Update: EPRI's Current CCP Research

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www.epri.com

About EPRI

ADVANCING SAFE, RELIABLE, AFFORDABLE, AND CLEAN ENERGY FOR SOCIETY THROUGH GLOBAL COLLABORATION, SCIENCE AND TECHNOLOGY INNOVATION, AND APPLIED RESEARCH

Nonprofit

Chartered to serve the public benefit, with guidance from an independent advisory council.

Thought Leadership

Systematically and imaginatively looking ahead to identify issues, technology gaps, and broader needs that can be addressed by the electricity sector.

Independent

Objective, scientific research leading to progress in reliability, efficiency, affordability, health, safety, and the environment.

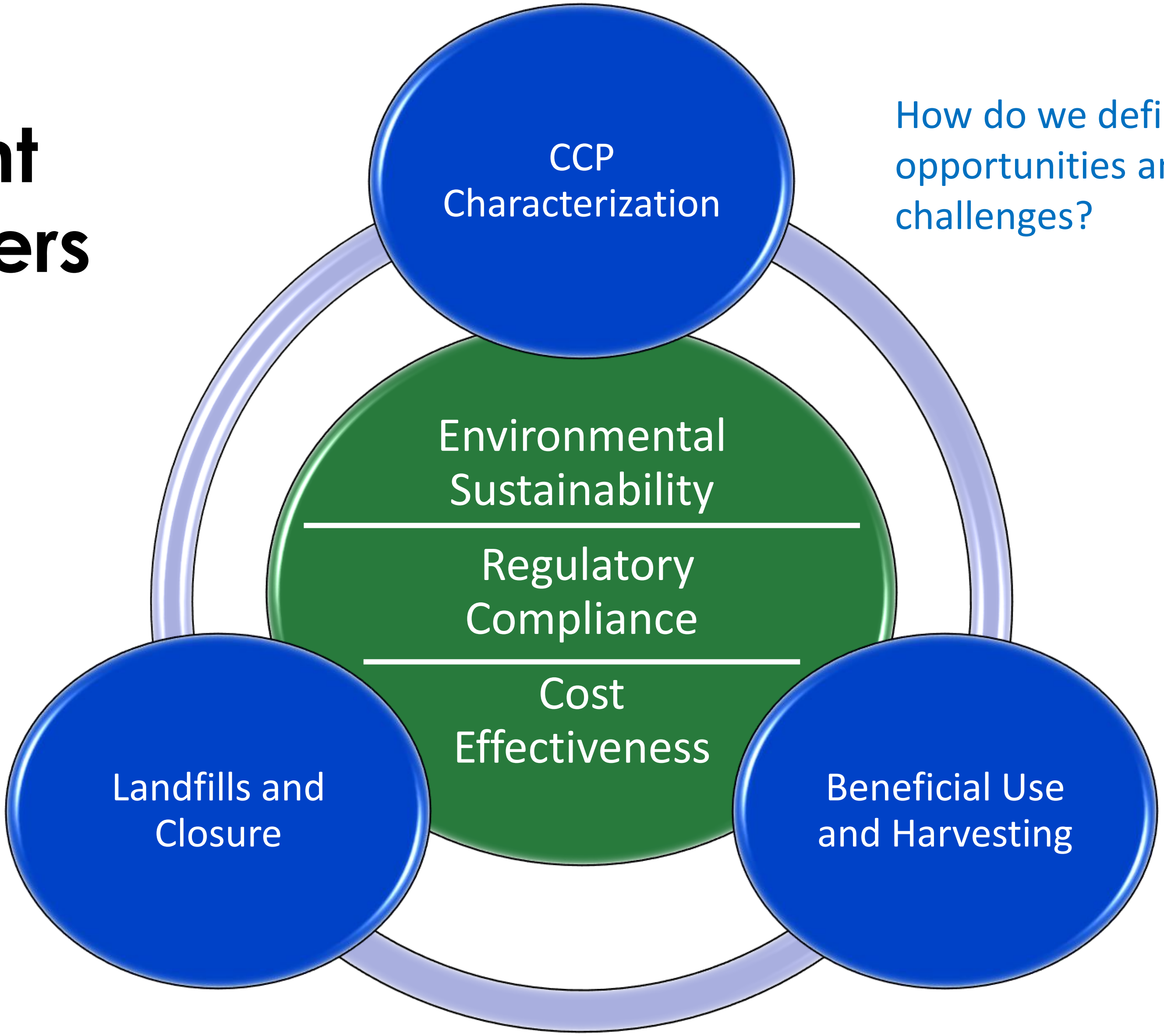
Scientific and Industry Expertise

Provide expertise in technical disciplines that bring answers and solutions to electricity generation, transmission, distribution, and end use.

Collaborative Value

Bring together our members and diverse scientific and technical sectors to shape and drive research and development in the electricity sector.

Key CCP Management Issues & Drivers



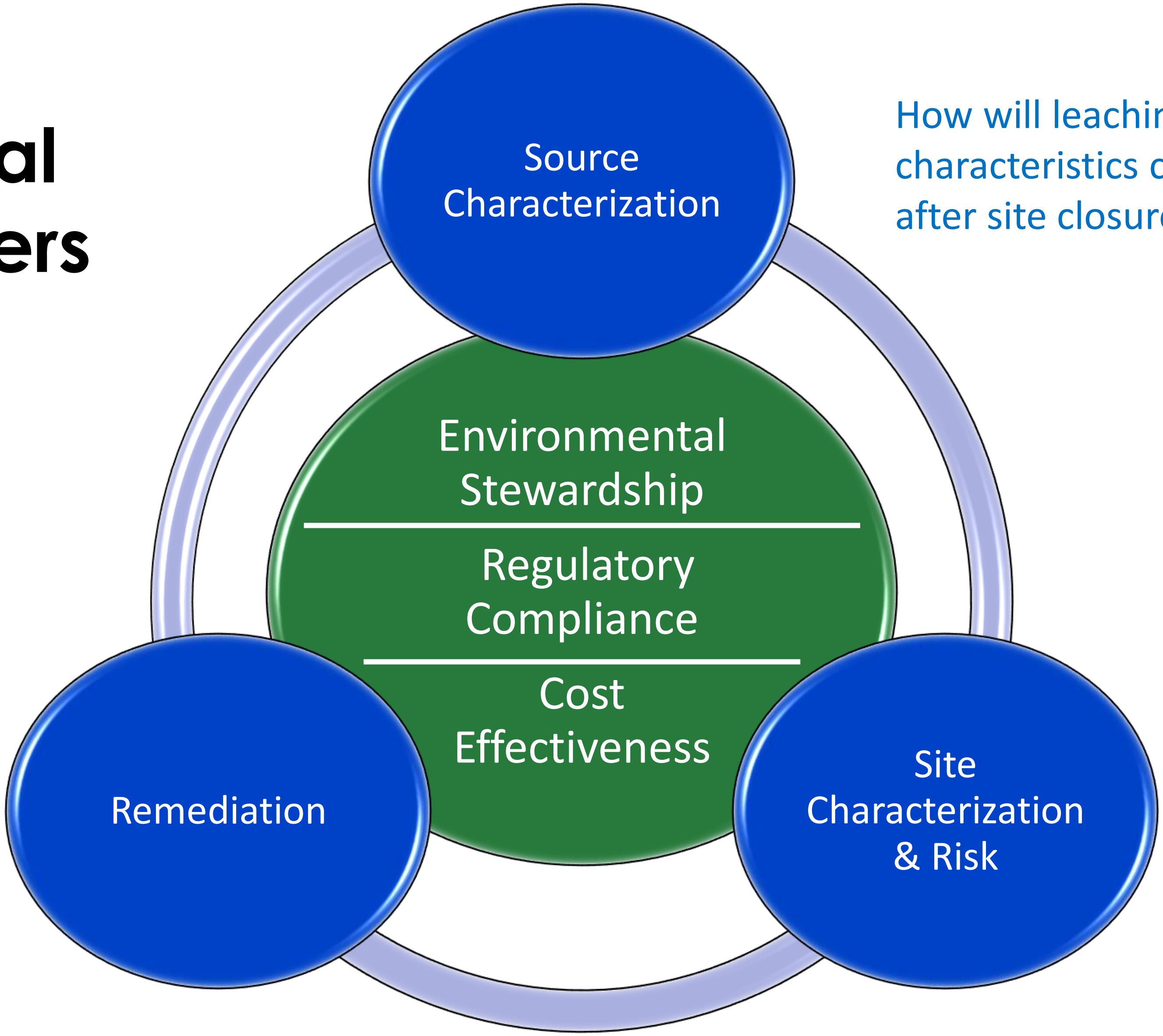
How do we define opportunities and challenges?

How do we best operate and close CCP units?

How will beneficial use transition from fresh production to harvested?

