TECHNICAL EXCELLENCE

Environmental Restoration

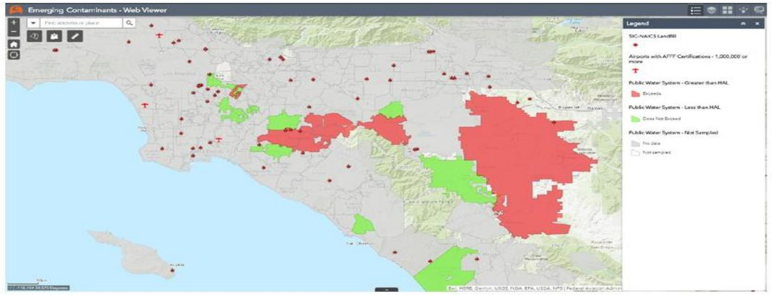
Developments in the Arcadis Restoration Practice

Jeff Burdick – Global Solutions Director
Antwerp, 17 April 2024

Restoration Highlights and Trends 2023-2024

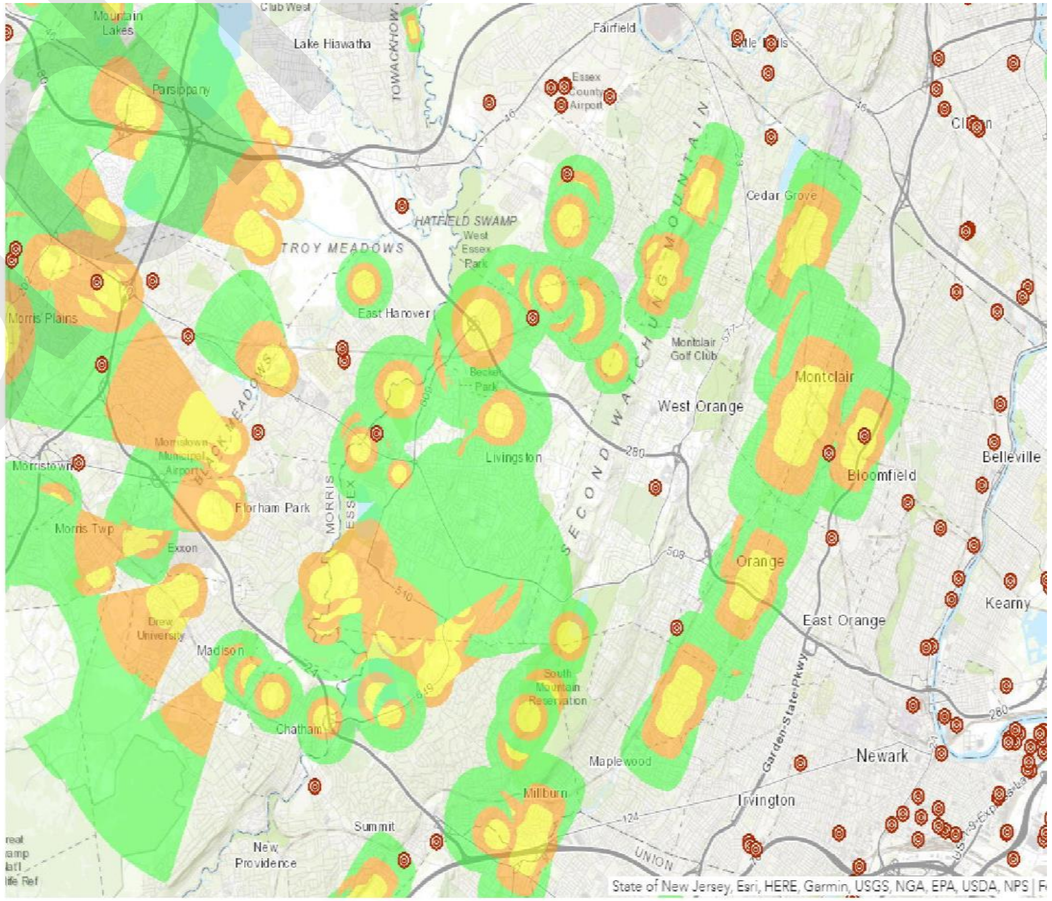
- Digital Innovation
  - GIS Vulnerability Tool
  - SearchBot: FluoroHunter (Supply Chains)
  - Green Metrics Analysis (GMA)
- Technology Innovation
  - Passive Sentinel Sampler
  - PFAS Decon: AFFF Systems and D-4
  - Concrete Leaching
- Critical Minerals: UK Coal Example
- Green Cement: Global Mineralogy/Prospecting
- Upstream O&G: NORM

