


Cost Effective and SAFE Renewable Energy Storage Using Encapsulated CCRs

A Cost Effective Way to Protect Groundwater and Construct Large Energy Storage Structures

World of Coal Ash -- 2022
May 17, 2022

ENERGY & ENVIRONMENT
INNOVATION FOUNDATION, LLC

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Agenda and Discussion Topics

STATEMENT: A) **The projected cost of coal ash basin closure** and remediation is in **excess of $300 billion**, and construction of new renewable energy is expected to cost in excess of $4.5 trillion.

B) **Energy storage is an essential,** a challenging and very expensive part of the electric power energy transition. Practical and technical information on the following:

KEY POINTS:

- Financial and regulatory benefits of using encapsulated coal ash for construction of energy storage structures;
- Identification of the five main requirements in the Federal CCR Rule for coal combustion residuals (CCRs) to be considered a beneficial use;
- Explanation of how the energy storage structures can utilize large volumes of encapsulated CCRs, and provide a reduction in environmental liability;
- Guidelines on how the US EPA Leachability Environmental Assessment Framework (LEAF) testing can be used to verify encapsulation according to State regulatory requirements;
- Summary of recent applied research from the Department of Energy that provides guidelines for cost evaluation of energy storage options;
- Explanation of basic design and permitting requirements for pumped hydro storage and other energy storage methods;
- A list of recommended EPA guidance documents for the use and interpretation of leachability test methods as it pertains to stabilization and encapsulation of CCRs.

CALM Initiative – History of Safety Awareness Training Focused on Solving Problems with Ash Basin Construction – September 2015

- Invited 10 Industry Partners and 4 electric power utilities.
- Discussion on Demonstration Projects and shared funding approach to applied research.
- Listened and learned about industry needs and concerns.
- Results and recommendations:
  - Focus on access road and excavation stability – excess porewater pressures.
  - SAFETY AWARENESS: Ash basin safety training defined as an urgent and important need.
  - NEED FOR BMPs: Need to close gap between ash basin closure design approach and means and methods.

UNC CHARLOTTE
Energy Production and Infrastructure Center (EPIC)

Coal Ash and Liquid Managements (CALM)
AGENDA - Kick-off Meeting

Purpose: To develop practical, technology based solutions for the energy production industry problems and challenges with coal ash and liquid management.

Objective: To have an interactive discussion with respected industry leaders about how to accomplish the purpose of the EPIC CALM Office. This discussion will include discovering the unique, applied research capabilities at EPIC, and develop a practical set of ground rules and bylaws that solve problems in a cost effective manner.

Monday Sessions – September 14, 2015

11:30 a.m. to 12:30 p.m. – Monday Early Session: Midday start accounts for variable travel schedule, initial tours of EPIC and casual meetings with UNC Charlotte "coal ash" professors and other Industry Partners.

12:30 p.m. to 2 p.m. - Working Lunch and Introduction of Industry Partners: This session will allow each Industry Partner to provide 5 to 10 minute presentation of the following:
- Brief Introduction and Welcome to EPIC – David Young
- Brief Introduction of the EPIC CALM Office by Chris Hardin and Milind Khire.
- Introduction of Your Company and its unique capabilities
- How, what, when and where can the EPIC CALM Office provide assistance, leadership and guidance to you and your company?
- What would make the EPIC CALM Office relative to your company and help it with solving problems or obtaining new projects?
- Assuming your company would be one of the Founding Industry Partners what are the "hot buttons" positive and negative that you would like to see the CALM Office "Do and Not Do"?

CALM Initiative is the Largest Industry Consortium Focused on Safety and Solutions.
- 10 Contractors
- 3 Engineering Consultants
- 10 Special Technology Companies

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Background and Credentials of C. Hardin and the CALM Initiative

- Professional Engineer registered in six states including NC, SC, VA and GA.
- Former member of the American Coal Ash Association (ACAA) Executive Committee – Provided Industry Response Presentation – May 2009, Five months after TVA Kingston.
- Designed one of the first lined coal ash landfills in North Carolina – R.J. Reynolds Landfill in Rural Hall, NC and the first landfill after the TVA Kingston failure, Lee Steam Station in South Carolina. **Involved with coal ash remediation for over 25 years.**
- Designed and implemented one of the largest coal ash structural fills in North Carolina.
- Was present at the Dan River coal ash basin pipe repair to coach and guide contractors – Geotechnical & Safety
- Currently Managing Director of the Coal Ash and Liquid Management (CALM) Initiative at UNC Charlotte. Five of the largest Power Companies in the United States are members.
- Part-time sustainable, organic farmer who regularly interacts with environmental groups in the Carolinas. Over 70-percent "carbon neutral" and 70-percent recycle/reuse on our farm since 2012
- Purposely avoid litigation – periodically involved as a subject atter expert (SME) on several large coal ash projects.
- Currently involved with some of the largest, and most challenging ash basin closure design and construction projects in the United States.

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How BIG is the coal ash problem?

- **Coal ash is the second largest waste stream in the United States.** Over 1.9 Billion cubic yards of coal ash, plus and additional 130 million cubic yards each year.
- **The total cost of the coal ash basin cleanups will be in excess of $150 Billion across the United States.**
- **The majority on the cost of coal ash basins cleanups and closure will be passed on to the rate payers** – business, homeowners and the general public.
- **Summary: Anything we can do to reduce the cost of coal ash basin closure and increase beneficial use will reduce the "life cycle" cost of coal ash management and mitigation.**

US CCR units hold almost 2 billion cubic yards of coal ash

Operator	Total volume (cubic yards)
Duke Energy	158,229,472
Luminant Generation Co. LLC	149,167,842
FirstEnergy	135,311,789
Alabama Power	101,407,100
Tennessee Valley Authority	97,120,704
American Electric Power	83,222,886
DTE Electric Co.	66,743,230
PacifiCorp Energy	65,849,159
Monongahela Power Co.	64,660,910
Gavin Power LLC	64,426,618
Georgia Power Co.	63,798,436
Dominion Energy	62,771,197
NRG	59,469,762
Arizona Public Service Electric Co.	37,936,832
US total	**1,971,614,293**

Data compiled May 22, 2019.
CCR = coal combustion residuals
Includes CCR units that are subject to the U.S. Environmental Protection Agency's 2015 CCR rule.
Includes open and closed CCR units.
Excludes CCR units where volume data is not available or not reported at a unit level, which account for about 4% of all units.
Source: Earthjustice

CONTEXT: The Remediation of Coal Ash Basins will be the LARGEST and Could be the Most Expensive Cleanup in the History of the United States.

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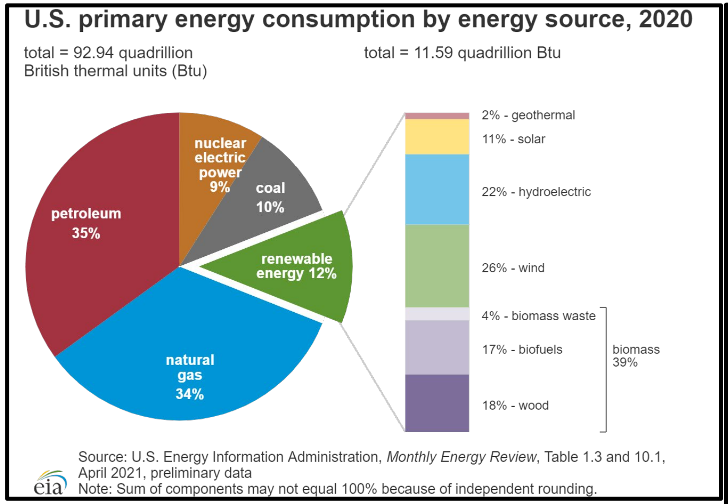
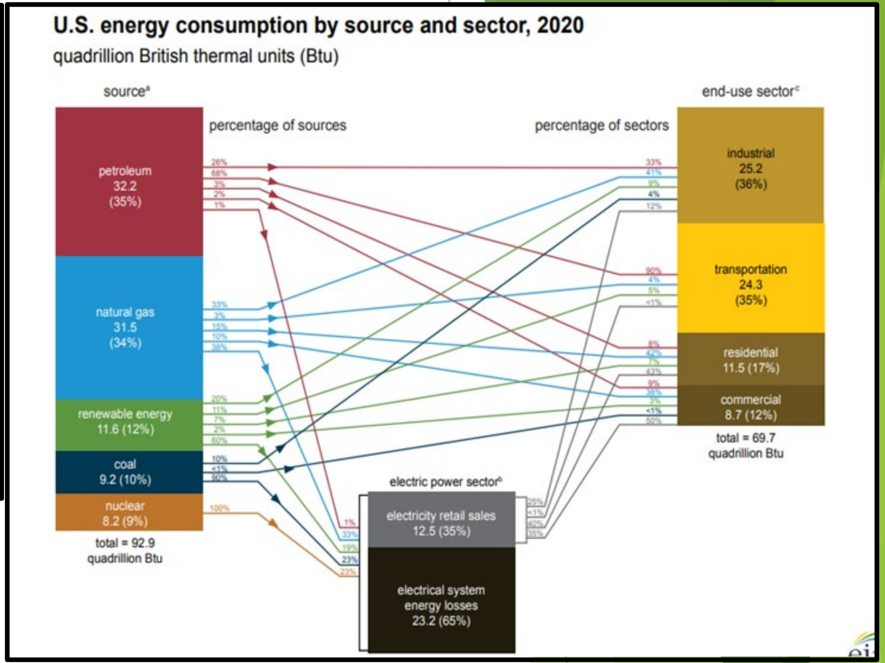
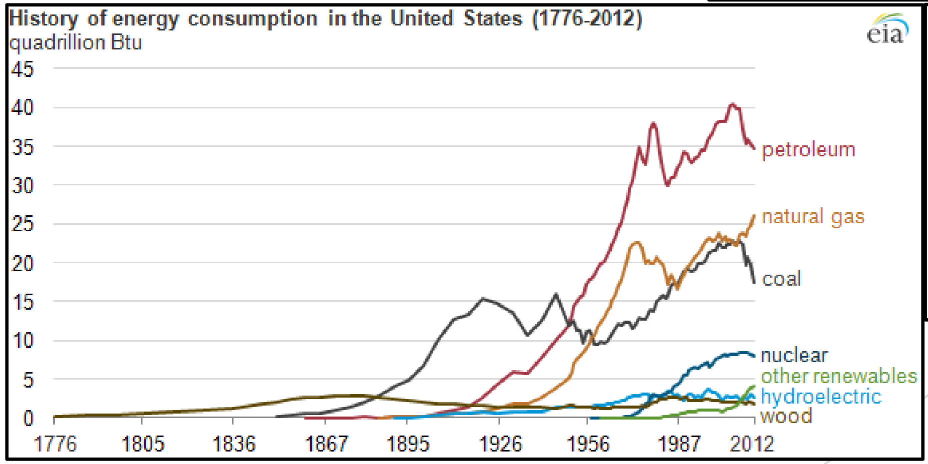
Where did all the coal cash come from?

- From a combination of residential, manufacturing and commercial electric power consumption.
- Coal combustion was a major source of electric power in the United States until 2010.
- Coal fired electric power production tended to be "cheap" energy, until the life cycle cost was considered.
- **The Answer: All or most Americans produced coal ash every they utilized and/or wasted electricity.**





https://www.eia.gov/todayinenergy/detail.php?id=11951



Probable Cost of Coal Ash Cleanups to Ratepayers and the Electric Power

Between $8 billion and $9 billion
The total cost to close all coal ash basins in the Carolinas will be between $8 billion and $9 billion, according to the utility. For years, the state and the utility have sparred over who should pay for the cleanup. Duke said customers should - Jan 25, 2021

North Carolina **ratepayers** were slated to pay $4 billion for the **cleanup** from 2015 to 2030, but after Friday's settlement they'll be on the hook for roughly $2.9 billion, according to Duke Energy spokeswoman Meredith Archie.
Jan 25, 2021

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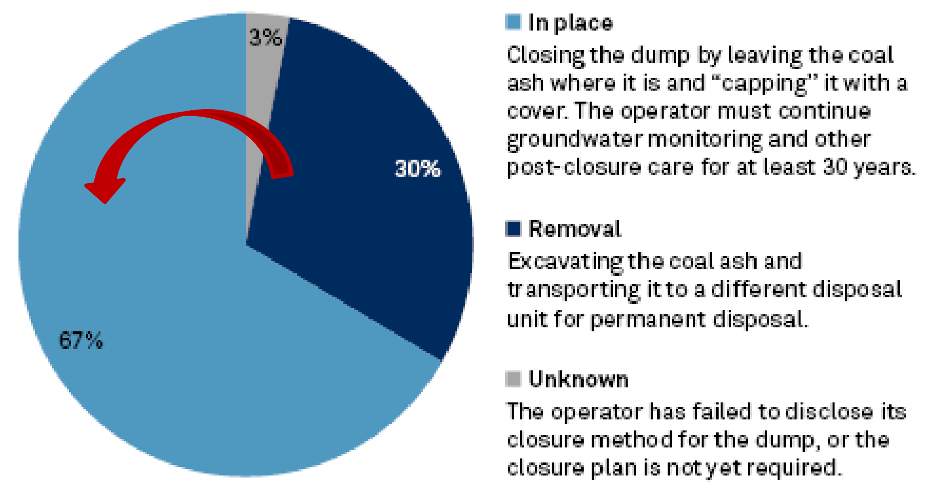
How will the cost of coal ash basin closure impact all Americans? Are there better options?