P241: CCP Management

Key Environmental Issues & Drivers



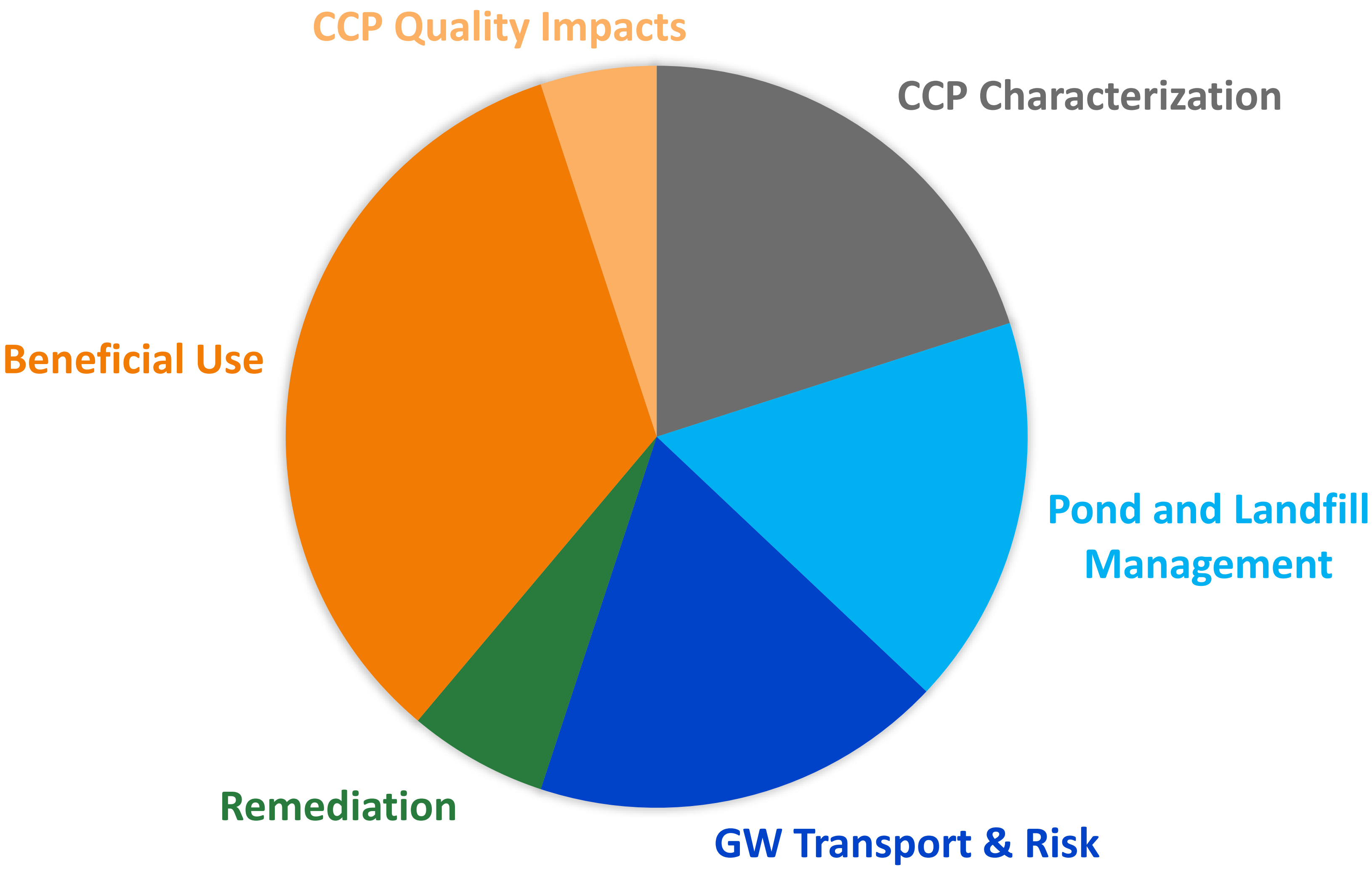
How will leaching characteristics change after site closure?

How do we deal with elements that are challenging to remediate?

How can we include risk within the regulatory structure?

P242: CCP Land and Groundwater Management

EPRI CCP Research: 1980 to Present



Based on number of reports on topic

Current Research Topics: Quick View

- CCP Characterization
  - Porewater variability and comparison to leach tests
  - Hydrogeochemistry
  - Soil physics and drainage of water in CCP deposits
  - Rapid field methods for beneficial use characterization
- Beneficial Use / CCP Quality
  - Case Study on CCP use in Concrete
  - Use of Coal Combustion Products in Sustainable Construction
  - Technologies to Recover High-purity Fly Ash or Gypsum from Mixed Coal Combustion Products
  - Ash Beneficial Use Center
- Pond & Landfill Management
  - Behavior of slurry-deposited CCPs during loss of containment
  - Potential Challenges in Landfill Water Management: A Changing Operations Paradigm
  - Landfill Water Management: Qualitative Evaluation of Practices
  - Ground Penetrating Radar for CCP Unit Inspections: Surface and Aerial Applications
  - HDPE Liner Durability
- Groundwater Transport & Risk
  - Groundwater interactions with CCP deposits
  - Changes in GW Quality after pond closure
  - Characterization of geochemistry and effects of closure-in-place for CCP units with intersecting groundwater and active remediation
  - Geophysical characterization of high TDS plumes
  - Groundwater monitoring paradigm / no-purge sampling
  - New techniques in alternate source demonstrations
  - Groundwater-surface water interactions
  - Ionizing radiation
- Remediation
  - Framework for evaluating corrective action alternatives at CCP units
  - Sequestration of molybdenum on biogenic pyrites, and co-benefits for cobalt and lithium
  - Practical limits of reversibility
  - In-situ remediation for B, Li, Mo / In-situ pilot tests

Why EPRI calls it a “Coal Combustion Product”