PFAS Vulnerability Assessment Tool



Large-scale PFAS detection with airports

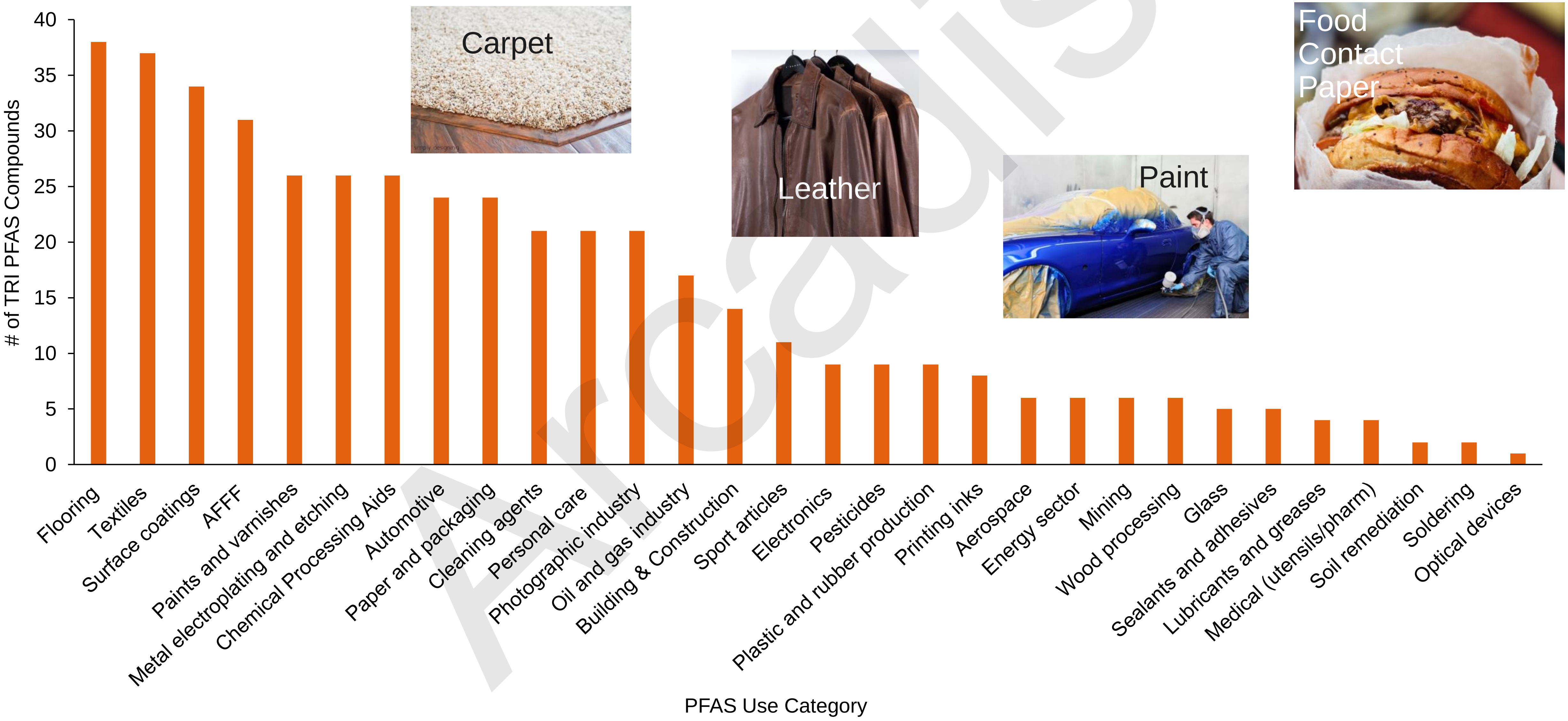
- GIS – based
- Screening Level: Access public databases with graphical presentation
- Integration Level: Incorporate site-specific data
- Rank and compare portfolio sites
- Data protected and secure



Well-head protection areas and potential PFAS users

FluoroHunter: SearchBot – PFAS in Products

Arcadis' assessment of the individual PFASs added to the EPA's Toxic Release Inventory (TRI) reporting



Fluoro Hunter (SDS PFAS Searchbot)

SDS Searchbot Steps:

1. **Collect SDSs to be searched**
2. Determine PFAS search list (s)
3. Run Program
4. Manually screen output for false positives & negatives
5. Summarize all positive hits

Compatible with any type of searchable PDF

Possible to convert non-searchable PDF to PDF

PDF files compiled into a single folder

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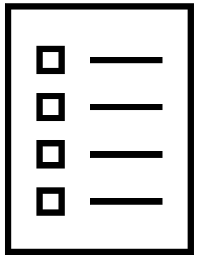


Possible PFAS Search Lists Include:

- US EPA TSCA
- US EPA TRI
- Arcadis developed search terms
- Stockholm Convention POPs
- ECHA REACH SVHC
- Other client specific

Arcadis Green Metrics Analysis (GMA(Greenhouse gases calculator | ER

Objective: estimate the greenhouse gases emissions at **field activities**.