CONTEXT: The January 11, 2022 US EPA interpretation puts many Completed and To Be Completed Close-In-Place projects "At Risk".

- The majority of CCR units closed to date have been "closure in place".
- Closure in Place is approximately half of the cost of Closure by Removal.
- Many citizens and non-government organization (NGOs) clean water advocates are bringing legal action to force Closure by Removal.
- Closure by Removal can and will increase the cost of electricity for the general public and businesses.
- Increasing beneficial use addresses groundwater protection needs, and keeps the cost of Closure by Removal and/or excavation and landfilling reasonable.
- **Summary: Additional methods for using coal ash in recycled products, and/or for construction of building and energy storage structures are needed.**

Most CCR units to be closed in place, requiring post-closure care for at least 30 years



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Includes open and closed CCR units.
Source: Earthjustice

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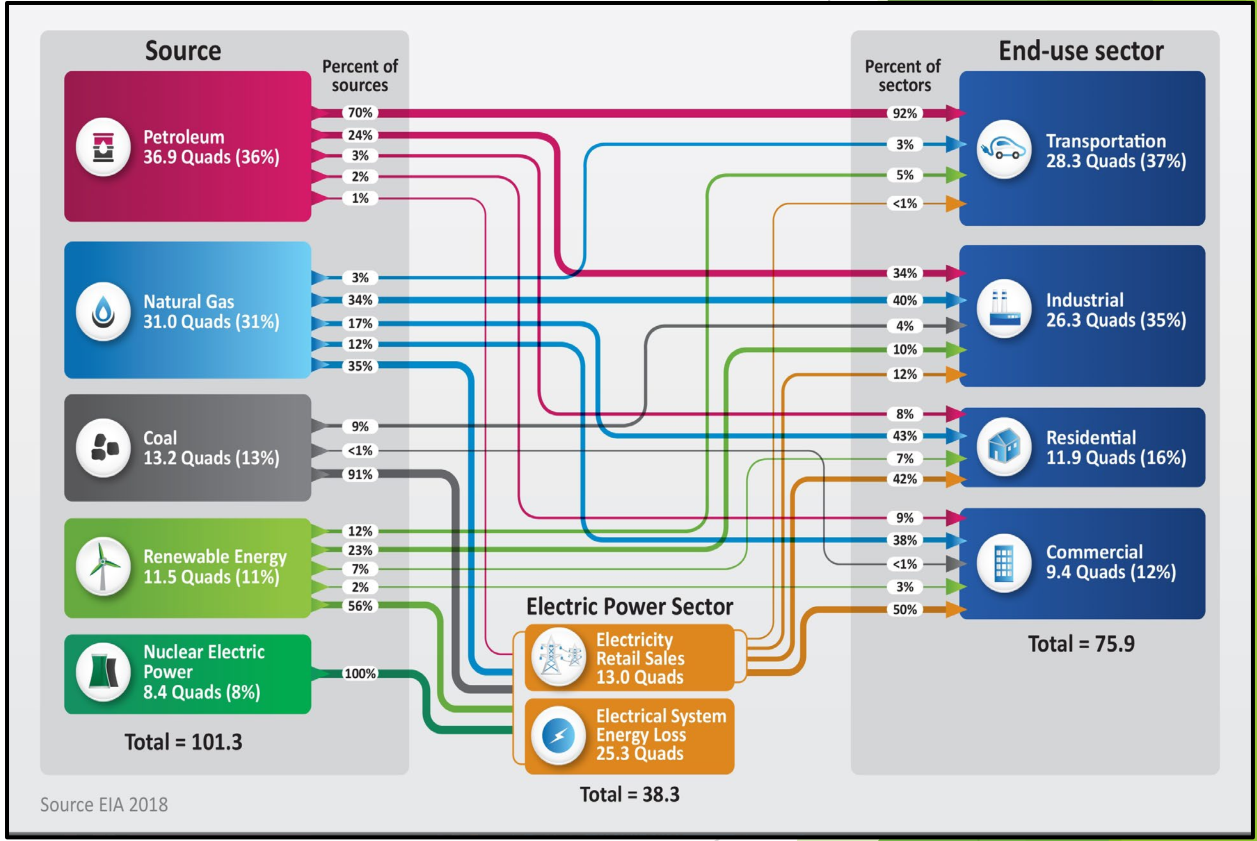
How Much Electric Power Energy is Wasted Every Day Before it Gets to the Consumer?

- **According to the Energy Information Administration (EIA), thirty-four (34) percent of electric power energy is wasted BEFORE it gets to the meter.**
- Most of the energy is wasted during transmission from the point of Generation to the location of use.
- Other sources include excess energy generated during non-peak periods, and release of excess energy from heated steam and process water.
- **Practical Ways to Save Electric Energy:** Voltage regulation close to the source of generation, and increasing the amount of cost effective distributed energy are



Ref: https://www.eia.gov/energyexplained/electricity/use-of-electricity.php
How Much Primary Energy Is Wasted Before Consumers See Value from Electricity? Bob Shively, Energy Dynamics, https://www.enerdynamics.com/

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Financial and Regulatory Benefits of Using Encapsulated CCRs for Energy Storage

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The Solution

Krubera's patented CCR Static Structures provide cost-effective options for the beneficial use of CCR that can utilize 100% of the ash stored in ponds, converting the material to a productive use within a reasonable timeframe.

Key Characteristics

- Beneficial Use of Large Volumes of CCR
  - Can utilize 100% of ponded ash
  - Able to coordinate with other beneficiators
- Compliant with CCR Rule
  - Meets all (4) beneficial use criteria
  - Meets/Exceeds CCR Rule project timeframe
- Practical / Cost Effective Solutions
  - Eliminate or minimize trucking expenses
  - Creates useable infrastructure*
  - Generates both short and long term jobs

Krubera Management Group, LLC

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*High Probability of being reimbursable through rate base

Contents are Confidential; Patent Nos. 9,790,703 and 9,988,317, licensed from Go Team CCR LLC, additional embodiments are Patent Pending. Copyright © 2016. All Rights Reserved.

Beneficial Use Criteria

Each of Krubera's solutions meet all of the beneficial use requirements mandated by EPA in its 2015 Final Rule.

Beneficial Use Criteria

1. Provide a functional benefit
2. Substitute for the use of a virgin material
3. Meet product specifications and/or design standards or not use excess quantities
4. Unencapsulated uses shall not impart environmental releases beyond relevant regulatory benchmarks*

Ref: https://www.epa.gov/coalash/frequent-questions-about-beneficial-use-coal-ash#t1q6

Krubera Management Group, LLC

* Encapsulated uses are not considered a regulated waste material.

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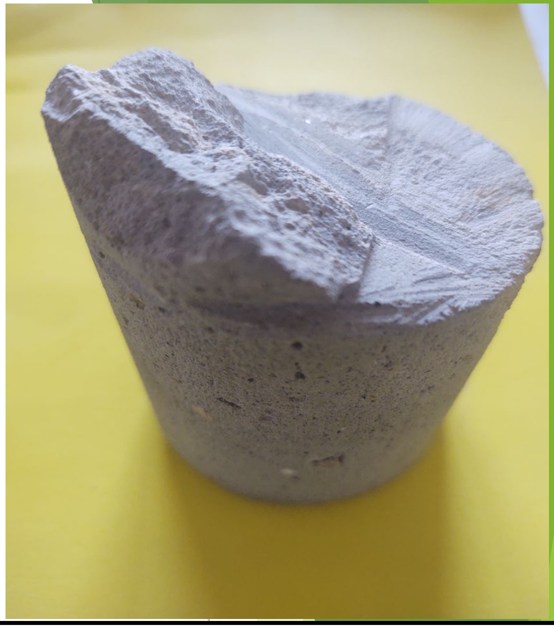
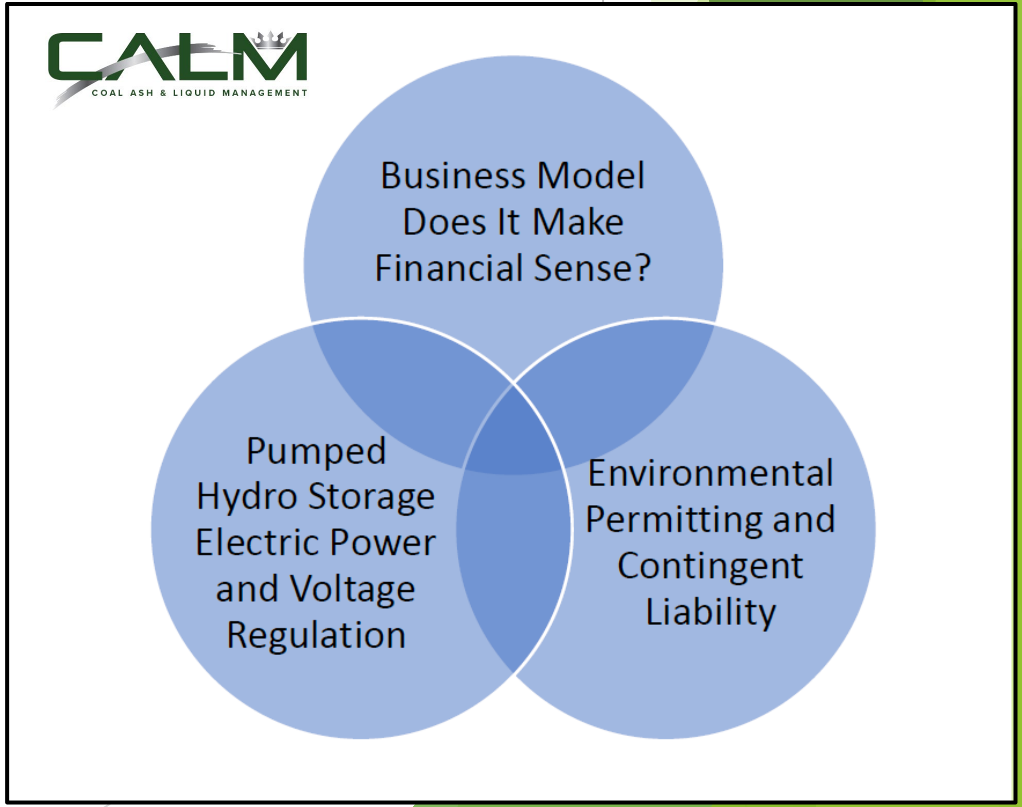
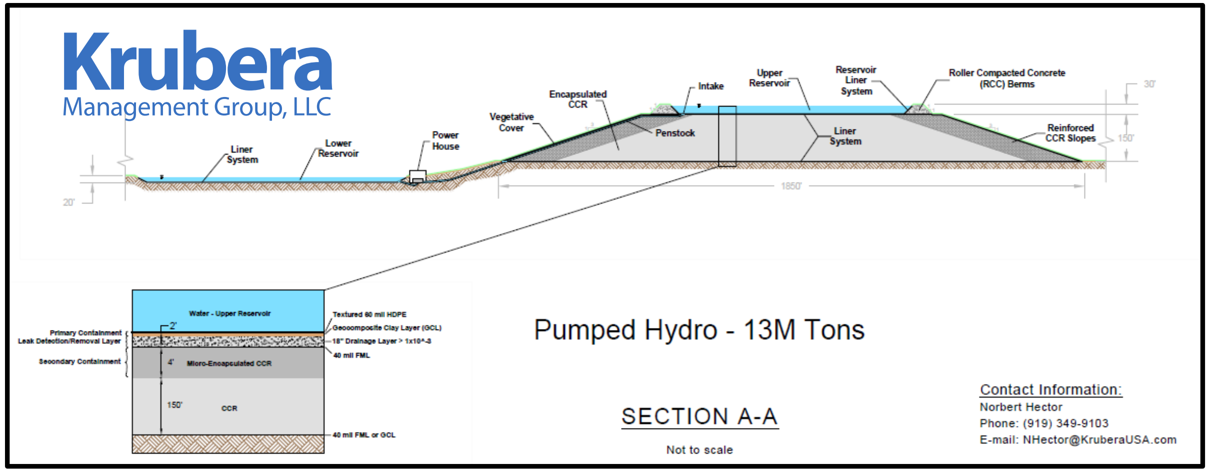
The Value of Encapsulated CCRs for Energy Storage Structures