Cement

Road Base



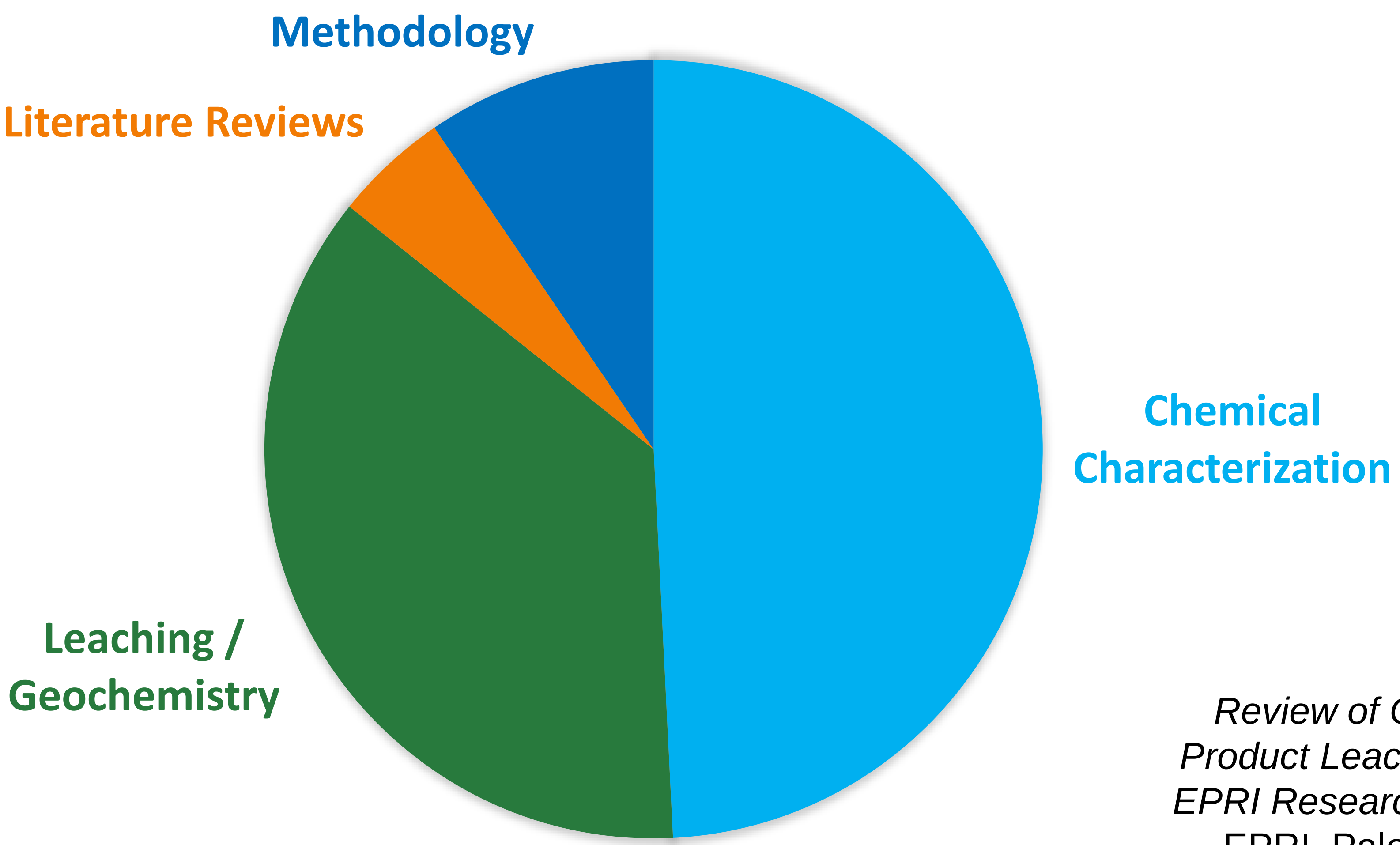
Wallboard

To reflect its status as a valuable material

CCP Characterization

EPRI

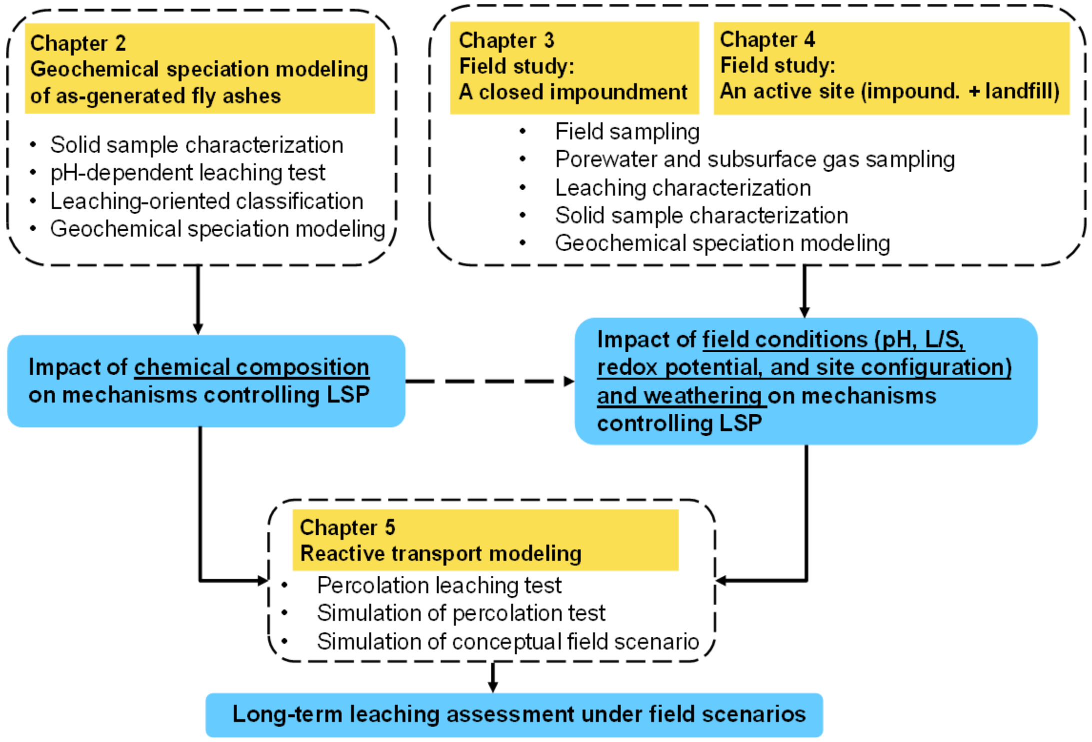
Technical Reports on CCP Leaching & Characterization



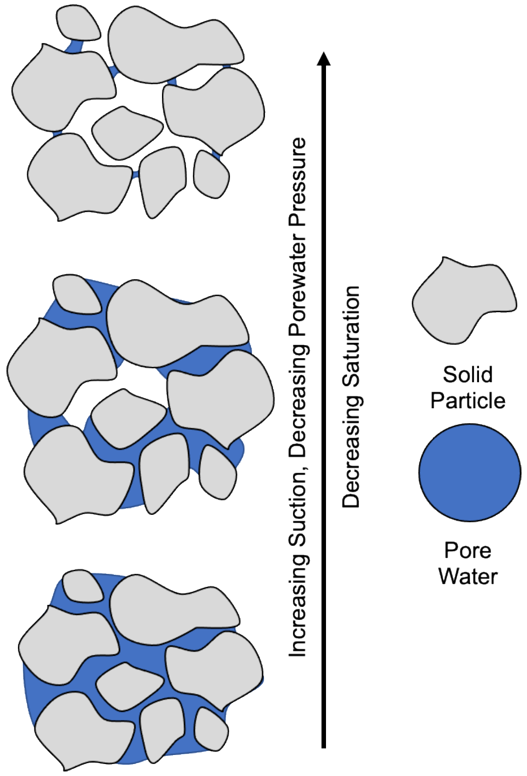
Review of Coal Combustion Product Leaching: Summarizing EPRI Research from 1980-2021. EPRI, Palo Alto, CA: 2021. 3002022051

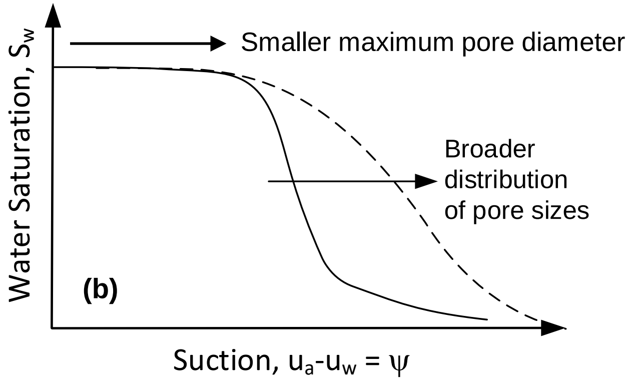
CCP Characterization

- Porewater variability and comparison to leach tests
  - *Advanced data analysis to characterize empirical relationships*
- Hydrogeochemistry
  - *Field, laboratory, and geochemical modeling studies enhancing our understanding of leaching dynamics*
- Soil physics and drainage of water in CCP deposits
  - *Characterize the drainage behavior of water in CCP pore space*
- *Rapid field characterization for beneficial use*
  - *Screening of handheld and benchtop devices for bulk composition analysis*



Soil Physics and Drainage from CCP

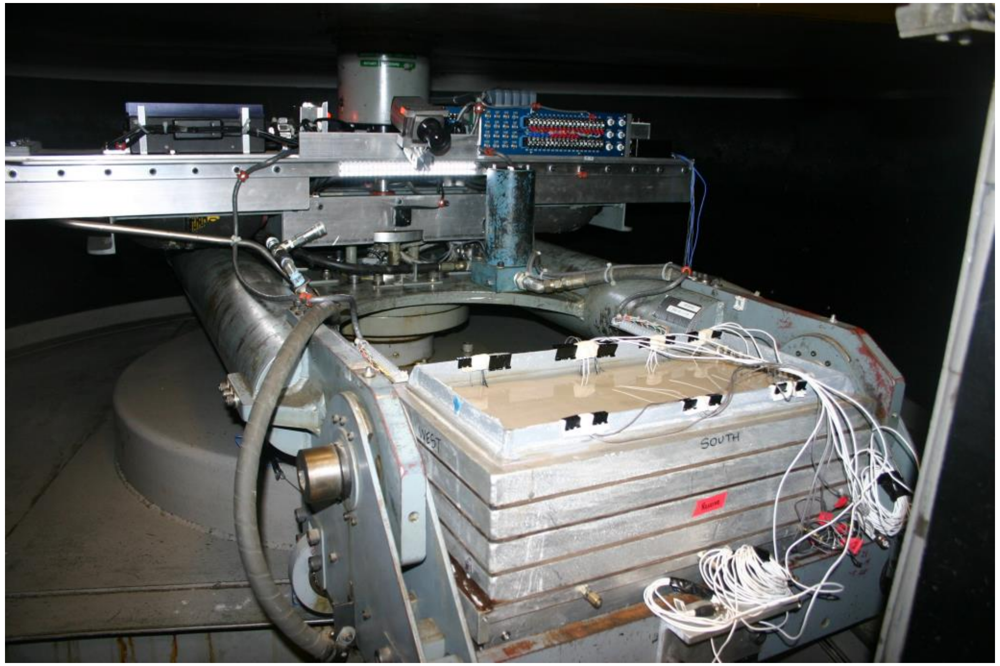




- Soil physics describes drainage of water from porous media as function of water pressure (suction):
  - Drainage primarily depends on the range of pore sizes
  - Surface properties of media become important at low water contents (high suction)
- Free liquids in other waste management is defined by empirical test (Paint Filter Liquids Test, PFLT)
  - EPA PFLT does not include guidance for sampling and testing in-situ materials