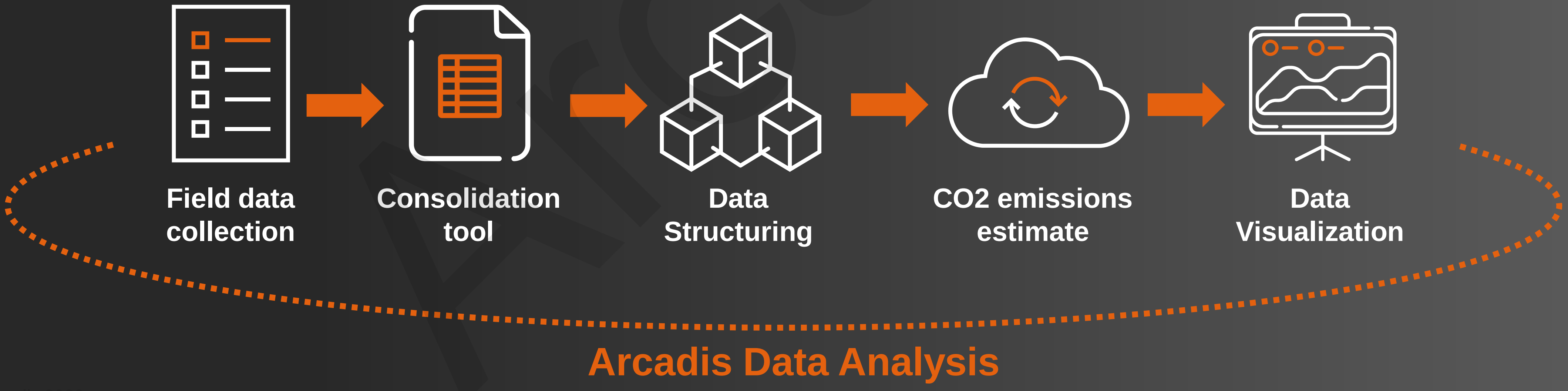
Field activities list and correlation with the GHG Protocol/scopes

\+

Limitations and assumptions definition, theoretical conversion factors adoption

=

Greenhouse gases calculation | ER



The Solution

Integrated Data

Different filters

Emissions by category

Emissions over time

Total emissions and comparison between different projects

Technology Innovation

Sentinel Sampler – potential for monitoring optimization

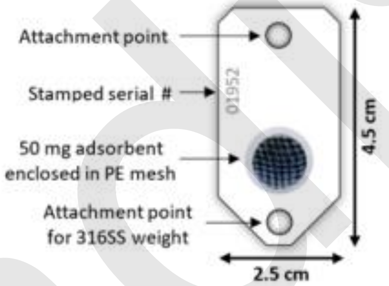
Passive, time-integrated sampling of water

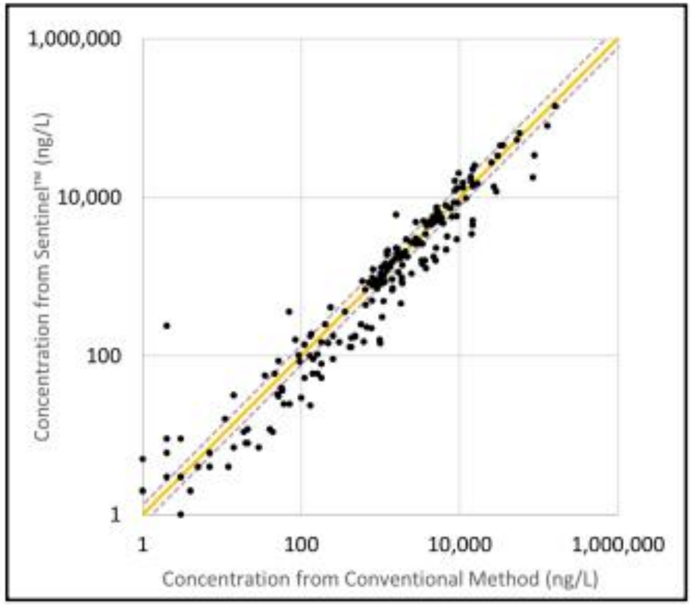
- Flexible deployment from <1 to > 4 weeks
- Wide range of PFAS compounds
- Reliably measure 6+ orders of magnitude