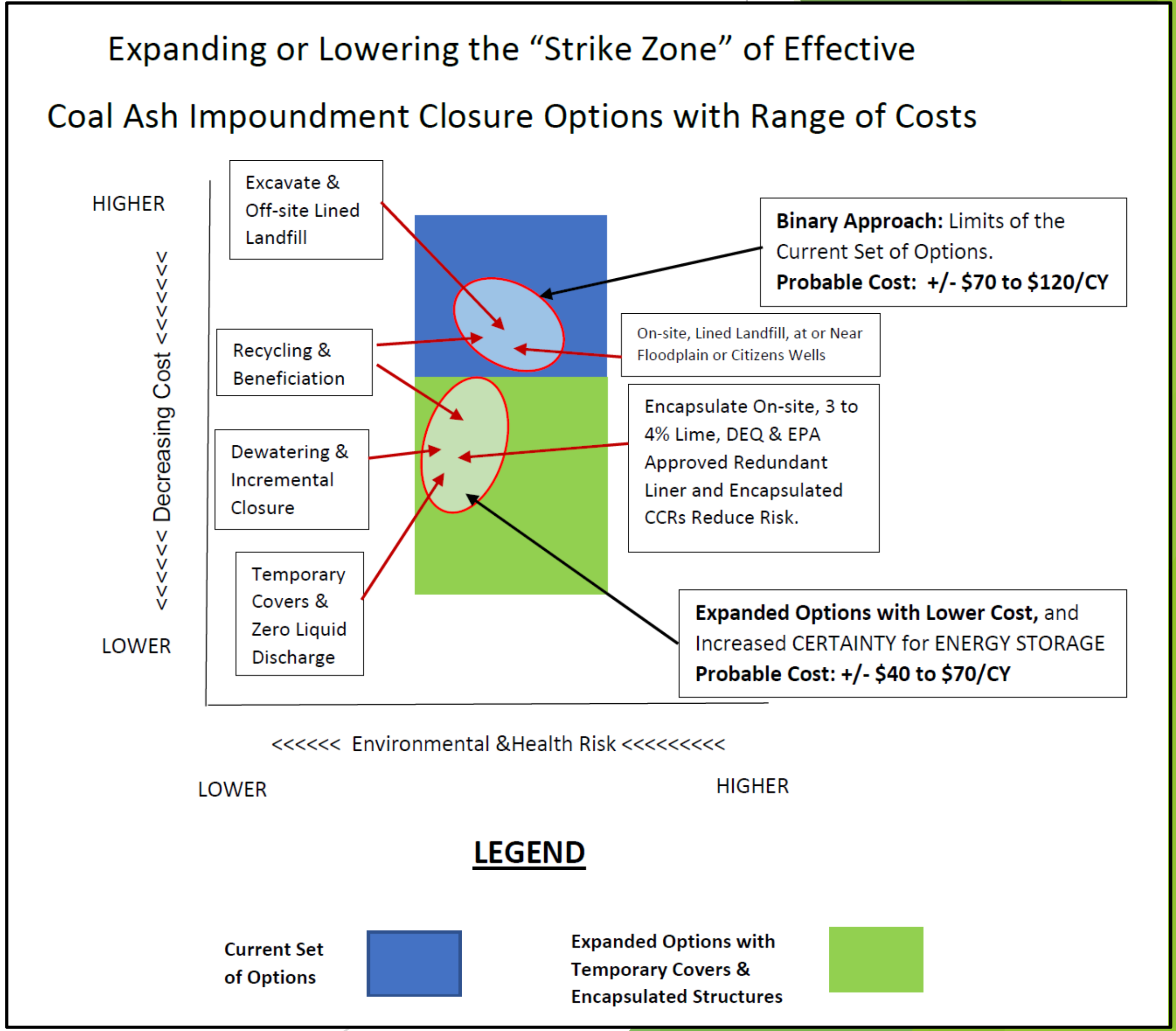
- Encapsulated Coal Combustion Residuals (CCRs) are no longer considered a waste material.
- Pumped Hydro Storage structures from CCRs can be monetized in the electric power rate base.
- Encapsulation of CCRs are equally protective as lined landfills, and reduce the Life Cycle Cost.





A Critical Need to Convert More CCRs to Useful Energy Storage and Ancillary Structures

- Coal Ash Basin Remediation by Excavation and Lined Landfills is necessary to protect groundwater, but tends to be EXPENSIVE.
- **QUESTION:** Are there better and more cost effective methods for handling and utilization of CCR materials?
- **Encapsulated CCRs placed over an HDPE liner Reduces Risk and Creates a Useful Energy Storage Structure.**



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Four Main Requirements for Encapsulated CCR from the Federal CCR Rule.

- Definition and Four Main Requirements – THIS IS THE LAW!
- Federal CCR Rule – Guidelines, Testing and Methodology
- Mix Design and Stabilization Methods

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Four Main Criteria for Beneficial Use of CCRs in Structures

- Provide a functional benefit
- Substitute for the use of a virgin material
- Meet product specifications and/or design standards or not use excess quantities
- Unencapsulated uses shall not impart environmental releases beyond relevant regulatory benchmarks

Ref: https://www.epa.gov/coalash/frequent-questions-about-beneficial-use-coal-ash#t1q6

FEDERAL REGISTER

Vol. 80 No. 74 Friday, April 17, 2015

Part II

Environmental Protection Agency

40 CFR Parts 257 and 261
Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities; Final Rule


21328 Federal Register / Vol. 80, No. 74 / Friday, April 17, 2015 / Rules and Regulations

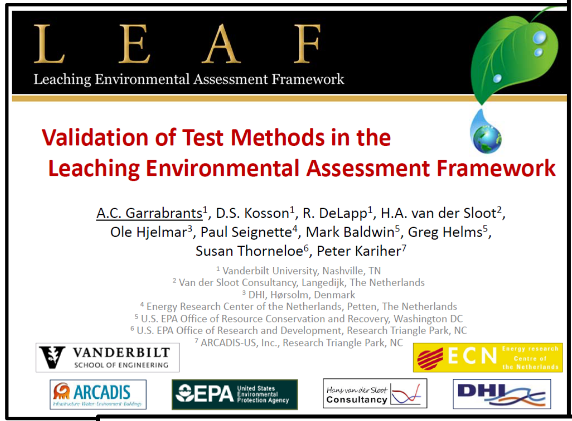
a. Final Definition of the Term "Beneficial Use of CCR"

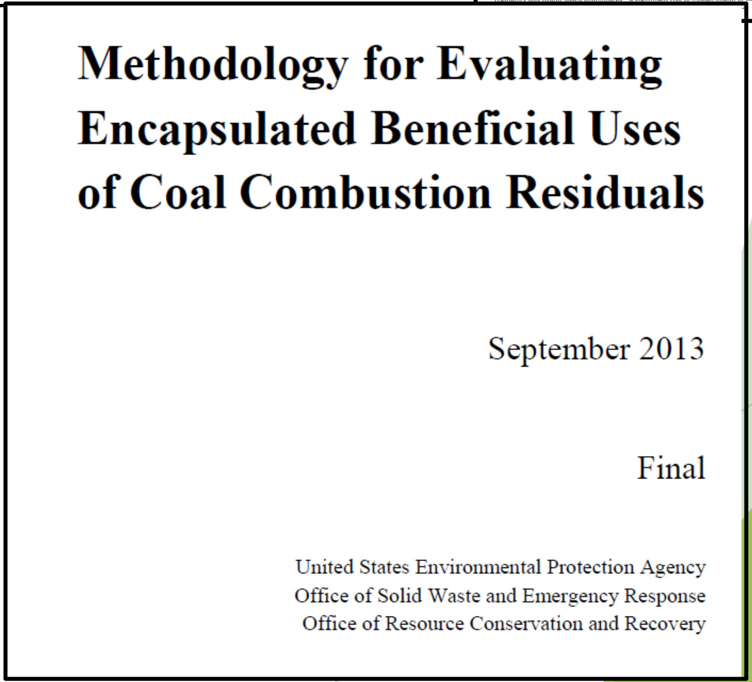
The final beneficial use criteria are as follows: (1) The CCR must provide a functional benefit; (2) The CCR must substitute for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices such as extraction; (3) the use of CCR must meet relevant product specifications, regulatory standards, or design standards when available, and when such standards are not available, CCR are not used in excess quantities; and (4) when unencapsulated use of CCR involves placement on the land of 12,400 tons or more in non-roadway applications, the user must demonstrate and keep records, and provide such documentation upon request, that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use. Any use that fails to comply with all of the relevant criteria will be considered to be disposal of CCR, subject to all of the requirements in the disposal regulations, and the user will be considered to be the owner or operator of a CCR disposal unit.

See Federal CCR Rule: Page 21349

Explanation of the Encapsulation and the Leachability Environmental Assessment Framework (LEAF)

- Encapsulation in a "cementious" solid matrix is identified on Page 21328 of the Federal CCR Rule as the preferred method for SAFE Beneficial Use of CCRs.
- LEAF is a useful Design Tool to evaluate Encapsulation.
- LEAF is NOT a Compliance Test, but a collection of:
  - Four leaching test methods that are designed evaluate leaching potential of industrial waste materials, and site specific conditions.
  - Associated with SW-846, a compendium of test method to evaluate and separate leaching potential of industrial material and hazardous materials.
  - LEAF waste developed by the US EPA to identify characteristic leaching behaviors in a wide variety of industry materials including CCRs.
- https://www.epa.gov/hw-sw846/how-guide-leaching-environmental-assessment-framework





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Regulatory Requirements for Encapsulation and Beneficial Use of CCRs

- **The Federal CCR Rule has clear guidelines on the beneficial use** of CCR materials.
- **Evaluation of beneficial use and testing for verification of encapsulation** is outlined on Pages 21327 to 21330 in the Federal CCR Rule.
- **The Leachability Evaluation and Assessment Framework (LEAF) is an EPA recognized method** that establishes a way to verify that heavy and metals and other constituents will not leach from stabilized CCR materials.
- **Summary: There are technical and regulatory considerations that must be addressed and "proven" by testing and evaluation using guidelines from the US EPA.**

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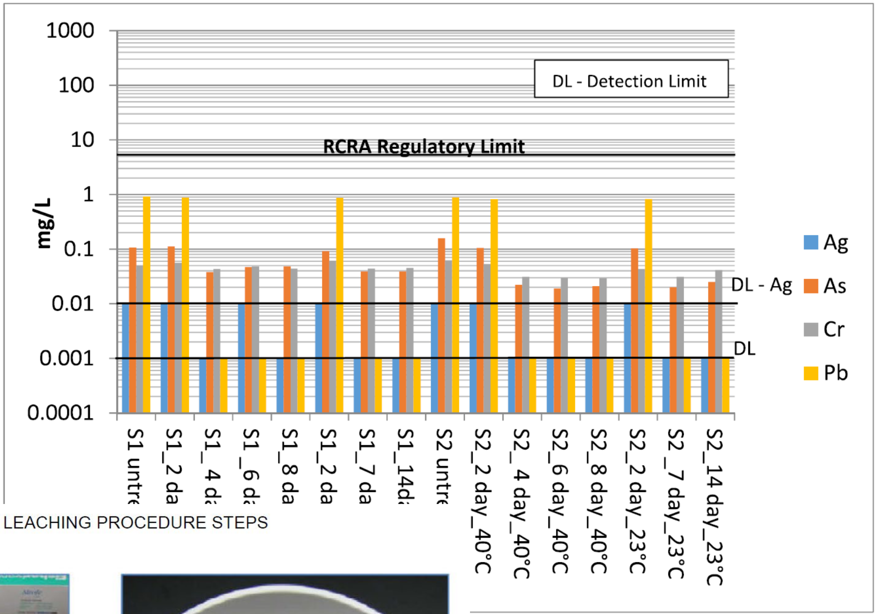
Definition and Historical Context on Encapsulation

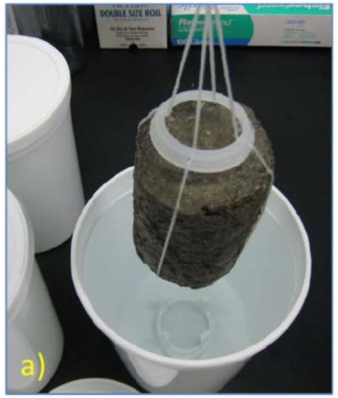
- Federal CCR Rule – Page 21327: "An encapsulated beneficial use is one that binds the CCR into a solid matrix that minimizes mobilization into the surrounding environment"
- Lime stabilized fly ash and volcanic ash has been used for hundreds of years in building construction, roadway construction and waterway construction.
  - Roman concrete, also called opus caementicium, was based on a hydraulic-setting cement. It is durable due to its incorporation of volcanic ash bound in chemical bond by lime, which prevents cracks from spreading and increases durability.
  - Lime stabilized fly ash is longer lasting and more stable than typical cement based concrete.
  - Lime stabilized fly ash is resistant to sulfate attack can be used to stabilize a wide variety waste materials.
- Coal fly ash encapsulated with lime and/or cement has been used for over 40 years to stabilize and prevent migration of contaminants from a wide variety of hazardous waste and industrial waste materials. **Ref: Solidification/Stabilization of Hazardous Waste, January 1986, EPA/600/D-86/028**

EPA Outlines a Step by Step Process to Verify Encapsulation of CCRs – Steps 1 and 2

- Step No. 1: Develop Mix Design utilizing EPA 1313: Leaching as a Function of pH. Develop Target pH and percentages of quicklime or cement – See Daniels and Das, 2006, Lhoist lab results and Ogunro, et al, WOCA 2015
- Step No. 2: Test Mix Design: Utilizing a combination of EPA 1315 and TCLP at different lime/cement percentages and target pH for leachate.