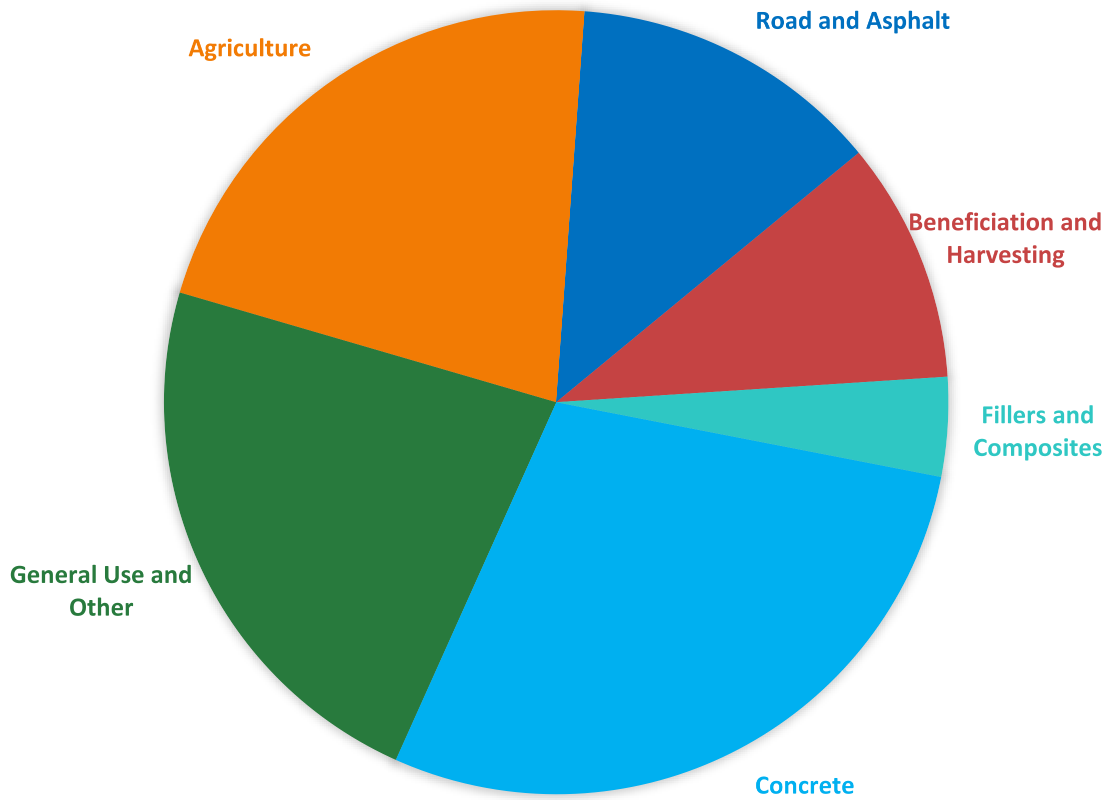
Soil Physics and Drainage from CCP

- Physical modeling of drainage in 1-meter geotechnical centrifuge (70g)
  - Benchtop drainge tests challenging to execute on soft, sluiced materials at field relevant densities
  - Centrifuge modeling can easily reproduce field conditions and speeds testing compared to 1g
  - Centrifuge model enables coupling of drainage observations with strength of drained material (ability to support a cap)
- Field and benchtop testing of samples compliments centrifuge results
  - PFLT at varying densities
  - Intact samples with piston sampler
  - Cone penetration resistance



Beneficial Use / CCP Quality

Beneficial Use



167 total reports on beneficial use

- **Most popular beneficial use research topic has been fly ash as replacement for cement in concrete**

Recent example of concrete research:

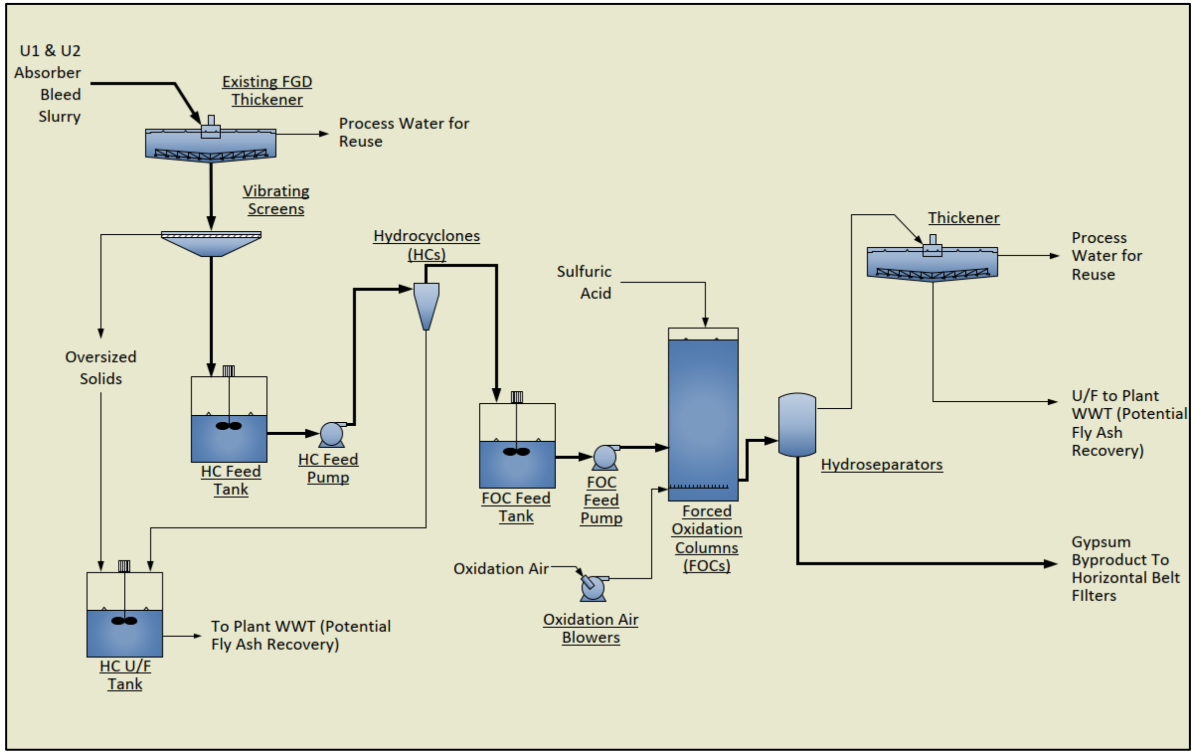
- Performance-Based Mixture Proportioning of Concrete Incorporating Off-Spec Fly Ash: Mixture Proportioning Method Development and Validation 3002018795

- Successfully linked chemical properties and reactivity of coal fly ash to performance of concrete
  - Thermodynamic and pore portion modeling used

- Research suggests how modern approaches to concrete mix design may increase the range of materials that can be used
  - May enable lower CO2 concrete

Beneficial Use / CCP Quality

- CCP use in Concrete
  - *Documenting the excavation, processing, and use of fly ash from a landfill*
- Use of Coal Combustion Products in Sustainable Construction
  - *Quantifying reduction in CO2 and other environmental impacts from beneficial use*
- Technologies to Recover High-purity Fly Ash or Gypsum from Mixed Coal Combustion Products
  - *Reviewing technologies to recover CCPs for use in concrete or wallboard*
- Ash Beneficial Use Center
  - *Pilot testing beneficial use technologies*



Concrete Mix Designs

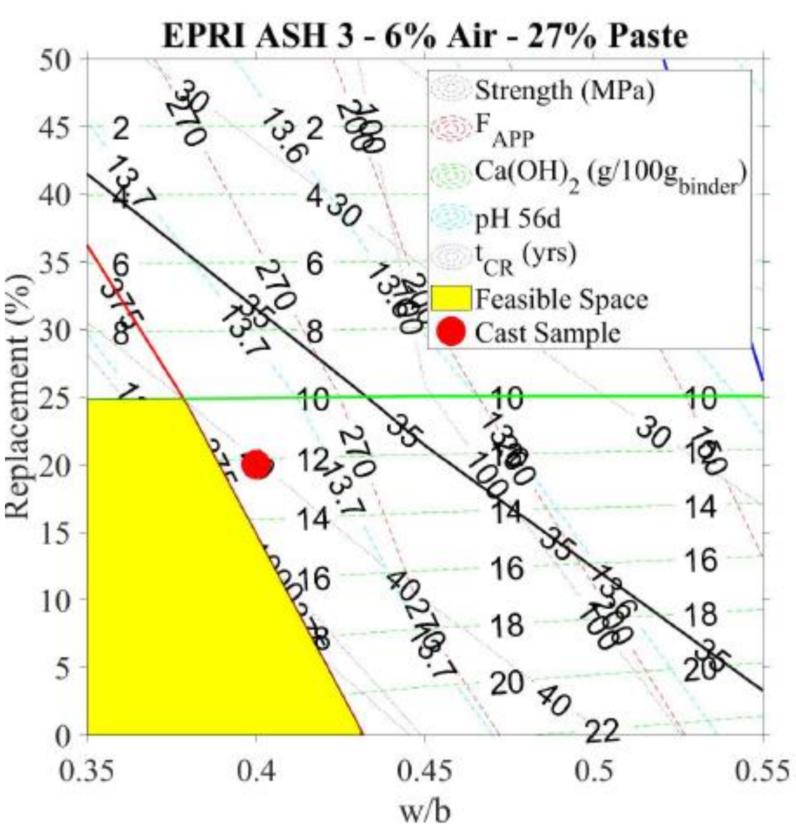
Concrete Application	Bridge deck mixture	Midwest pavement mixture (no reinforcement)	Foundation mixture
Concrete Exposure	ACI 318: F3, S0, W0, C2 (Resistance to chloride ingress, corrosion, and freeze-thaw damage)	ACI 318: N/A (Resistance to CaOxy and freeze-thaw damage as specified by Indiana DOT [86])	ACI 318: F0, S1, W1, C0 (Moderate sulfate and ASR resistance)
Strength, f'_c (56 day, min)	5000 psi [34 MPa]	4225 psi [29 MPa]	4000 psi [27 MPa]
Slump (ACI 211 [1])	1–4 in (25–100 mm)	1–2 in (25–50 mm)	1–3 in (25–75 mm)
Formation Factor, F_{APP} (56 day, min)	375	270	200
Calcium Hydroxide **CH** (56 day)	10 g/100 g binder (min)	20 g/100 g binder (max)	N/A
pH (56 day)	12.8 (min)	N/A	13.6 (max)
Time to critical saturation, t_{CR}	30 years	30 years	N/A