Monitoring and Identification

- Simple deployment and analyses
  - mailed to lab
- Minimize intrusion to homeowner
- Reduce O&M costs

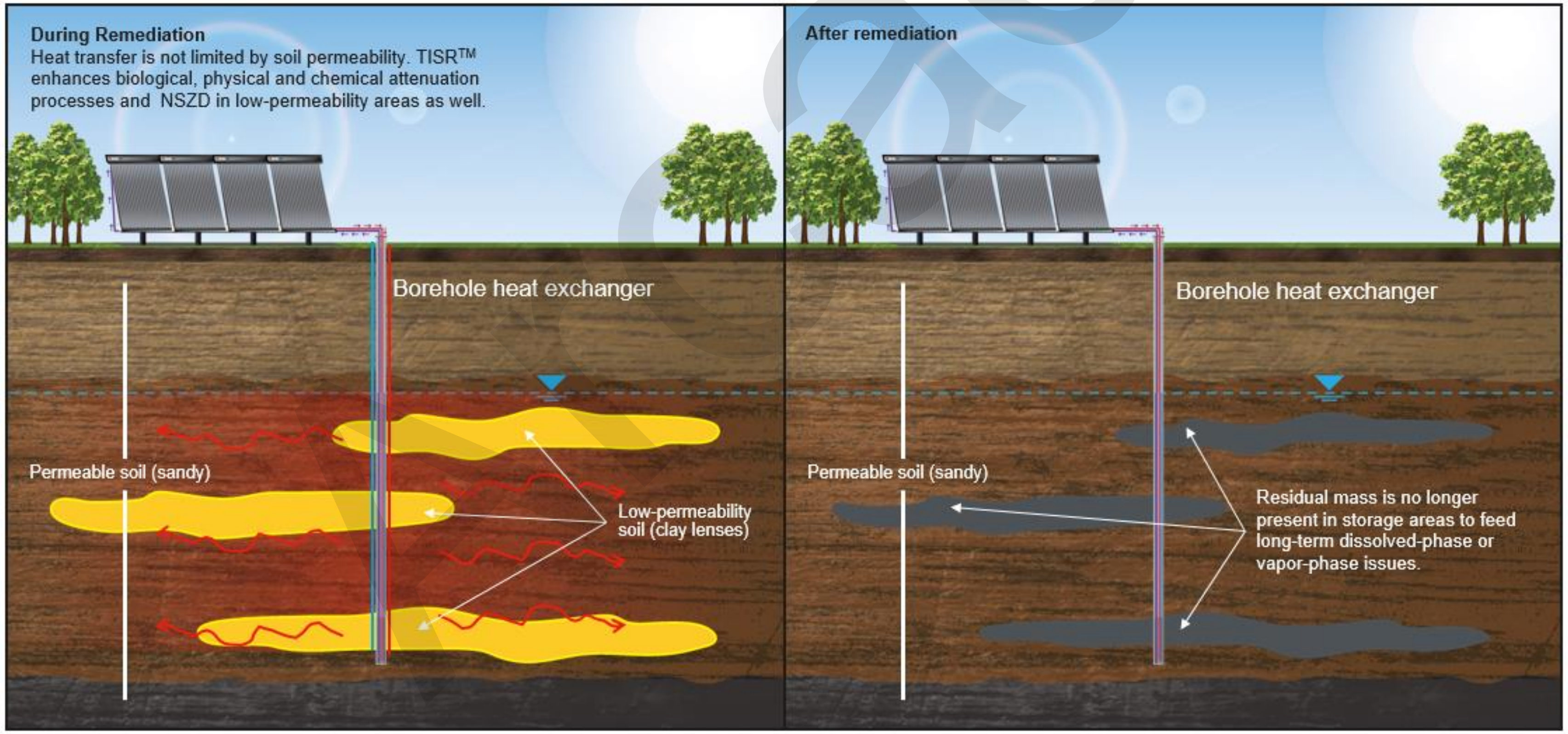
ESTCP project funding for validation of method