EXAMPLE LEACHING PROCEDURE STEPS



Start of Leaching Interval

Sample Centered in Eluant (top view)

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Summary of Technical Literature Dams and Highways

- Leaching Behavior of Lime-Fly Ash Mixtures, Daniels and Das, 2006

  - Provides specific guidelines for lime required to stabilize metals in coal ash

- US Bureau of Reclamation and Federal Highway Administration reports and projects demonstrate mix designs and methods to stabilize coal fly ash.
- EPRI and other ACAA funded research reports indicate that coal fly can be stabilized with lime and cement mixtures.
- Lhoist mix designs and test results from previous CALM meeting presentation, November 2018 are available upon request.

Fly Ash Facts for Engineers
FHWA-IF-03-019

INTRODUCTION
Fly ash stabilized base courses are proportioned mixtures of fly ash, aggregate, and an activator (cement or lime) that, when properly placed and compacted, produce a strong and durable pavement base course. Fly ash stabilized base courses are cost-effective substitutes for properly engineered full-depth asphalt, cement-treated, and crushed stone base courses. Fly ash stabilized base course is suitable for both flexible and rigid pavements.

MIX DESIGN AND SPECIFICATION REQUIREMENTS
Mix design. The stabilization of aggregate road bases with fly

Fly Ash in Stabilized Base C

REC-ERC-84-15

MIX DESIGN INVESTIGATION —
ROLLER COMPACTED CONCRETE
CONSTRUCTION,
UPPER STILLWATER DAM, UT

June 198
Engineer

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Brine-Encapsulation Bench & Field Testing Recommendations

y Yeboah[2], and Corné Pretorius[3]

1300 W. WT Harris Blvd., Charlotte, NC 282621;
nblee Tucker Rd, Atlanta, GA 30341;
2920 Virtual Way, Vancouver, BC, V5M 0C4.

ne, ELG, CCP, Encapsulation, Paste

rs, and EPC firms are all actively investigating the
hnically and environmentally feasible approach for
onsite byproducts such as fly ash. Many sites are
f volume reduction technologies, such as thermal
ns exists for responsible disposal of the resulting
that brines can be combined with fly ash for landfill
ing the viability of the concept has not been
a recommended methodical approach for testing
ort, deposition, geotechnical, and environmental
recommendations presented here are by no means
n ongoing projects and lessons learned for both
ons and are intended to be updated over time as
d of research.

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Leaching Behavior of Lime–Fly Ash Mixtures

John L. Daniels,* and Gautham P. Das

Department of Civil Engineering and GIEES
University of North Carolina at Charlotte
Charlotte NC 28223

ABSTRACT

As part of a larger investigation that included numerical and field-based components, the use of lime to reduce the leachability of a coal combustion fly ash was evaluated in the laboratory. The focus of this paper is on the experimental assessment of lime–fly ash leachability through sequential leach (SL), freeze–thaw (FT), and wet–dry (WD) leaching as well as multileachant sequential extraction (SE) tests. The objectives were to study the leachability of trace elements, including arsenic (As), cadmium (Cd), chromium (Cr), and selenium (Se). These results suggest that lime addition reduces the leachability for Cd, Se, and to some extent As. They also suggest that Cr is rendered more leachable with increasing lime content, for the conditions and low levels tested. It appears that there is a threshold lime content (>1.0%) that must be exceeded prior to reducing the leachability of As and Se. In particular, this threshold likely corresponds to the level at which appreciable cementitious reactions have developed. For example, in the case of As after the first cycle of leaching, the concentration was below the reporting limit (10 μg/L) for 0% lime. However, at 0.5% lime amendment, the leached concentration increased to nearly 50 μg/L. Subsequent lime additions reduced this concentration. No such threshold was observed for Cd leachability as was expected as a direct consequence of hydroxide precipitation, which is well established under the measured pH conditions. As such, Cd mobility is insensitive to the extent to which cementitious reactions are initiated. Overall, the results suggest that while lime stabilization may be effective for reducing leachability, sufficient amounts must be added; otherwise, the leachability of some constituents can actually be exacerbated.

Key words: lime stabilization; fly ash; leachability

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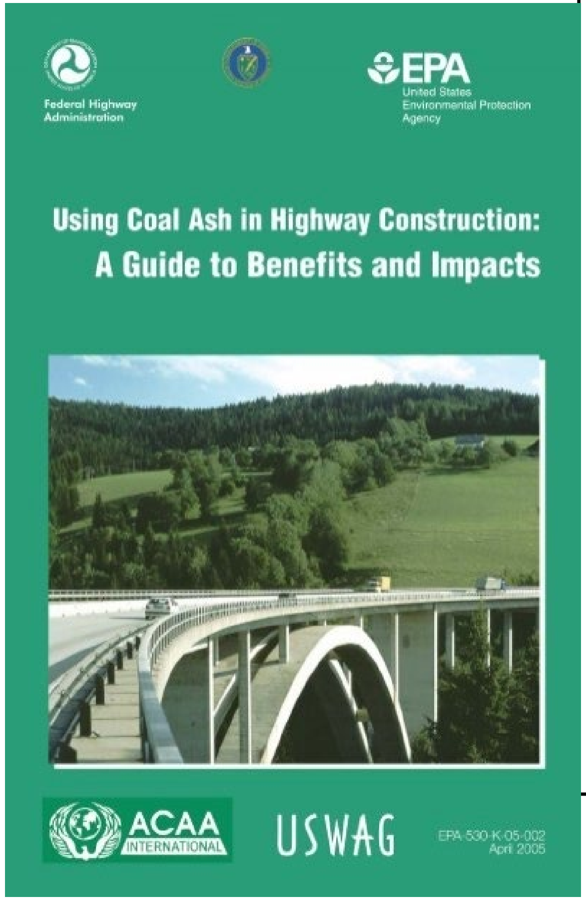
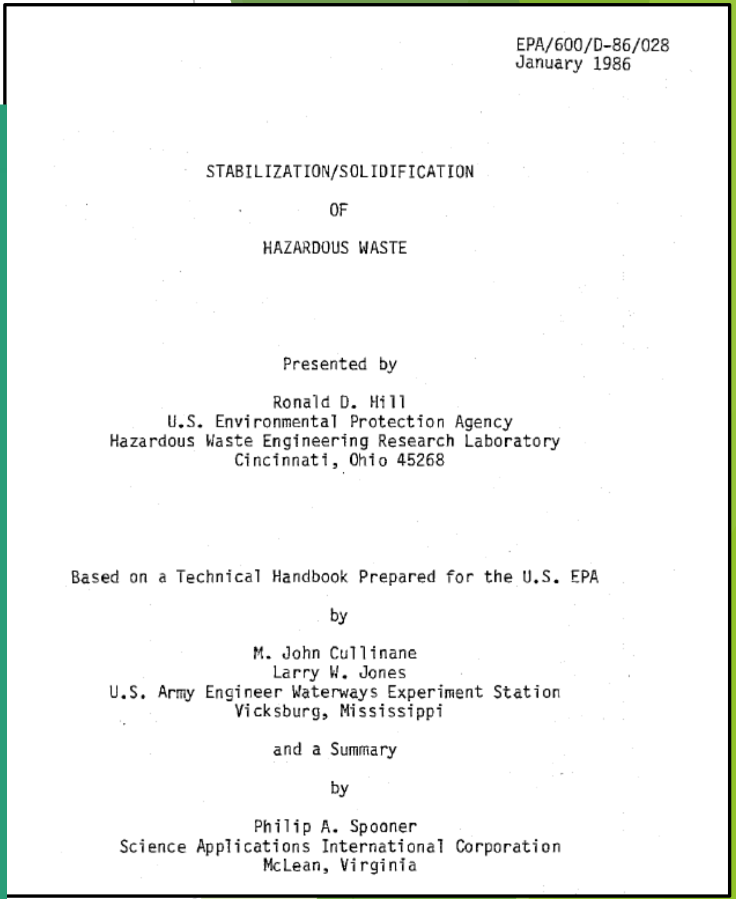
Historical Context of Encapsulation and Stabilization US EPA, FHWA and USWAG

- **Support from Test Results and Standard Methods from Federal Agencies:** The Federal Highway Administration (FHWA), the US EPA Hazardous Waste Research Laboratory and the US Bureau of Reclamation (USBR) have research, test results and standard methods verifying that coal fly ash is a SAFE, and cost effective construction material with cement, lime and other additives.
- **Encapsulation and Stabilization are similar terms** from a scientific and engineering perspective. See Stabilization/Solidification of Hazardous Waste, EPA/600/D-86/028, US EPA Hazardous Waste Engineering Research Laboratory.
- Federal Highway Administration (FHWA) has recognized the benefits of using coal fly ash for SAFE and effective road subbase stabilization for over 40 years.
- **Summary: The US EPA, FHWA, and other Federal organizations have recognized that coal fly is a SAFE and effective way to stabilize waste materials and improve road subgrades for construction, IF they are pre-tested and used properly.**




EPA/600/D-86/028
January 1986

STABILIZATION/SOLIDIFICATION

OF

HAZARDOUS WASTE

Presented by

Ronald D. Hill
U.S. Environmental Protection Agency
Hazardous Waste Engineering Research Laboratory
Cincinnati, Ohio 45268

Based on a Technical Handbook Prepared for the U.S. EPA

by

M. John Cullinane
Larry W. Jones
U.S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

and a Summary

by

Philip A. Spooner
Science Applications International Corporation
McLean, Virginia

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How Energy Storage Structures Utilize Large Volumes of Encapsulated CCRs, and Reduce Environmental Liability