		Bridge Deck	Pavement	Foundation
EPRI Ash 3	Coarse aggregate	937	965	895
	Fine aggregate	822	842	816
	Cement	299	280	310
	Fly ash	75	70	78
	Water	119	110	116
	WRA	2160 ($ml/m^3_{concrete}$)	3024 ($ml/m^3_{concrete}$)	2450 ($ml/m^3_{concrete}$)
	AEA	648 ($ml/m^3_{concrete}$)	756 ($ml/m^3_{concrete}$)	-

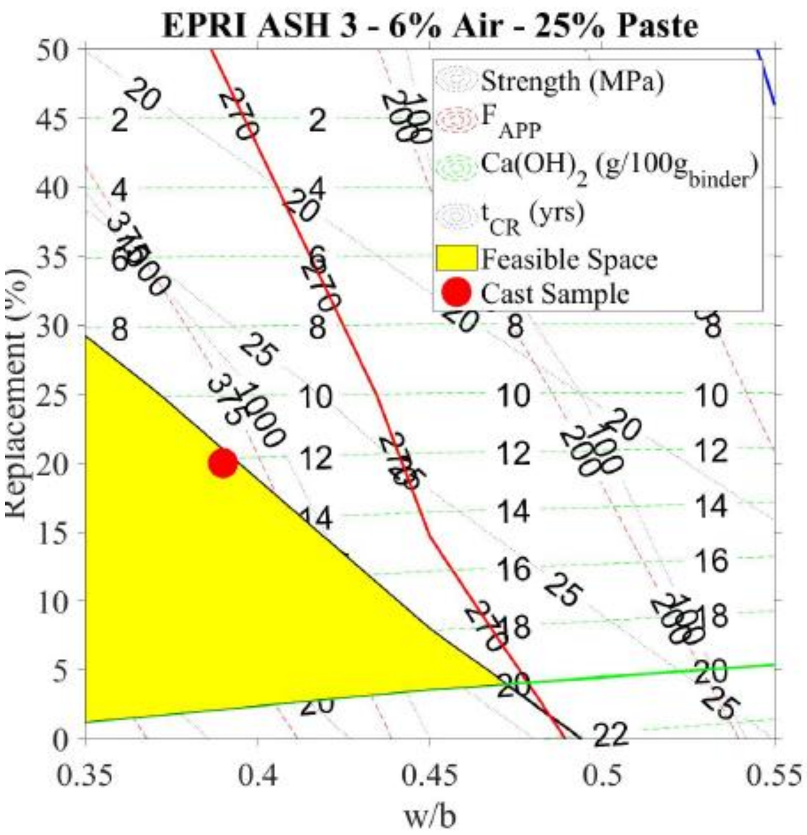
EPRI Ash 3	Slump (inches)	2.25	1.00	2.00
	Unit Weight (kg/m^3)	2195	2227	2371
	Fresh Air Content	7.0%	6.5%	1.6%
	Temperature	22.8°C	21.1°C	18.3°C