TISR℠ - Benefits

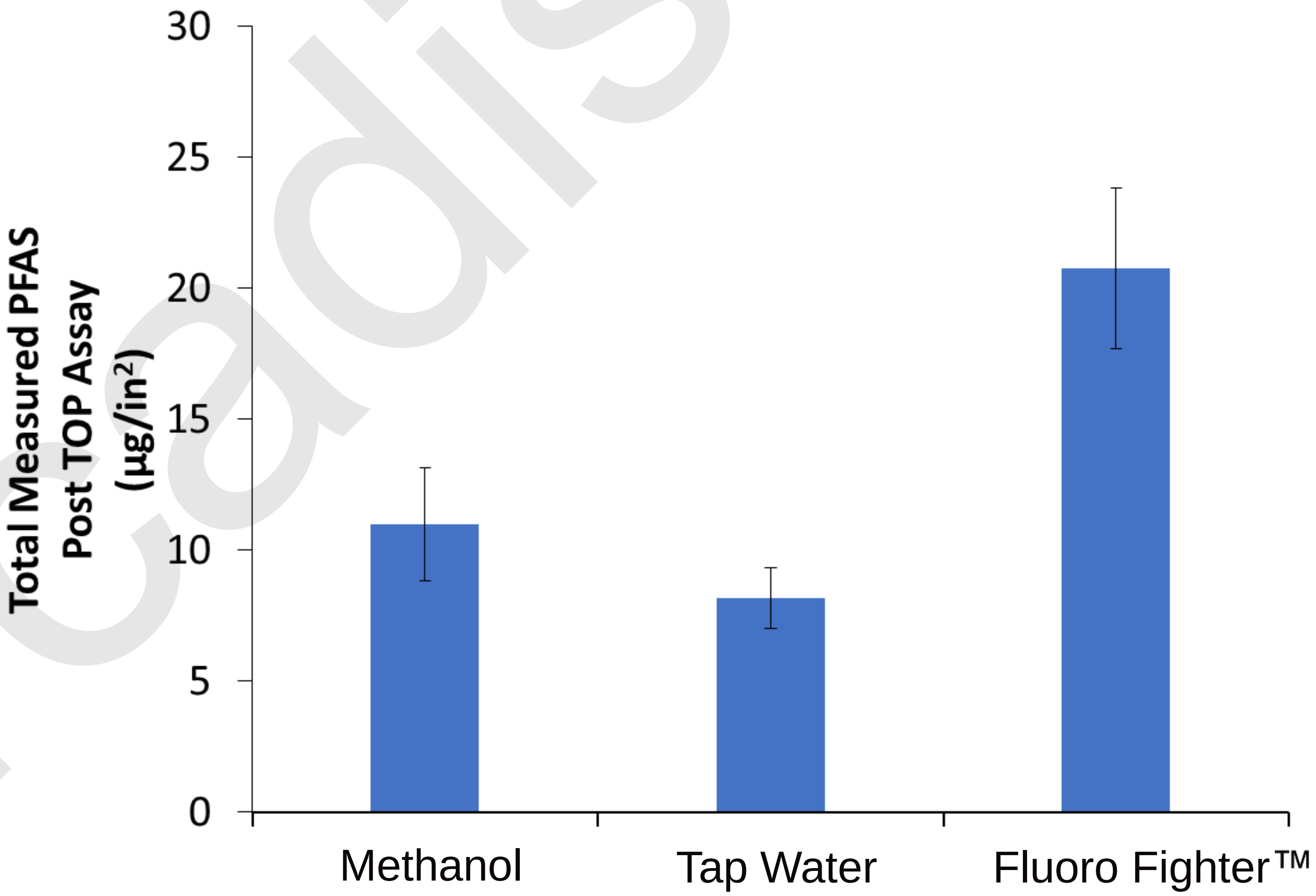
- Solar powered Sustainable technology with negligible operation and maintenance costs.
- Abiotic and Biotic degradation rate enhancement – reduced lifecycle costs.
- Application in tandem with AS/SVE, MPE systems.
- Effective in Complex Geology with residual mass.