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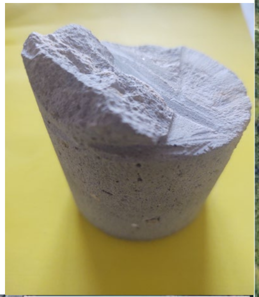
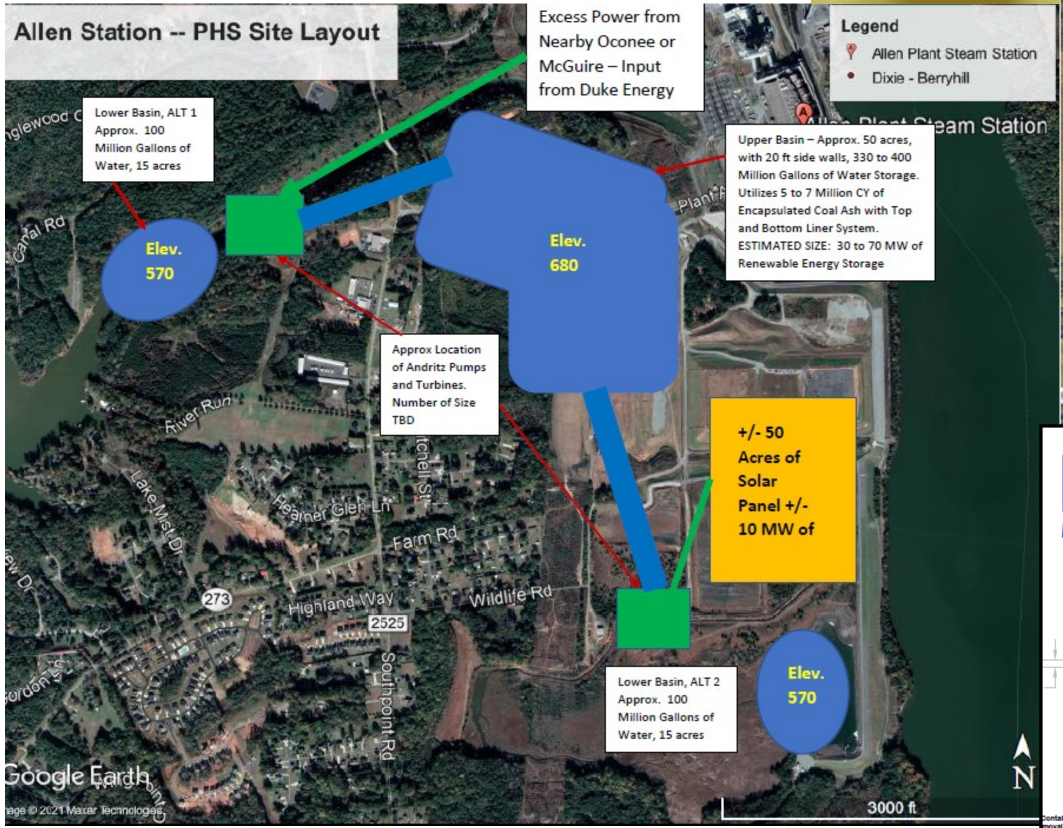
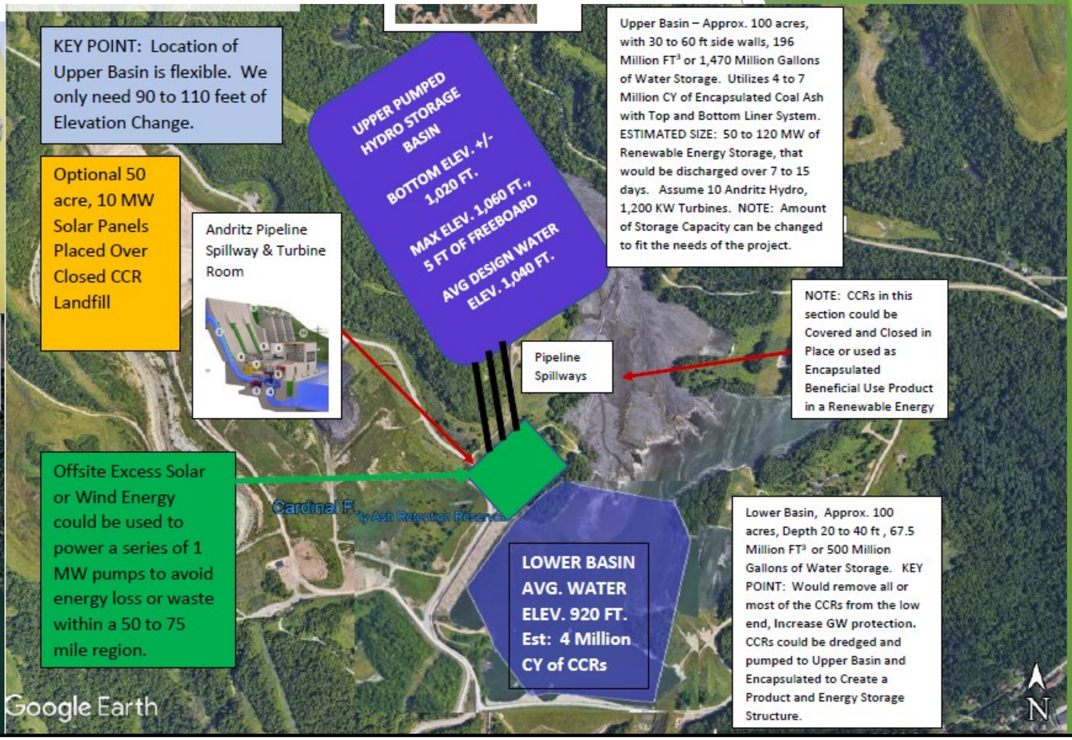
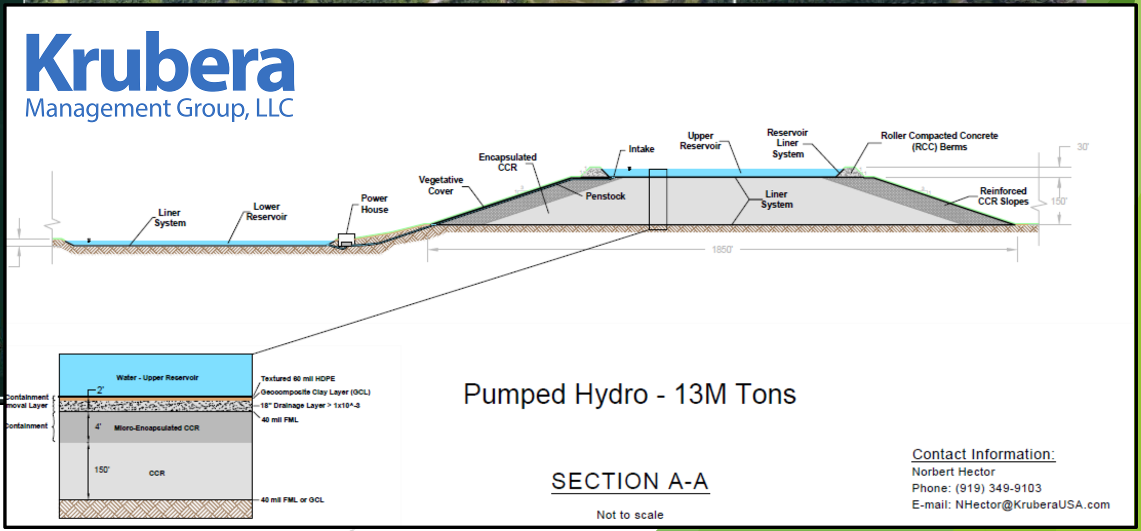
Typical Layout for Energy Storage on a Coal Ash Basin Sites

Example Project Sites
Photos from Public Record









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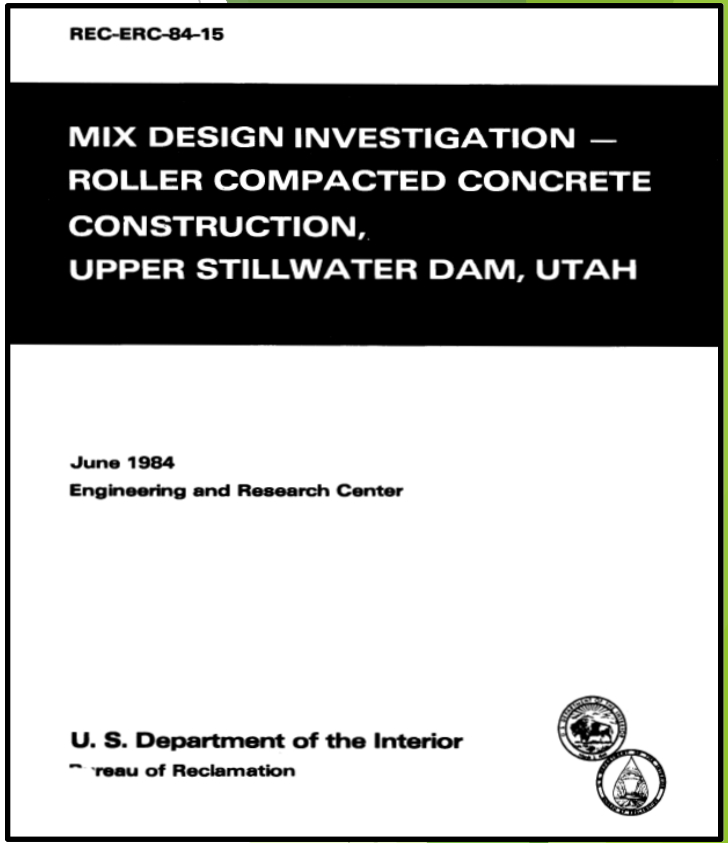
Coal Fly Ash Mixes Have Been Used for Over 50 years in Dam and Water Impoundments

- US Bureau of Reclamation has used high volume fly ash cement mixes since the 1980s.
- The Ameren, Taum Sauk Pumped Hydro Dam repair was completed with a high fly mix to reduce micro cracking and seepage.
- **High Fly Mix Designs are a time tested, technically sound way to encapsulate coal fly ash and build useful water and energy storage structures.**

Taum Sauk Pumped Hydro Storage (PSH) Embankment Failure

Taum Sauk During Repair – Cement, Fly Ash & RCC

Taum Sauk PSH After Repair with High Volume Fly Ash Mix



REC-ERC-84-15

MIX DESIGN INVESTIGATION — ROLLER COMPACTED CONCRETE CONSTRUCTION, UPPER STILLWATER DAM, UTAH

June 1984
Engineering and Research Center

U. S. Department of the Interior
reau of Reclamation

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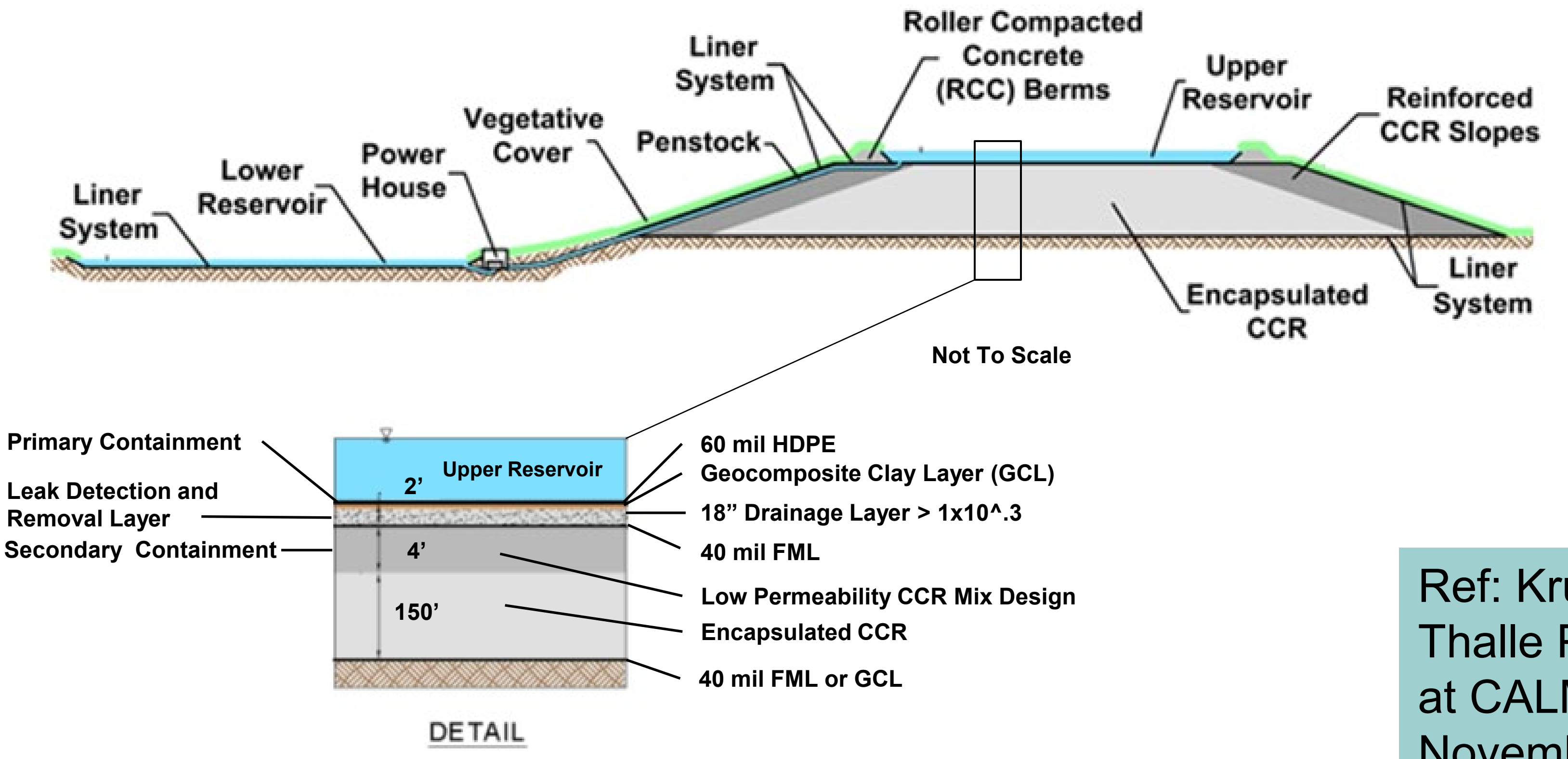
Pumped Hydro Energy Storage

Krubera's pumped hydro system can be designed using proven technology and sized to meet the site specific project requirements.