Concrete Modeling Results

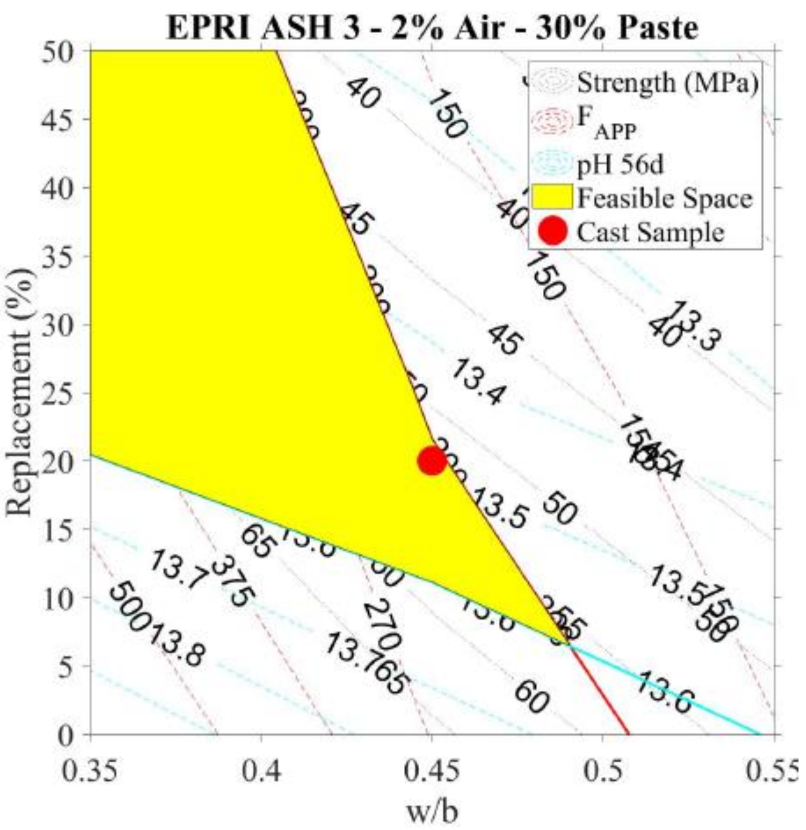
Bridge Deck



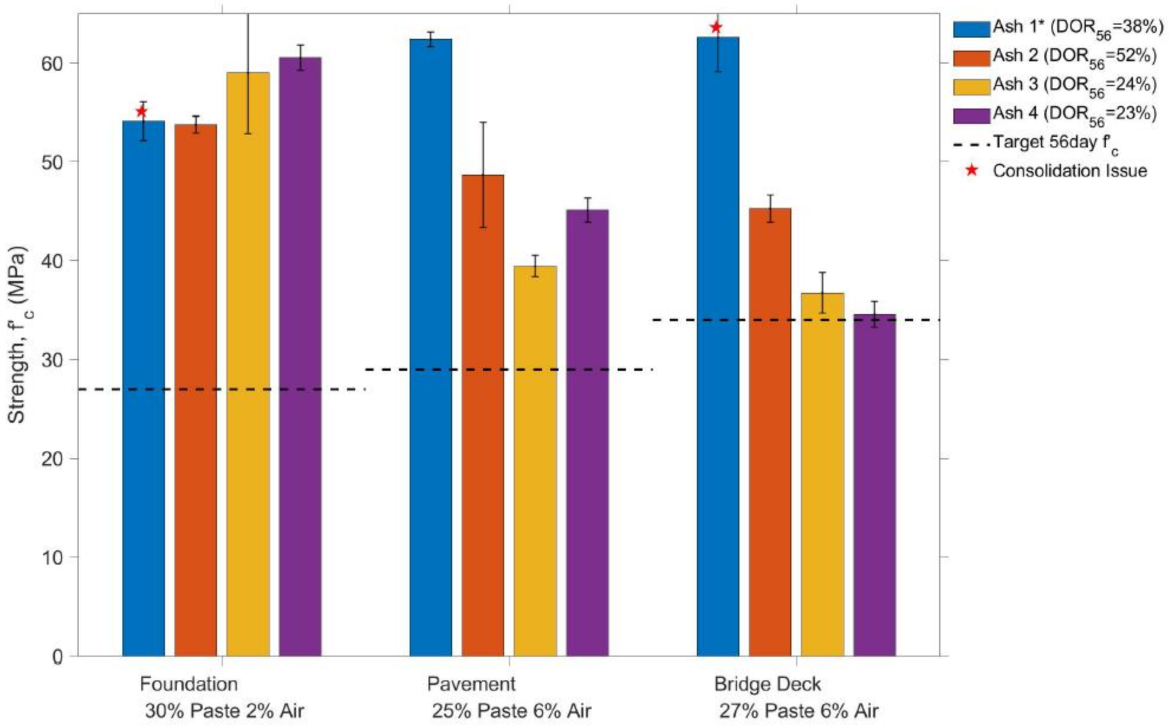
Pavement

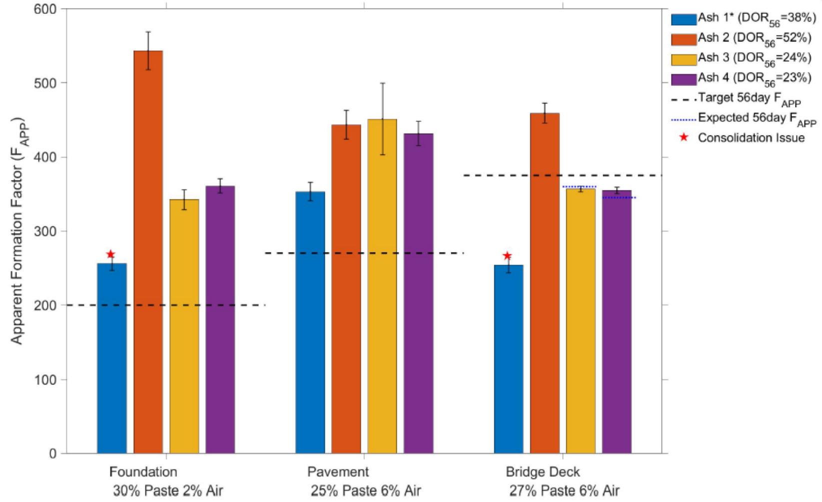


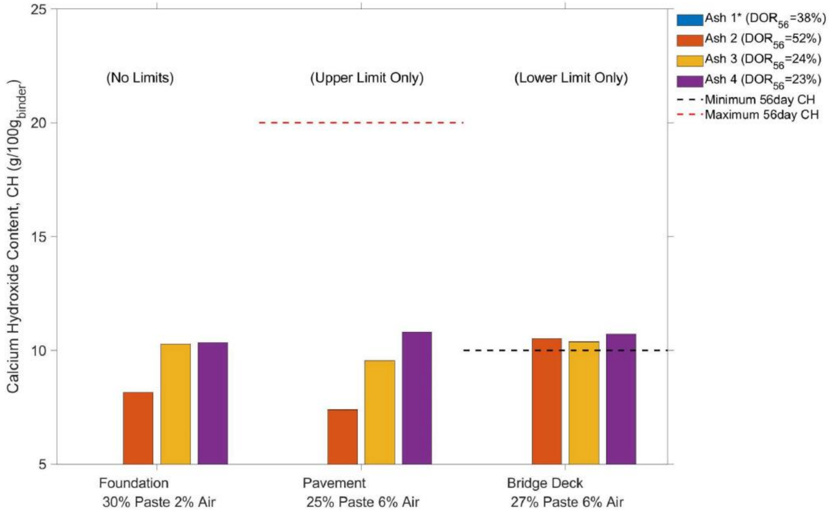
Foundation

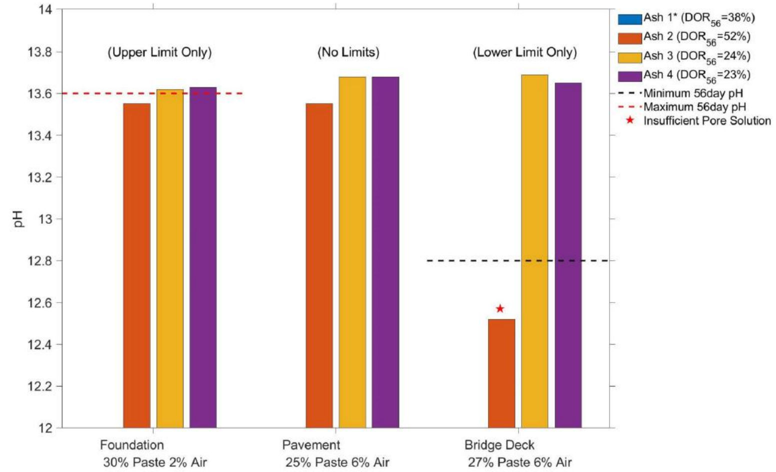


Concrete Physical Test Results









Pond and Landfill Management

CCP Management in Ponds & Landfills

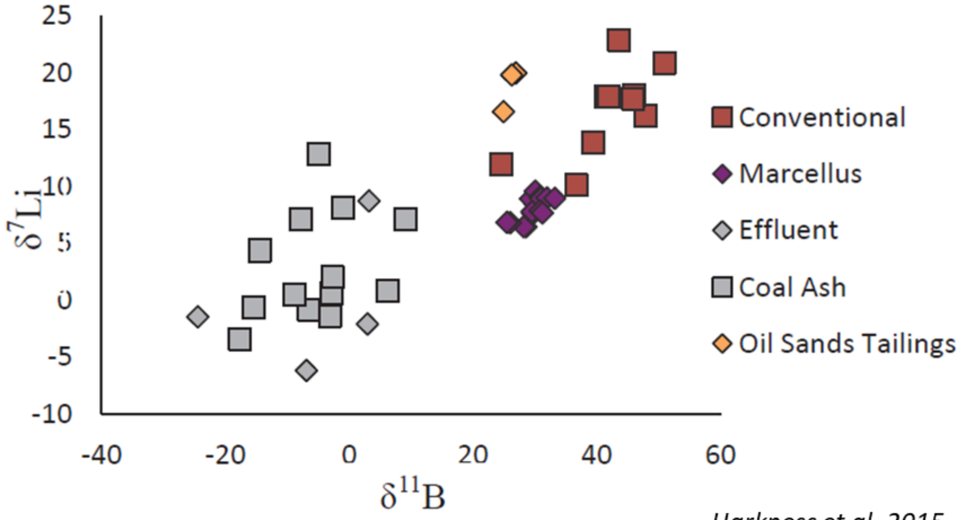
- Behavior of slurry-deposited CCPs during loss of containment
  - *Model changes in runout behavior with drainage*
- Potential Challenges in Landfill Water Management: A Changing Operations Paradigm
  - *Gather range of utility views on challenges in landfill water management*
- Landfill Water Management: Qualitative Evaluation of Practices
  - *Model practices for leachate reduction for quantitative comparison*
- Ground Penetrating Radar for CCP Unit Inspections: Surface and Aerial Applications
  - *Demonstrate the potential use of automated ground penetrating radar in cap inspections*
- HDPE Liner Durability
  - *Evaluate physical properties of retired 20-year old HDPE membrane*

Groundwater Transport & Risk

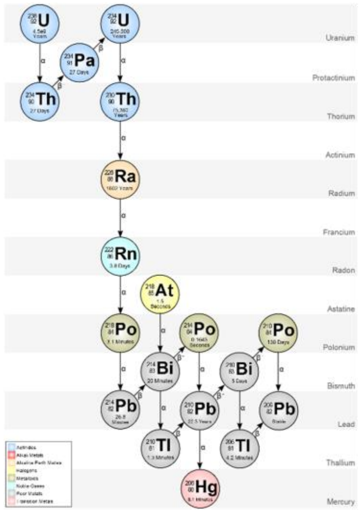
Groundwater Transport & Risk I

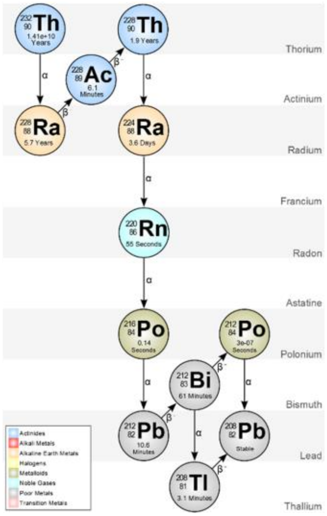
- Groundwater interactions with CCP deposits
  - *Provide insight to inform and support decisions related to source control*
- Changes in GW quality after pond closure
  - *Using ML to evaluate GW quality changes after CIP and CBR*
- Characterization of geochemistry and effects of closure-in-place for CCP units with intersecting groundwater and active remediation
  - *Determine if closure-in-place can be performed when there is intersecting groundwater in a manner that can mitigate risk to human health and environment*
- Geophysical characterization of high TDS plumes →
  - *Field tests of tTEM and float-TEM geophysical surveys for plume delineation on land and at the GSI*

Groundwater Transport & Risk II



Harkness et al. 2015

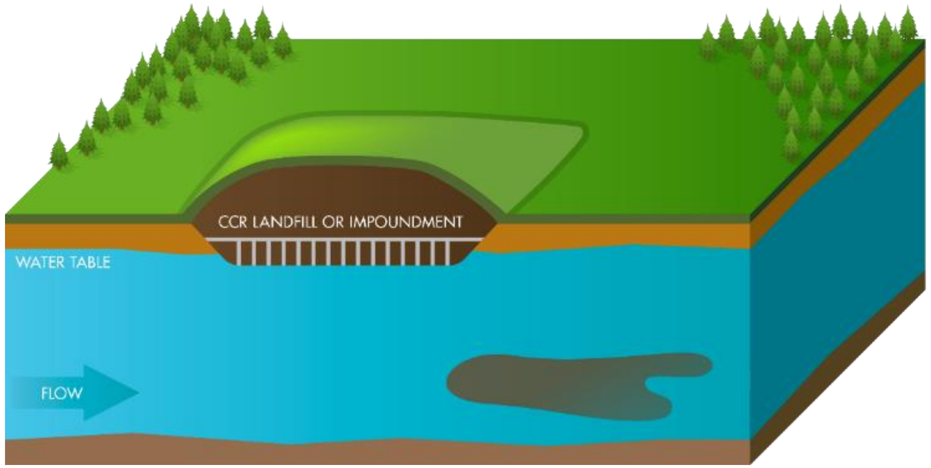




- Groundwater monitoring paradigm / no-purge sampling
  - *Can we improve the GW sampling process for sites where only inorganics are monitored?*
- New techniques in alternate source demonstrations
  - *Research to identify new techniques for environmental forensics with an evaluation of their applicability to CCP units*
- Groundwater-surface water interactions
  - *Advance understanding of physical and chemical interactions between groundwater, surface water, and sediments at the GSI*
- Ionizing radiation
  - *Advance the industry understanding of the potential ionizing radiation doses to workers at CCP units*

Characterization of geochemistry and effects of closure-in-place for CCP units with intersecting groundwater and active remediation