AFFF Concentrate Pipe Extraction Demonstration

- Bench-scale steel pipe extraction using methanol, water, and Fluoro Fighter™
- Fluoro Fighter™ removed > 2.5x PFAS vs water and 1.9x vs methanol
- Equivalent to up to 2 mg/L of PFAS returned to new foam after uncleaned changeout

ESTCP Project # ER20-5364



Error bars represent one standard deviation on the mean from n = 5 replicates

CONFIDENTIAL US CHEMICAL CLIENT D3 PROJECT, TENNESSEE

ARCADIS Design & Consultancy for natural and built assets

Building Materials Assessment

Our Role

- Evaluation of potentially PFAS impacted building materials removed from an industrial chemical facility
- Evaluate alternatives to handle these impacted materials after plant shut down to minimize current and future risk associated PFAS
- Alternatives evaluated include (but are not limited to) leaving materials in place, cleaning, lining, and/or removal/disposal
- Provide additional information on disposal options for solid waste known to be impacted by PFAS

Sample ID	P1	P2	P3	P4	P5	P6	P7
Description	Foam Concentrate from Bladder Tank	Riser Up Supply to 3rd Floor	Riser Up Supply to 5th - 8th Floors	Sprinkler Feed Piping	Sprinkler Feed Piping	Tank Farm Head	Tank Farm Head
Pipe ID (in)	3	3	8	1.25	1	2.5	2.5
Photo							

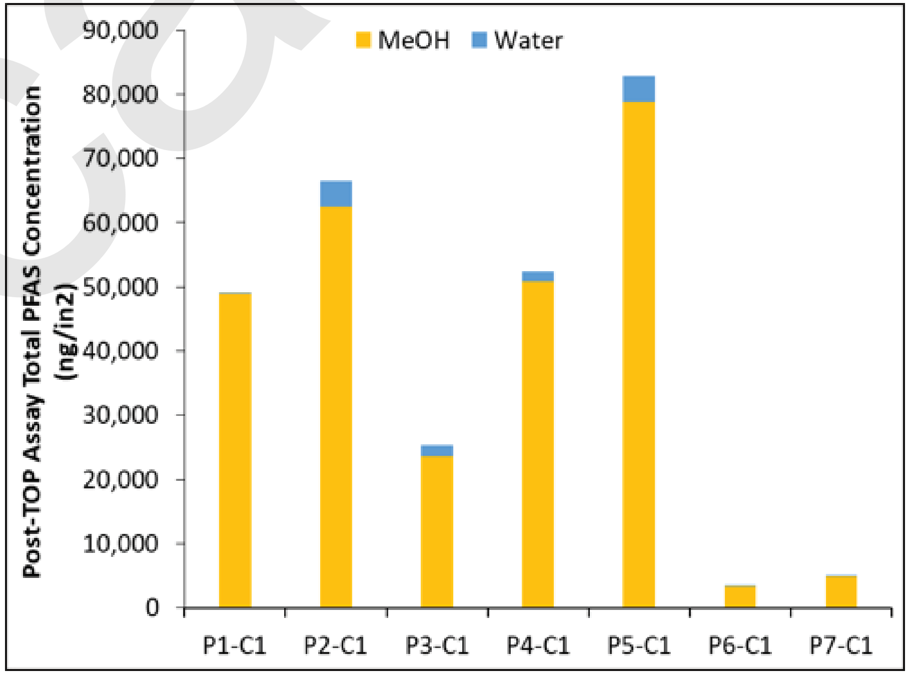
Pipe ID	Total PFAS (ng/in^2)	Pipe Radius (in)	Surface Area for 12" Length of Pipe (in^2)	Volume for 12" Length of Pipe (L)	PFAS Dissolution Concentration for Single Volume (ug/L)
P1	49069	1.5	113	1.4	3989
P2	66586	1.5	113	1.4	5413
P3	25368	4	302	9.9	773
P4	52431	0.625	47	0.2	10231
P5	82867	0.5	38	0.2	20211
P6	3415	1.25	94	1.0	333
P7	4979	1.25	94	1.0	486

Key Challenges

- Cost escalation related to disposal of PFAS impacted building materials

Innovation/Best Practice

- PFAS concentrations on fire suppression piping were evaluated based on the average mass of PFAS removed using aggressive extraction conditions considered to maximize removal
- Field cup test procedure developed by Arcadis for PFAS was used for in place sampling of a tank farm concrete secondary containment structure



