Assessment, response to NASEM summary in Pueblo and Allegheny County

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Questions?

Thank You!