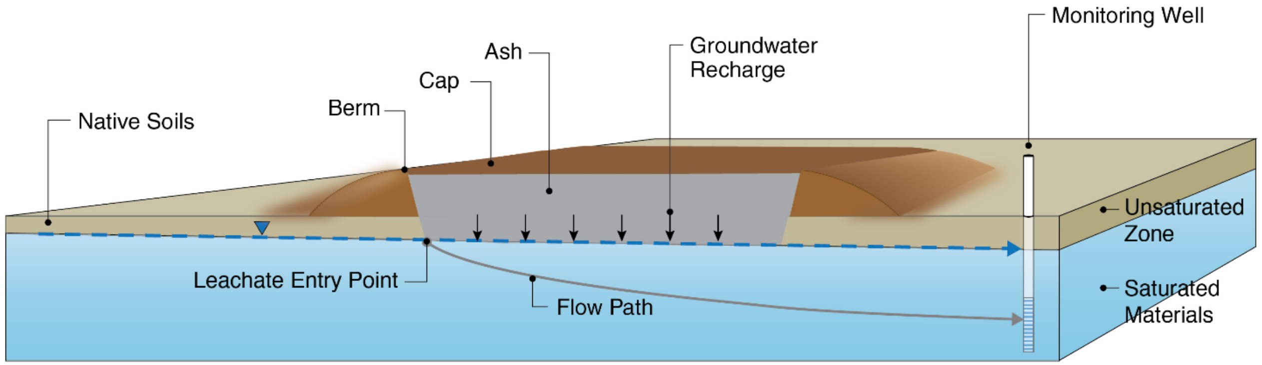
- Objective
  - Determine if closure-in-place can be performed when there is intersecting groundwater in a manner that can mitigate risk to human health and environment
- Approach
  - Task 1a: Preliminary Evaluation
    - EPACMTP
    - Determine common attributes for units that CIP with intersecting groundwater, but without corrective action, for high, moderate, and low risk
  - Task 2b: Case documentation
    - Summarize hydrogeology and long-term groundwater quality for published cases where CCP units with intersecting groundwater have been closed



Risk-based evaluation of CIP when there is intersecting groundwater

Characterization of geochemistry and effects of closure-in-place for CCP units with intersecting groundwater and active remediation

- Approach (*continued*)
  - Task 2: Impacts of CCP Units on Groundwater Geochemistry
    - Understand how a release from a CCP unit can affect groundwater geochemistry, and how those changes can positively or negatively impact corrective action
  - Task 3: Refined Modeling and Data Analysis
    - Determine if/when/how CIP can be performed when there is intersecting groundwater in a manner that can mitigate risk to HHE
    - Reactive transport modeling
- Outcomes & Time Frame
  - Interim deliverable for task 1 in 2022
  - Task 2 & 3 / Final deliverable in 2023



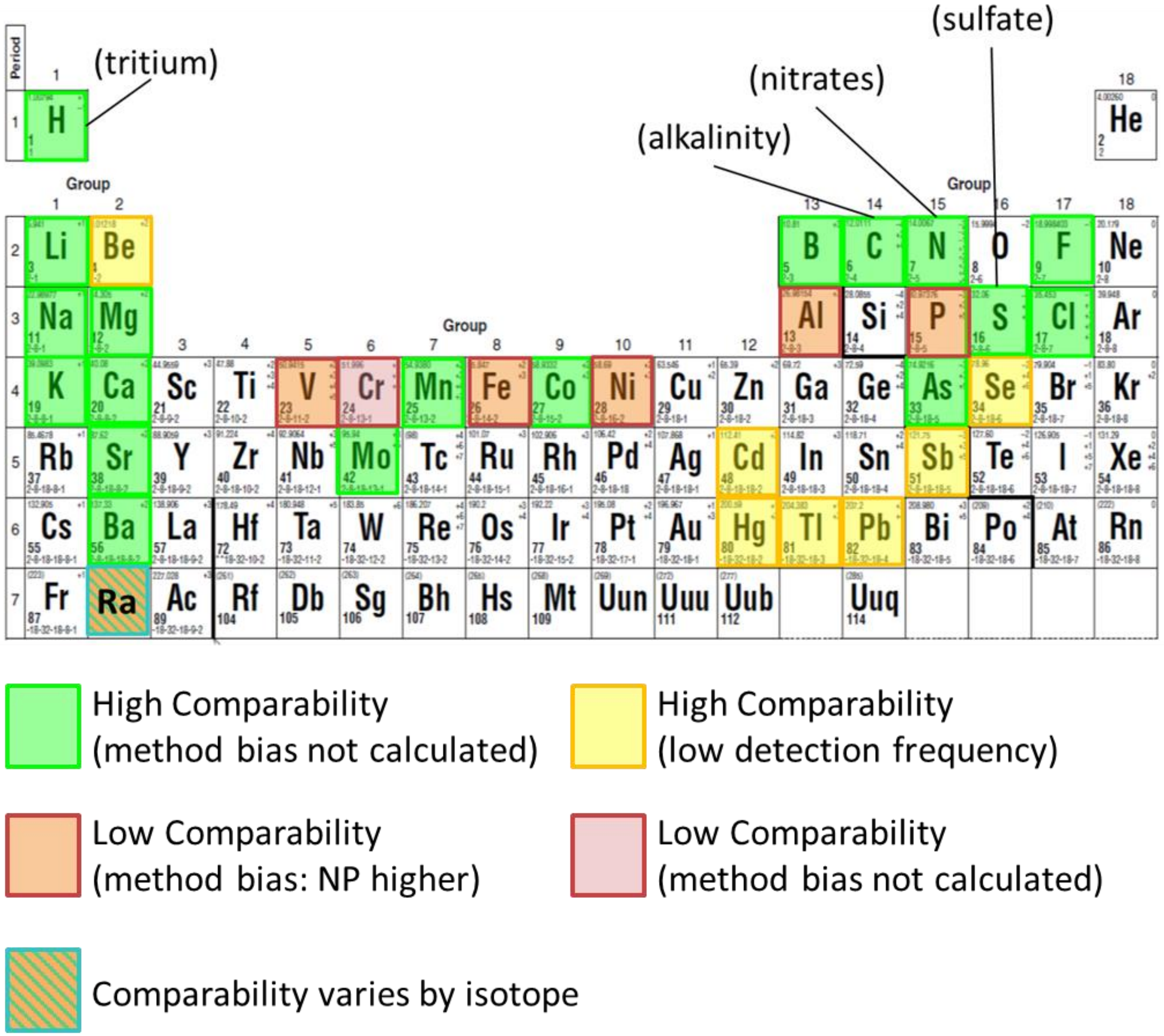
Applicable to Landfills and Impoundments with Intersecting Groundwater

No-Purge Sampling

- Minimizes drawdown for wells in low-yield formations
  - Less potential for exposing screen to oxygen
  - Less potential for sampling stagnant water from casing
- Minimizes generation of purge water
- Increases sampler efficiency

Elements that can precipitate as oxides, co-precipitate with oxides, or sorb to oxides:

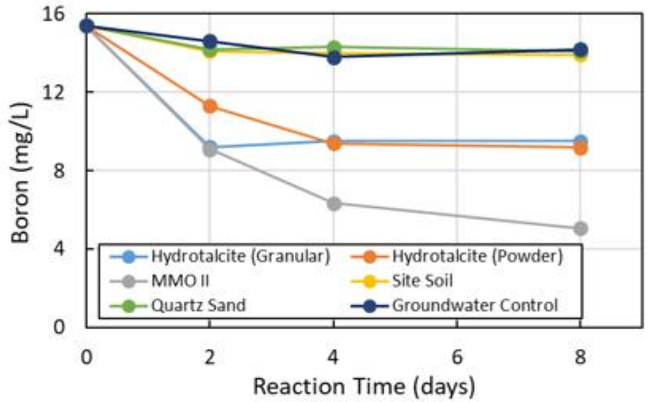
Sb, As, Cd, Cr (III), Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Ra, Se, Tl, V, and Zn

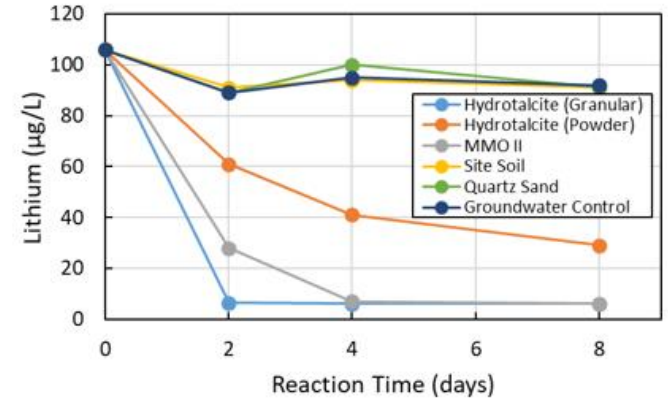


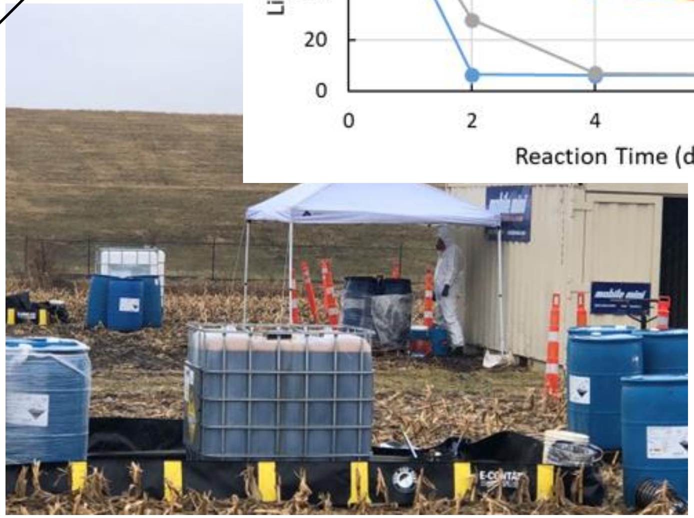
Remediation

Remediation

- Framework for evaluating corrective action alternatives at CCP units
  - *Information to consider risk, sustainability, and environmental justice when choosing between the viable options determined by an ACM*
- Sequestration of molybdenum on biogenic pyrites, and co-benefits for cobalt and lithium
  - *Establish the geochemical range for viable SRB-based bioremediation by quantifying SRB activity limits for molybdenum, sulfide, iron, and organic matter*
- Practical limits of reversibility
  - *Model-based research to enhance understanding of the practical limits of attenuation and geochemical reversibility at CCP sites*
- In-situ remediation for B, Li, Mo / In-situ pilot tests
  - *Laboratory and field tests: can we immobilize these elements?*