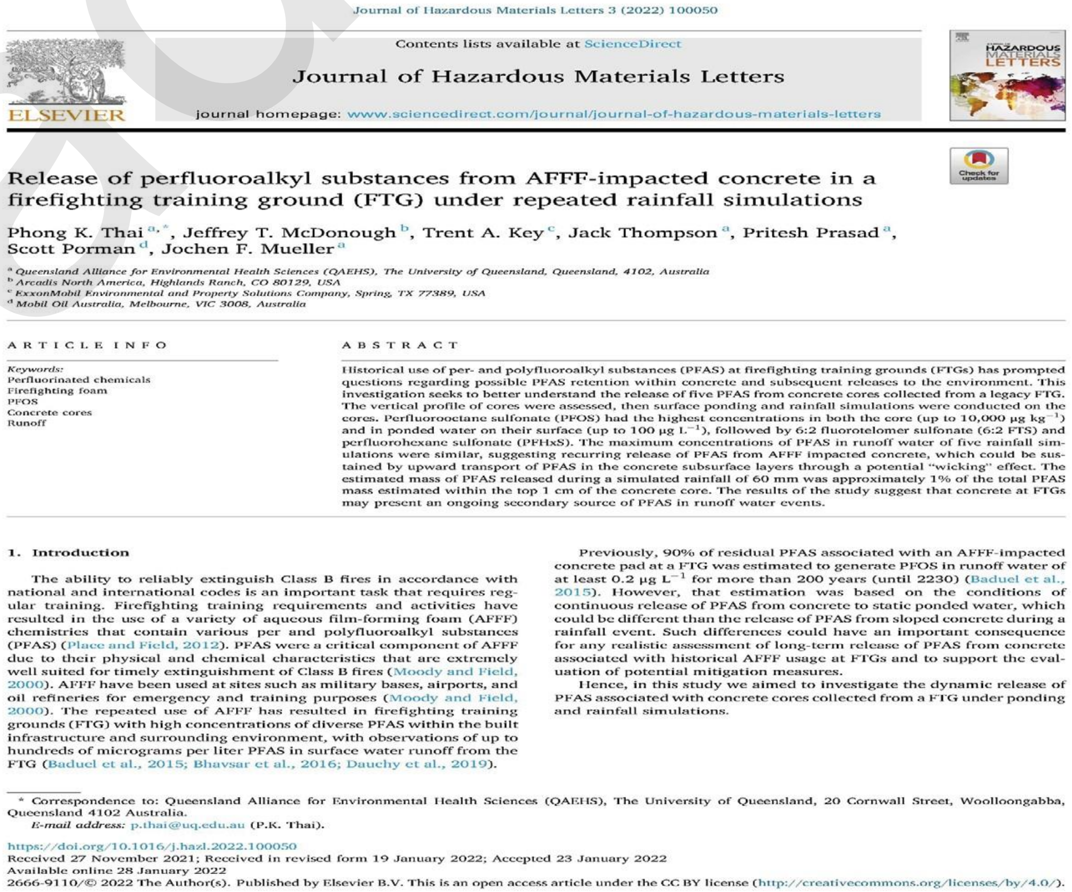
MANAGEMENT AND MITIGATION OF PFAS LEACHING FROM CONCRETE

SEVERAL GLOBAL PROJECTS

Concrete is porous, and PFAS can partition into concrete matrices, especially after years or decades of contact with PFAS containing liquids. Arcadis is or has led two efforts related to characterizing PFAS present in concrete, as well as evaluating means and methods to remove or contain the PFAS within the concrete.

The first was for an **Oil and Gas facility in Australia and consisted of coring into concrete and identifying PFAS mass at various depths of penetration** (Two sealants were applied to PFAS-containing cores from this site and their effectiveness in minimizing leaching of PFAS was compared; the results are published in Vo et al., 2023, Water Research X 20. Evaluation of sealants to mitigate the release of per- and polyfluoroalkyl substances (PFAS) from AFFF-impacted concrete: Characterization and forecasting.

The second effort is ongoing, with funding from the **US DOD under ESTCP and involves bench scale testing to characterize PFAS present in stockpiled concrete debris from a DOD BRAC site,** where concrete rubble management/disposal can have large financial considerations in the redevelopment goals for this base. As part of this work, we are also evaluating several types of concrete sealants that can be used to minimize/eliminate leaching.



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Release of perfluoroalkyl substances from AFFF-impacted concrete in a firefighting training ground (FTG) under repeated rainfall simulations

Phong K. Thai [a,*], Jeffrey T. McDonough [b], Trent A. Key [c], Jack Thompson [a], Pritesh Prasad [a], Scott Porman [d], Jochen F. Mueller [a]

[a] Queensland Alliance for Environmental Health Sciences (QAEHS), The University of Queensland, Queensland, 4102, Australia
[b] Arcadis North America, Highlands Ranch, CO 80129, USA
[c] ExxonMobil Environmental and Property Solutions Company, Spring, TX 77389, USA
[d] Mobil Oil Australia, Melbourne, VIC 3008, Australia

ARTICLE INFO

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Perfluorinated chemicals
Firefighting foam
PFOS
Concrete cores
Runoff