Pumped Hydro Energy Storage



Ref: Krubera & Thalle Presentation at CALM Meeting, November 2019

Contents are Confidential; Patent Nos. 9,790,703 and 9,988,317, licensed from Go Team CCR LLC, additional embodiments are Patent Pending. Copyright © 2016. All Rights Reserved.

Mix Design / LEAF and US EPA Encapsulation Methodology

The mix design for this project (for CCR materials at the Dominion sites) has been developed based on site specific testing of concrete mixes and recently completed applied research testing by UNC Charlotte and Lhoist.

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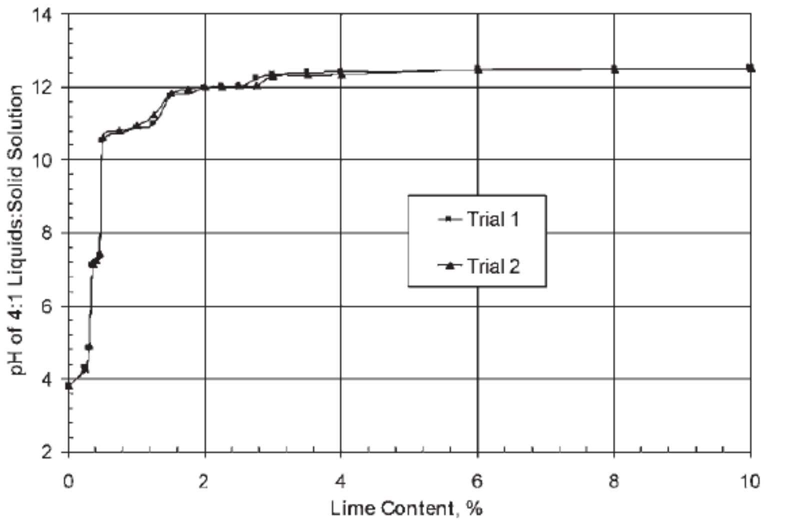

Figure 1. Relationship between pH and lime content

Ref: Krubera & Thalle Presentation at CALM Meeting, November 2019

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ANDRITZ GROUP

MODULAR PUMP STORAGE

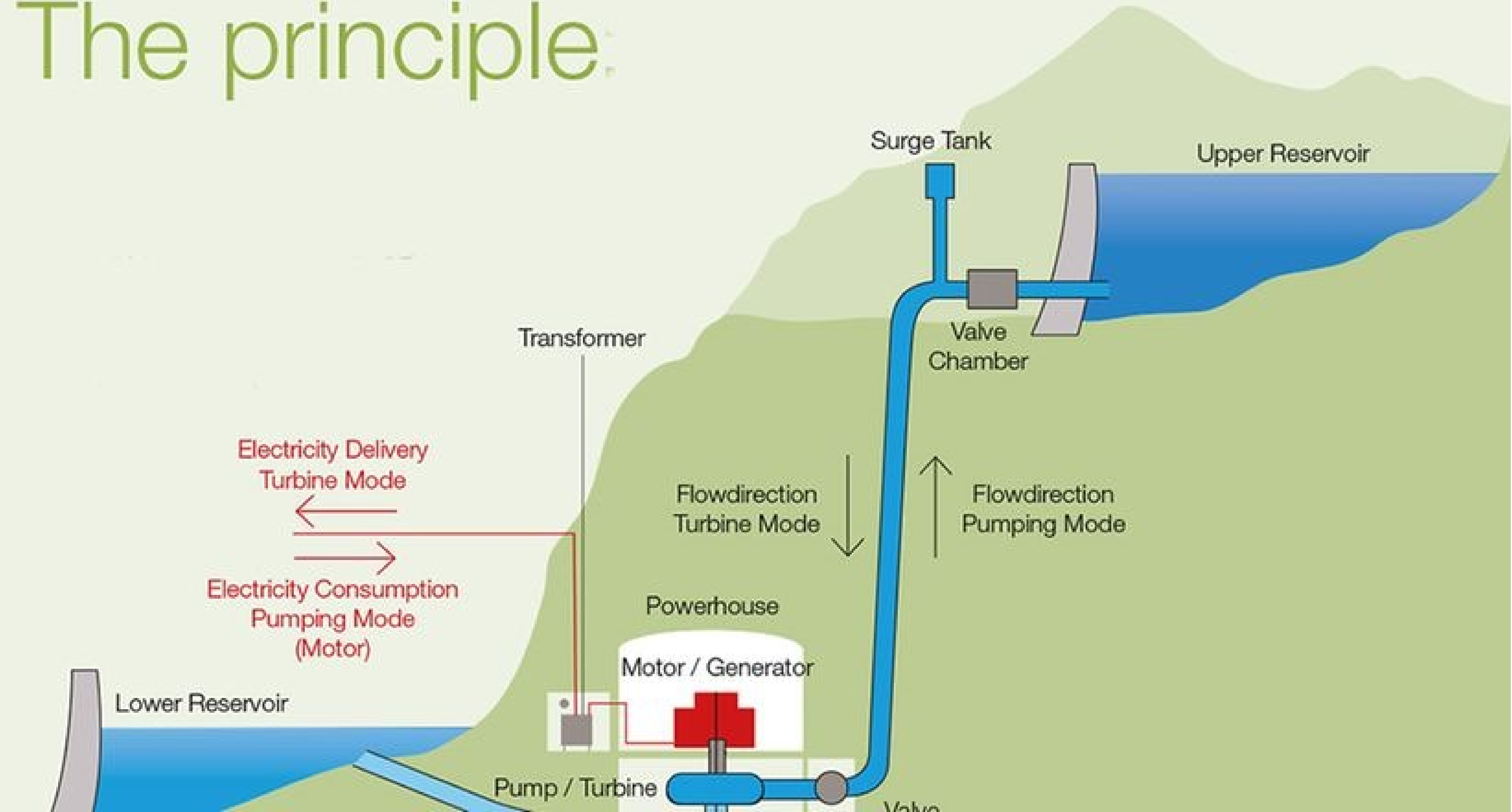
CALM INITIATIVE AND ENVIRO WORKSHOPS
ENERGY & ENVIRONMENT WORKSHOP

ANDRITZ HYDRO SLIDES
CALM Initiative Fall 2021
Technology Meeting

ENGINEERED SUCCESS

Brian A. Murtha, PE
Business Development Director
ANDRITZ
Charlotte, NC USA
704.712.8611
brian.murtha@andritz.com

The principle



ANDRITZ HYDRO-DIVISION SUMMARY

LARGE HYDRO

hydro- and electro-mechanical equipment for large turn-key / expansion projects; as well as modification of existing plants

COMPACT HYDRO

world's leading provider for small and mini hydropower plants - providing the full spectrum of electro-mechanical equipment

SERVICE & REHAB

solution oriented state-of-the-art service and rehabilitation solutions to increase profitability and extend plant life span

PUMPS

pumps that meet the demand for ever-larger, higher performance units, whether for low flow rates or wear-resistant applications

→ Modular Pump Storage ←

DEFINITION OF COMPACT HYDRO

COMPACT HYDRO APPLICATION RANGE

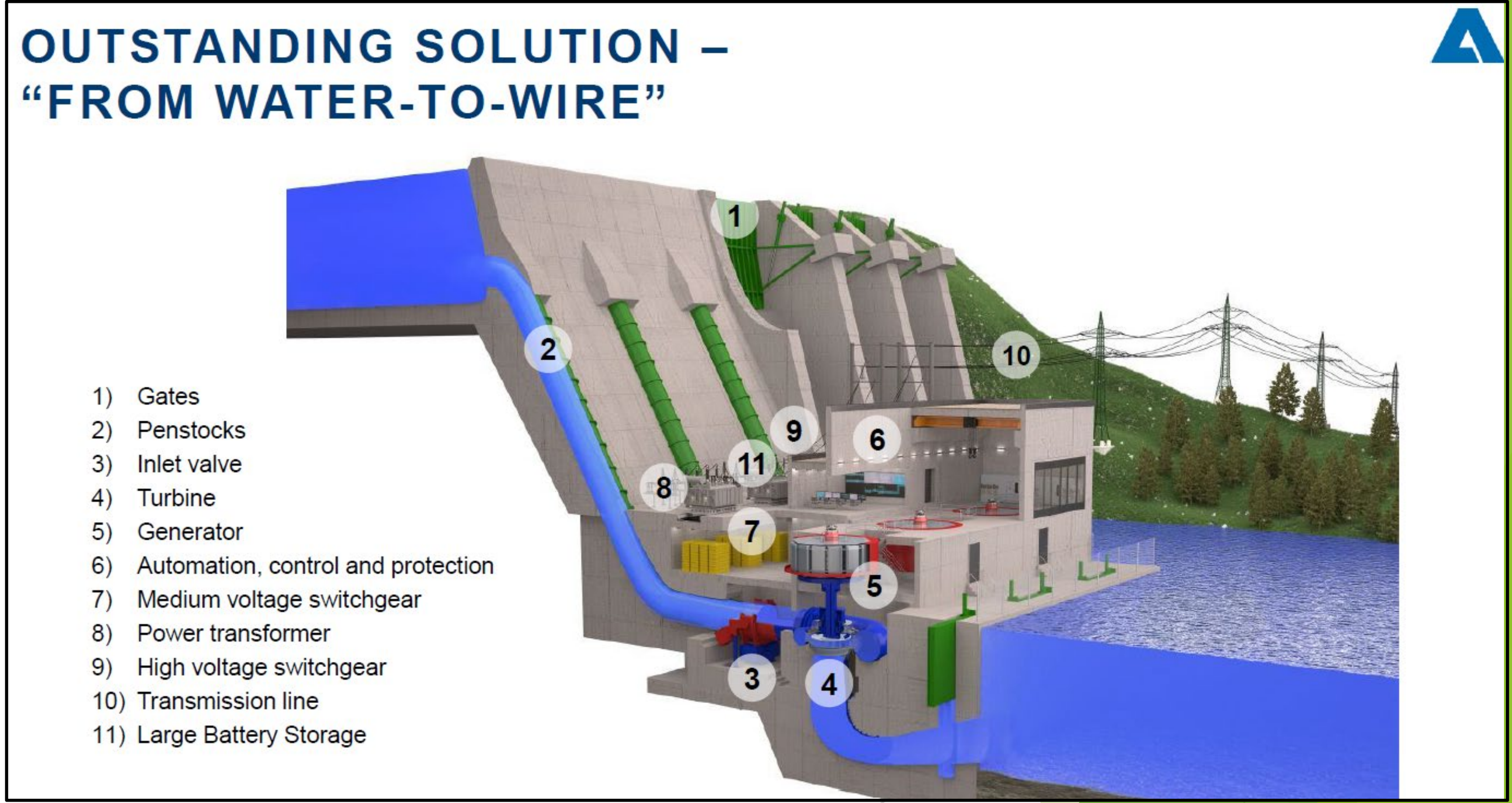
Head:	H ≤ 35 m
Output:	P ≤ 10 MW

Head:	H ≤ 300 m
Output:	P ≤ 30 MW

Head:	H ≤ 1,000 m
Output:	P ≤ 30 MW

Andritz Modular Pumped Hydro Equipment is Off the Shelf Technology

- Encapsulated Coal Ash can be used to repair older, non-powered dams.
- Cost effective for Voltage Regulation and/or Power Grid Stability in locations where coal plants are being closed down.
- **KEY POINT: Modular Pumped Hydro Pumps and Turbines ready to be deployed to a wide variety of Pumped Hydro Storage sites.**