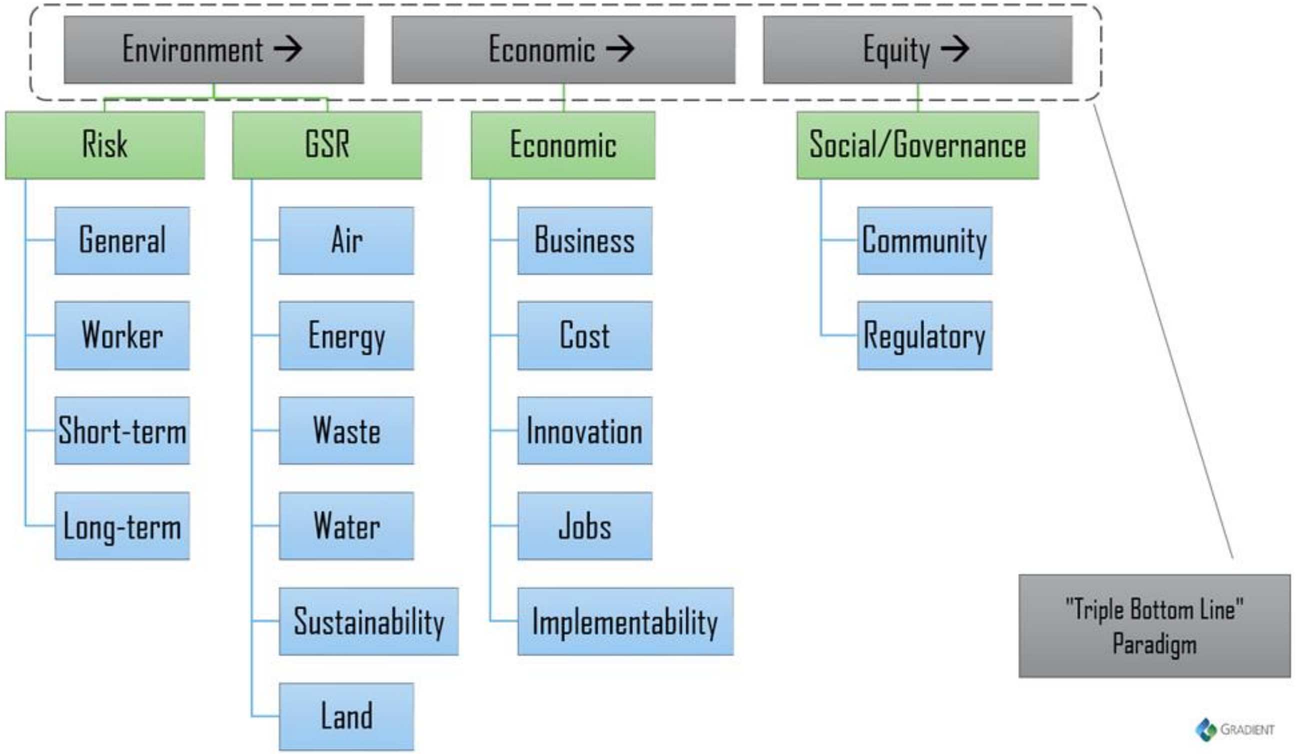






Framework for evaluating corrective action alternatives at CCP units

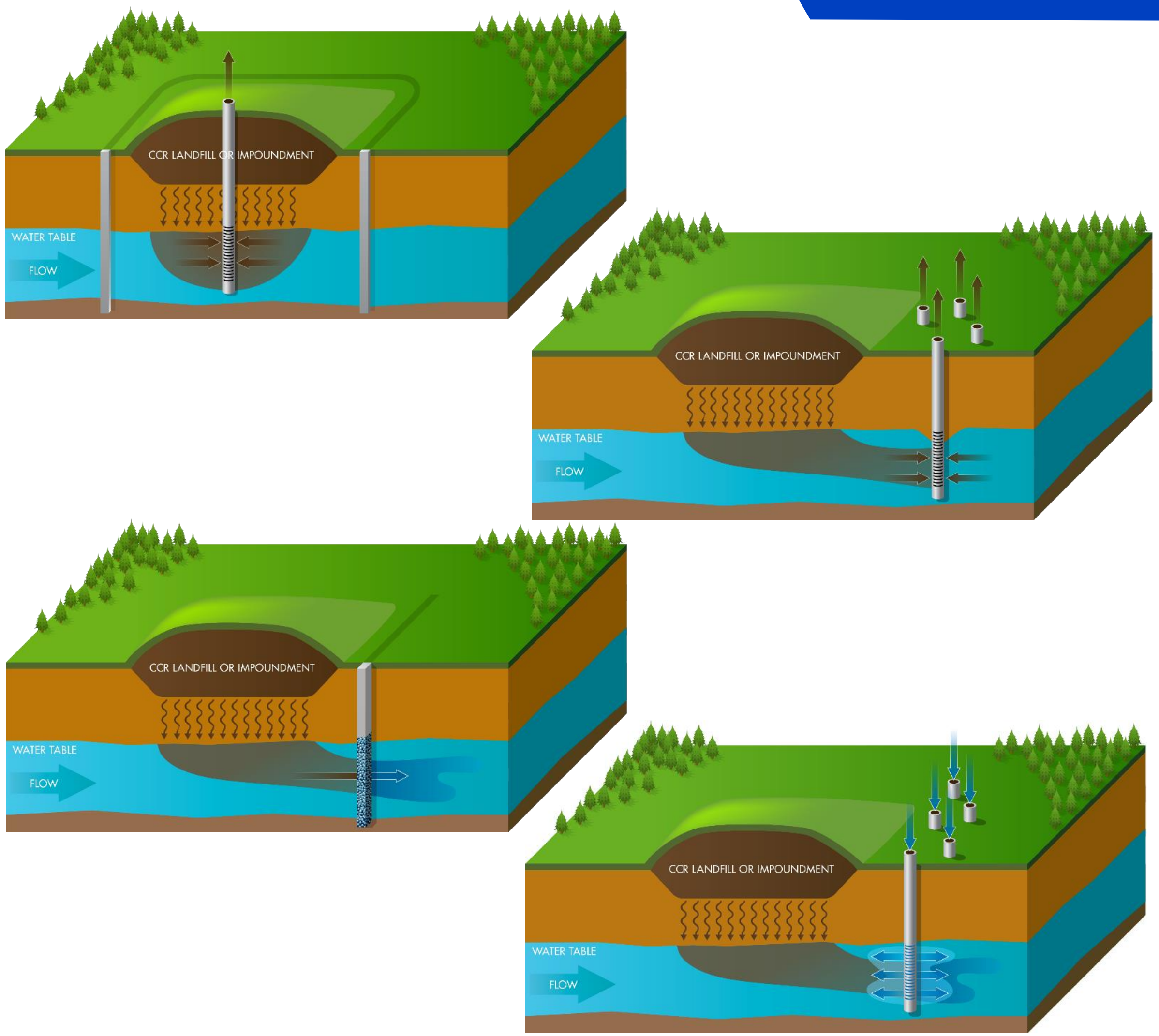
- Objectives
  - Provide information that can be used to consider risk, sustainability, and environmental justice when choosing between the viable options determined by an ACM
- "Sustainability"
  - Human health and ecological risk assessment
  - Green and sustainable remediation
  - Social equity
  - Cost
  - Performance
- Derived from concepts related to
  - Triple-bottom-line economics
  - Environmental, social, and governance (ESG)
  - Life-cycle analysis (LCA)
  - Net environmental benefit analysis (NEBA)
  - Sustainable remediation forum (SURF)
  - Environmental justice (EJ)
  - and other holistic remedy assessment literature.



Research to evaluate and demonstrate remedies with respect to risk, EJ, sustainability, and cost

Framework for evaluating corrective action alternatives at CCP units

- Assumptions
  - Closure option decided
  - Assessment of corrective actions completed
- Topics
  - Sustainable corrective action evaluation resources
  - Identification of relevant performance criteria
  - Framework development
  - Framework applications
    - Individual remedies and remedies in combination with MNA
    - For combinations, spatial or temporal MNA applications
  - Example site application
- Early 2023 deliverable



Applicable to landfills and impoundments; and to both CIP and CBR

Wrap-Up

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Questions?


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