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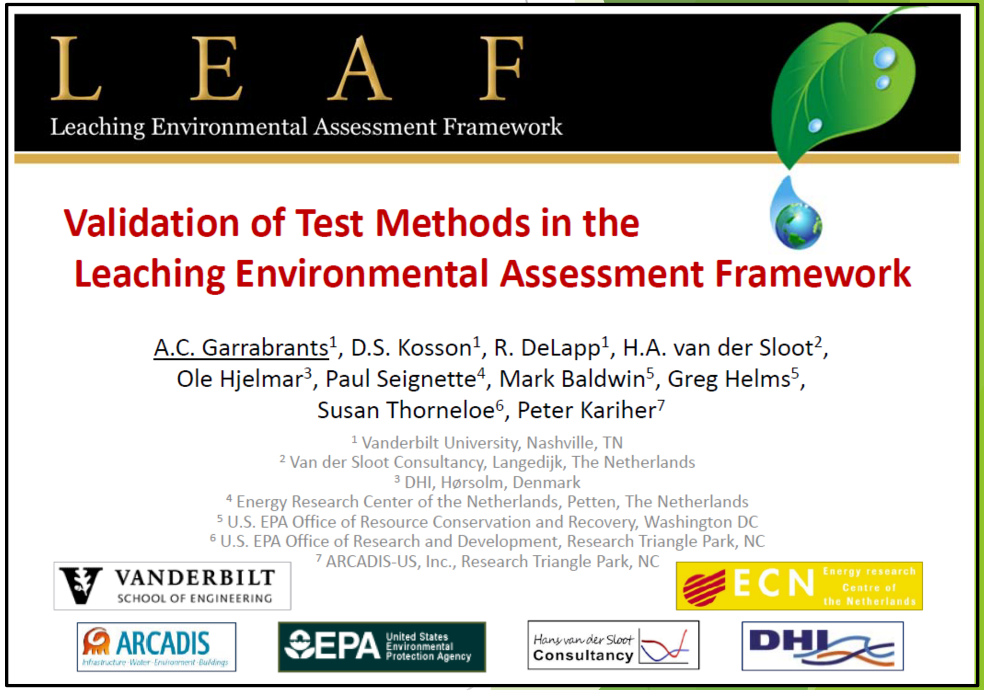
US EPA Guidelines on Encapsulation and Beneficial Use

Explanation of the Leachability Environmental Assessment Framework (LEAF)

- LEAF is a collection of:
  - Four leaching test methods that are designed evaluate leaching potential of industrial waste materials, and site specific conditions.
  - Associated with SW-846, a compendium of test method to evaluate and separate leaching potential of industrial material and hazardous materials.
  - Leaching assessment approach and it is NOT a compliance test method.
  - Designed to identify characteristic leaching behaviors in a wide variety of industry materials including CCRs.
- https://www.epa.gov/hw-sw846/how-guide-leaching-environmental-assessment-framework


L E A F

Leaching Environmental Assessment Framework

Validation of Test Methods in the Leaching Environmental Assessment Framework

A.C. Garrabrants[1], D.S. Kosson[1], R. DeLapp[1], H.A. van der Sloot[2], Ole Hjelmar[3], Paul Seignette[4], Mark Baldwin[5], Greg Helms[5], Susan Thorneloe[6], Peter Kariher[7]

[1] Vanderbilt University, Nashville, TN
[2] Van der Sloot Consultancy, Langedijk, The Netherlands
[3] DHI, Hørsolm, Denmark
[4] Energy Research Center of the Netherlands, Petten, The Netherlands
[5] U.S. EPA Office of Resource Conservation and Recovery, Washington DC
[6] U.S. EPA Office of Research and Development, Research Triangle Park, NC
[7] ARCADIS-US, Inc., Research Triangle Park, NC

VANDERBILT SCHOOL OF ENGINEERING

ECN Energy research Centre of the Netherlands

ARCADIS

EPA United States Environmental Protection Agency

Hans van der Sloot Consultancy

DHI

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Acceptable EPA Methods for Testing Encapsulation

- Leachability Environmental Assessment Framework (LEAF) methods can be used to test whether and a solid matrix material is encapsulated.
  - EPA Method 1313: For determining the target pH concentration for monolithic slab test.
  - EPA 1315: Testing of a solid monolithic slab in a tank over 60 days to determine if the encapsulated mix is stable.
  - Toxicity Characteristic Leaching Procedure (TCLP). A compliance test that is part of SW-846. Can be correlated to LEAF tests and other test results.

LEAF Leaching Methods

Method 1313 – Liquid-Solid Partitioning as a Function of Eluate pH using a Parallel Batch Procedure

Method 1314 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio (L/S) using an Up-flow Percolation Column Procedure

Method 1315 – Mass Transfer Rates in Monolithic and Compacted Granular Materials using a Semi-dynamic Tank Leaching Procedure

Method 1316 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio using a Parallel Batch Procedure

Note: Incorporation into SW-846 is ongoing; method identification numbers are subject to change

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Federal CCR Rule and EPA Beneficial Use Verification Methodology

- Clear Methodology referenced on Page 21327 in the Federal CCR Rule for determining if an encapsulated product.
- Step 2: Comparison to Analogous Product. Encapsulated CCRs is similar to concrete and other cementious construction products.
- If leaching potential is tested using LEAF, TCLP and other methods in EPA SW-846 and determined to be less than the Maximum Contaminant Levels (MCLs) then it would be considered encapsulated.

Methodology for Evaluating the Beneficial Use of Industrial Non-Hazardous Secondary Materials

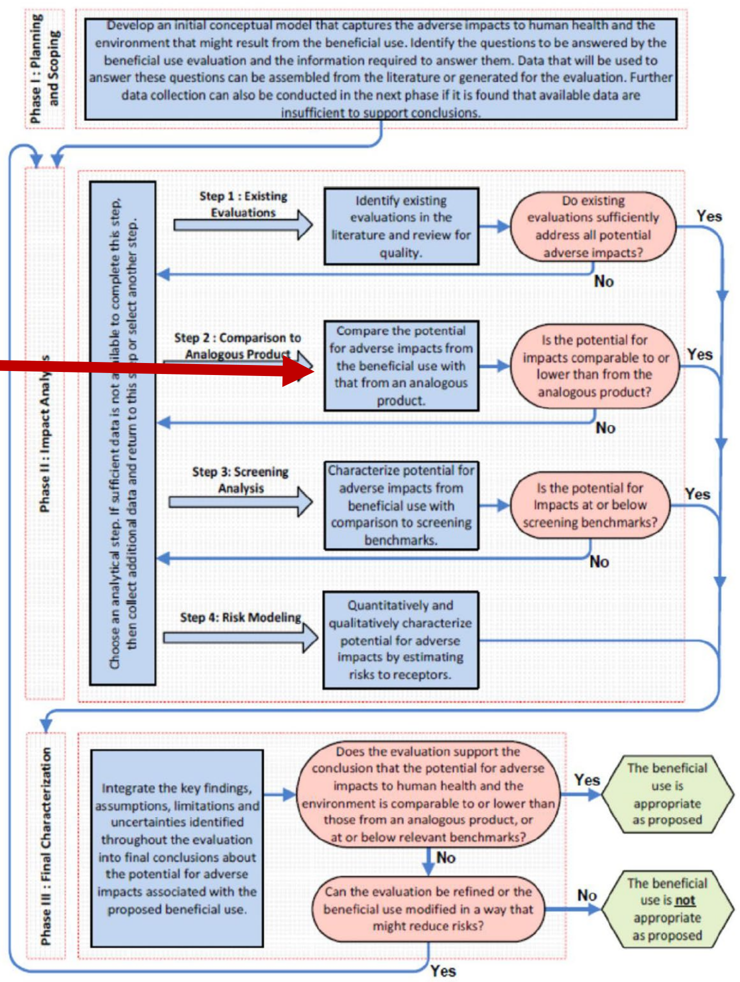

Figure 1. Summary Flowchart of the Beneficial Use Methodology

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Encapsulated CCRs are No Longer a Waste Material – Pages 21328 to 21330

- Federal CCR Rule on Page 21328 provides guidelines for the creation and beneficial use of encapsulated CCRs.
- Encapsulated CCRs may include:
  - Beneficiated fly ash material like products from the STAR Process by SEFA.
  - Solid matrix materials that are tested using LEAF methods and TCLP to below the RCRA MCLs.
- Analogous materials encapsulated in solid matrix and tested using TCLP and proper applied LEAF methods is no longer considered as waste material. It's a product.

21328 Federal Register / Vol. 80, No. 74 / Friday, April 17, 2015 / Rules and Regulations

concentrated location. And in the case of surface impoundments, the CCR is managed with water, under a hydraulic head, which promotes rapid leaching of contaminants into neighboring groundwater. The beneficial uses identified as excluded under the Bevill exemption for the most part present a significantly different risk profile.

a. Encapsulated Beneficial Uses

An encapsulated beneficial use is one that binds the CCR into a solid matrix that minimizes mobilization into the surrounding environment. Examples of encapsulated uses include, but are not limited to: (1) Filler or lightweight aggregate in concrete; (2) a replacement for, or raw material used in production of, cementitious components in concrete or bricks; (3) filler in plastics, rubber, and similar products; and (4) raw material in wallboard production.

Since publication of the proposal,

extrapolate from the risk assessments conducted to evaluate the management practices associated with CCR landfills and CCR surface impoundments, because the exposure patterns are too dissimilar: The amounts and manner involved with beneficial use are very different than the thousands, if not millions of tons of CCR that are mounded in a single concentrated location in a landfill. And the potential exposures are entirely unlike surface impoundments, where CCR is managed with water under a hydraulic head, which promotes more rapid leaching of contaminants. By contrast "beneficial uses," even unencapsulated uses, are typically subject to engineering specifications, and for certain uses, federal oversight, and material requirements. For example, fly ash used as a stabilized base course in highway construction is subject to both

4. Documented Cases in Which Damage to Human Health or the Environment From Surface Run-off or Leachate Has Been Proved

To date, EPA has seen no evidence of damages from the encapsulated beneficial uses of CCR that EPA identified in the proposal. For example, there is wide acceptance of the use of CCR in encapsulated uses, such as wallboard, concrete, and bricks because the CCR is bound into products. However, as of the date of the proposed rule, seven proven damage cases associated with unencapsulated uses have occurred, in which large quantities of unencapsulated CCR were used indiscriminately to re-grade the landscape or to fill old quarries or gravel pits. The proposed rule discussed two of these cases. (See 75 FR 35147.) The first case was in Gambrills, Maryland and involved the disposal of fly ash and

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How to Encapsulate CCR with Lime and/or Cement and Compaction

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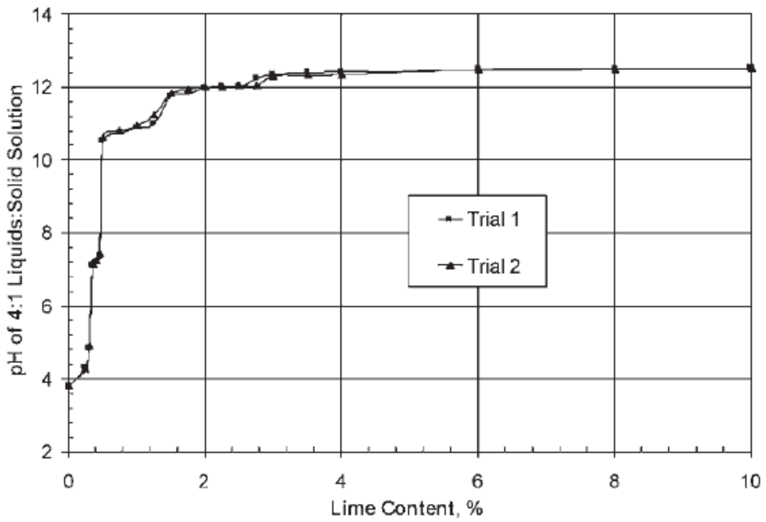

Figure 1. Relationship between pH and lime content

***UNC Charlotte and Energy & Environment Foundation to be utilized as third party check labs**

Ref: Krubera & Thalle Presentation at CALM Meeting, November 2019

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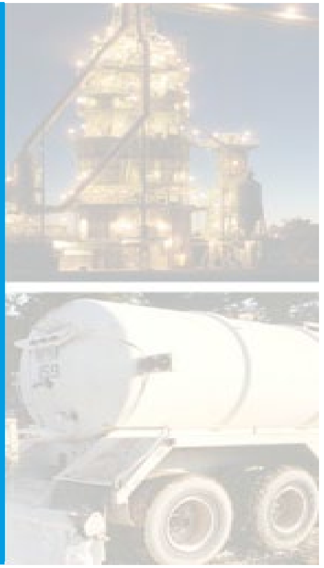
Lhoist North America
Lhoist Group

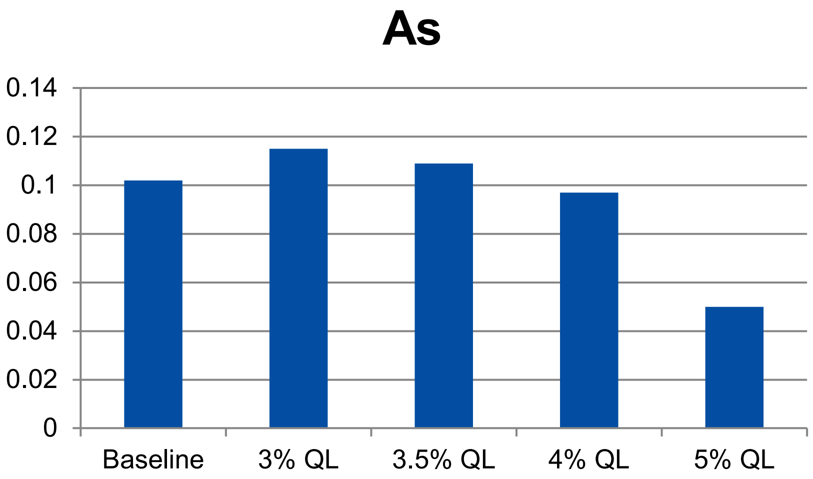
Mechanism for Lime Stabilization of CCRs

- ✓ Fly Ash is a pozzolan with high amounts of SiO_2 and Al_2O_3
- ✓ When $Ca(OH)_2$ is added to system
  - SiO_2 and Al_2O_3 become soluble above pH 10
  - SiO_2 reacts with Ca to form C-S-H
  - Al_2O_3 reacts with Ca to form C-A-H
  - Cementitious products agglomerate to form stable matrices
- ✓ But calcium must be added to insure pH of 11 is achieved for stabilization

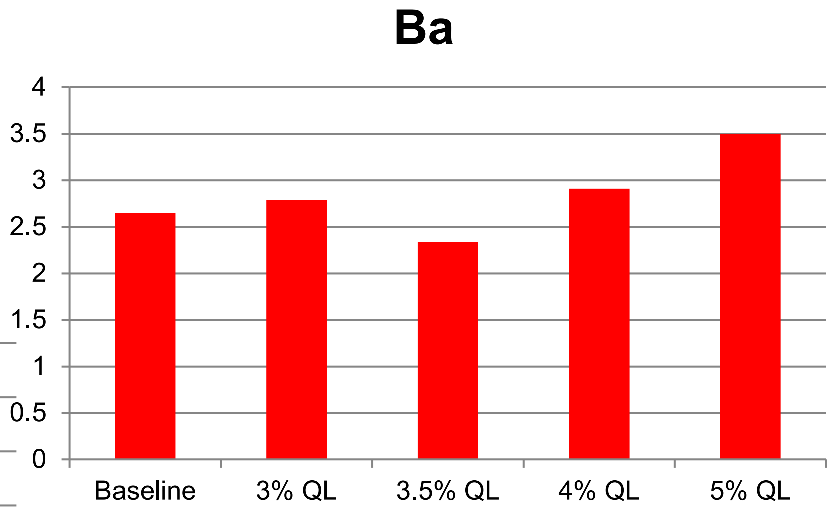


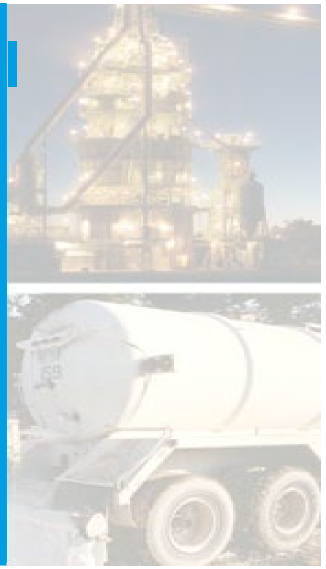
Ref: Lhoist Presentation at CALM Meeting, November 2018

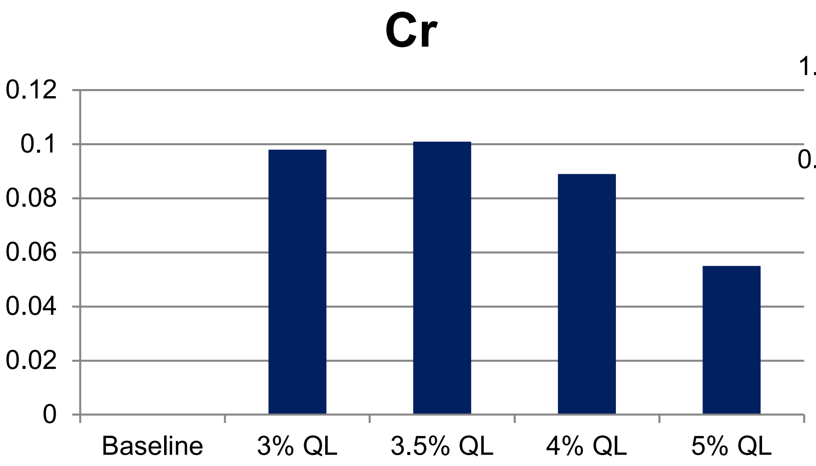
Metals Leaching as function of QL addition



RCRA Haz Limits:
- As - 5 ppm
- Cr – 5 ppm
- Ba - 100 ppm







Ref: Lhoist Presentation at CALM Meeting, November 2018

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Department of Energy Guidelines on Pumped Hydro Energy Storage

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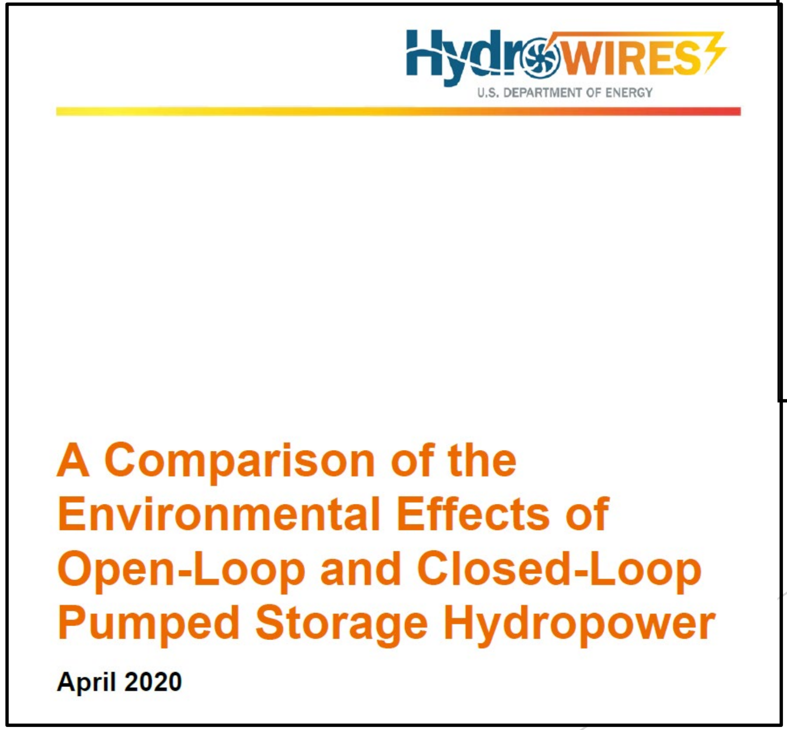
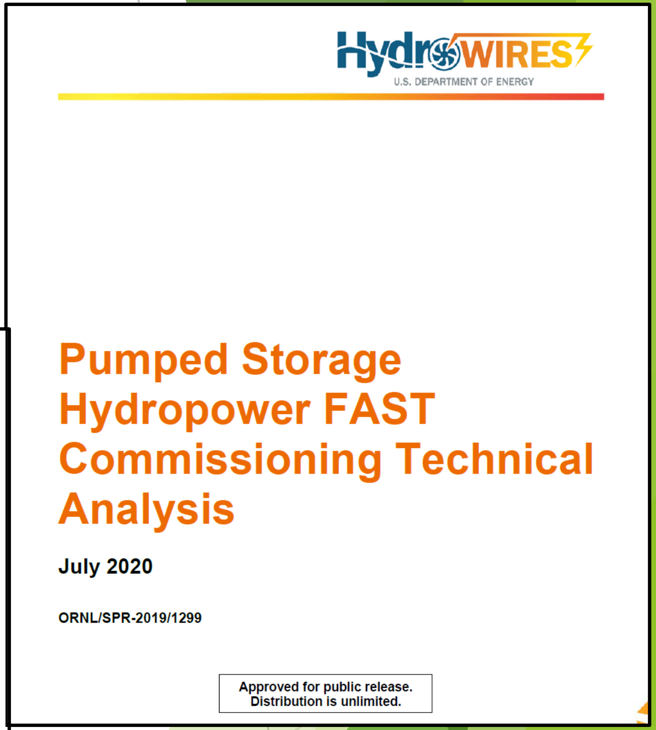
Department of Energy Applied Research Energy Storage and Non-Powered Dams

- **Dept of Energy - HydroWIRES Research recommends repowering small to medium sized dams.** NOTE: Many Non-Powered Dams (NPDs) are located in former rural manufacturing areas. Estimated at over 2,000 dams nationwide.
- DOE – HydroWIRES Research provides comparison of Environmental Effects and probable cost for different types of PHS projects.
- **SUMMARY: Non-powered dams and PHS are reasonable cost energy storage resources that are typically located near existing transmission and distribution lines.**


HydroWIRES
U.S. DEPARTMENT OF ENERGY

A Comparison of the Environmental Effects of Open-Loop and Closed-Loop Pumped Storage Hydropower

April 2020


HydroWIRES
U.S. DEPARTMENT OF ENERGY

Pumped Storage Hydropower FAST Commissioning Technical Analysis

July 2020

ORNL/SPR-2019/1299

Approved for public release.
Distribution is unlimited.

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Dept of Energy – HydroWires References and Resources

- Recent DOE Research completed in 2020 and 2021. Ready for implementation.
- References and Resources:

  https://www.energy.gov/eere/water/hydrowires-initiative

  https://www.energy.gov/gmi/grid-modernization-initiative

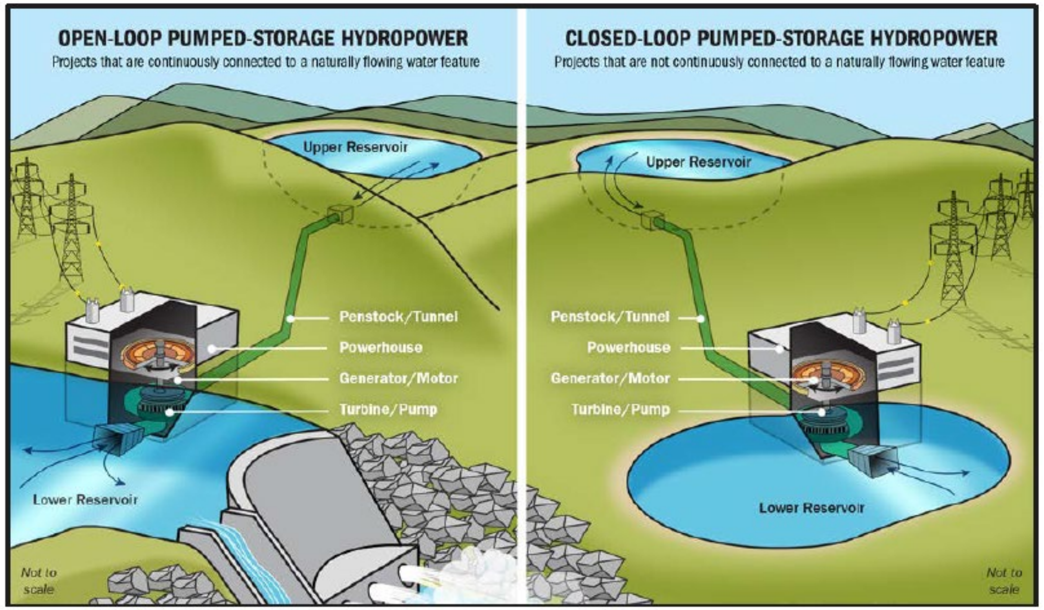
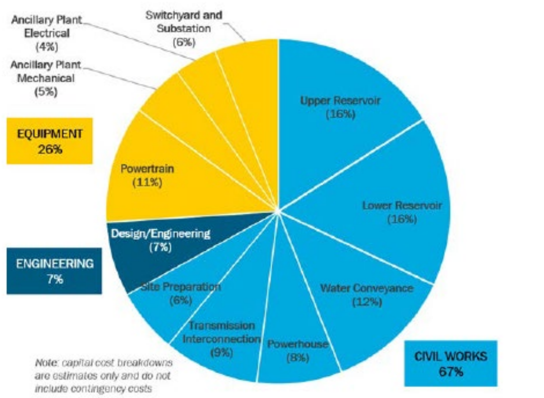


Figure ES-1. Generic comparison of open-loop and closed-loop PSH projects. (*Source*: DOE 2019)



Representative capital cost breakdown for an example PSH project

NOTE: CALM Initiative Contractors and Engineers can provide Level 2/3 Cost Estimates on Pumped Hydro Storage projects using Encapsulated Coal Ash.

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QUESTIONS?

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