ABSTRACT

Historical use of per- and polyfluoroalkyl substances (PFAS) at firefighting training grounds (FTGs) has prompted questions regarding possible PFAS retention within concrete and subsequent releases to the environment. This investigation seeks to better understand the release of five PFAS from concrete cores collected from a legacy FTG. The vertical profile of cores were assessed, then surface ponding and rainfall simulations were conducted on the cores. Perfluorooctane sulfonate (PFOS) had the highest concentrations in both the core (up to 10,000 μg kg^{-1}) and in ponded water on their surface (up to 100 μg L^{-1}), followed by 6:2 fluorotelomer sulfonate (6:2 FTS) and perfluorohexane sulfonate (PFHxS). The maximum concentrations of PFAS in runoff water of five rainfall simulations were similar, suggesting recurring release of PFAS from AFFF impacted concrete, which could be sustained by upward transport of PFAS in the concrete subsurface layers through a potential "wicking" effect. The estimated mass of PFAS released during a simulated rainfall of 60 mm was approximately 1% of the total PFAS mass estimated within the top 1 cm of the concrete core. The results of the study suggest that concrete at FTGs may present an ongoing secondary source of PFAS in runoff water events.

1. Introduction

The ability to reliably extinguish Class B fires in accordance with national and international codes is an important task that requires regular training. Firefighting training requirements and activities have resulted in the use of a variety of aqueous film-forming foam (AFFF) chemistries that contain various per and polyfluoroalkyl substances (PFAS) (Place and Field, 2012). PFAS were a critical component of AFFF due to their physical and chemical characteristics that are extremely well suited for timely extinguishment of Class B fires (Moody and Field, 2000). AFFF have been used at sites such as military bases, airports, and oil refineries for emergency and training purposes (Moody and Field, 2000). The repeated use of AFFF has resulted in firefighting training grounds (FTG) with high concentrations of diverse PFAS within the built infrastructure and surrounding environment, with observations of up to hundreds of micrograms per liter PFAS in surface water runoff from the FTG (Baduel et al., 2015; Bhavsar et al., 2016; Dauchy et al., 2019).

Previously, 90% of residual PFAS associated with an AFFF-impacted concrete pad at a FTG was estimated to generate PFOS in runoff water of at least 0.2 μg L^{-1} for more than 200 years (until 2230) (Baduel et al., 2015). However, that estimation was based on the conditions of continuous release of PFAS from concrete to static ponded water, which could be different than the release of PFAS from sloped concrete during a rainfall event. Such differences could have an important consequence for any realistic assessment of long-term release of PFAS from concrete associated with historical AFFF usage at FTGs and to support the evaluation of potential mitigation measures.

Hence, in this study we aimed to investigate the dynamic release of PFAS associated with concrete cores collected from a FTG under ponding and rainfall simulations.

* Correspondence to: Queensland Alliance for Environmental Health Sciences (QAEHS), The University of Queensland, 20 Cornwall Street, Woolloongabba, Queensland 4102 Australia.
E-mail address: p.thai@uq.edu.au (P.K. Thai).

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Automotive Assembly Plant

AFFF Release Response near Central Tank Farm

- Cleaning of underground storage tank
- Cleaning of operations equipment and AFFF-impacted asphalt/concrete surface

Arcadis cleaned subsurface vault with Fluoro Fighter™ - used 825 gallons of cleaning agent over two days

Arcadis and Job Site Services used Fluoro Fighter™ to clean asphalt and concrete surfaces to remove PFAS from AFFF-impacted surfaces over three-day mobilization; used and cleaned on-site floor scrubbers to return them to service in plant

Critical Minerals: UK Example

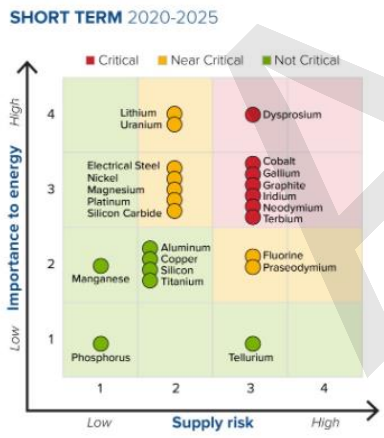
Critical Minerals – What are they?

ARCADIS

Critical minerals (CM) are identified based upon supply chain risks, and the dependence of the domestic manufacturing sector on foreign supplies (often “foreign entities of concern”)

NATIONAL NEWS RELEASE

U.S. Geological Survey Releases 2022 List of Critical Minerals

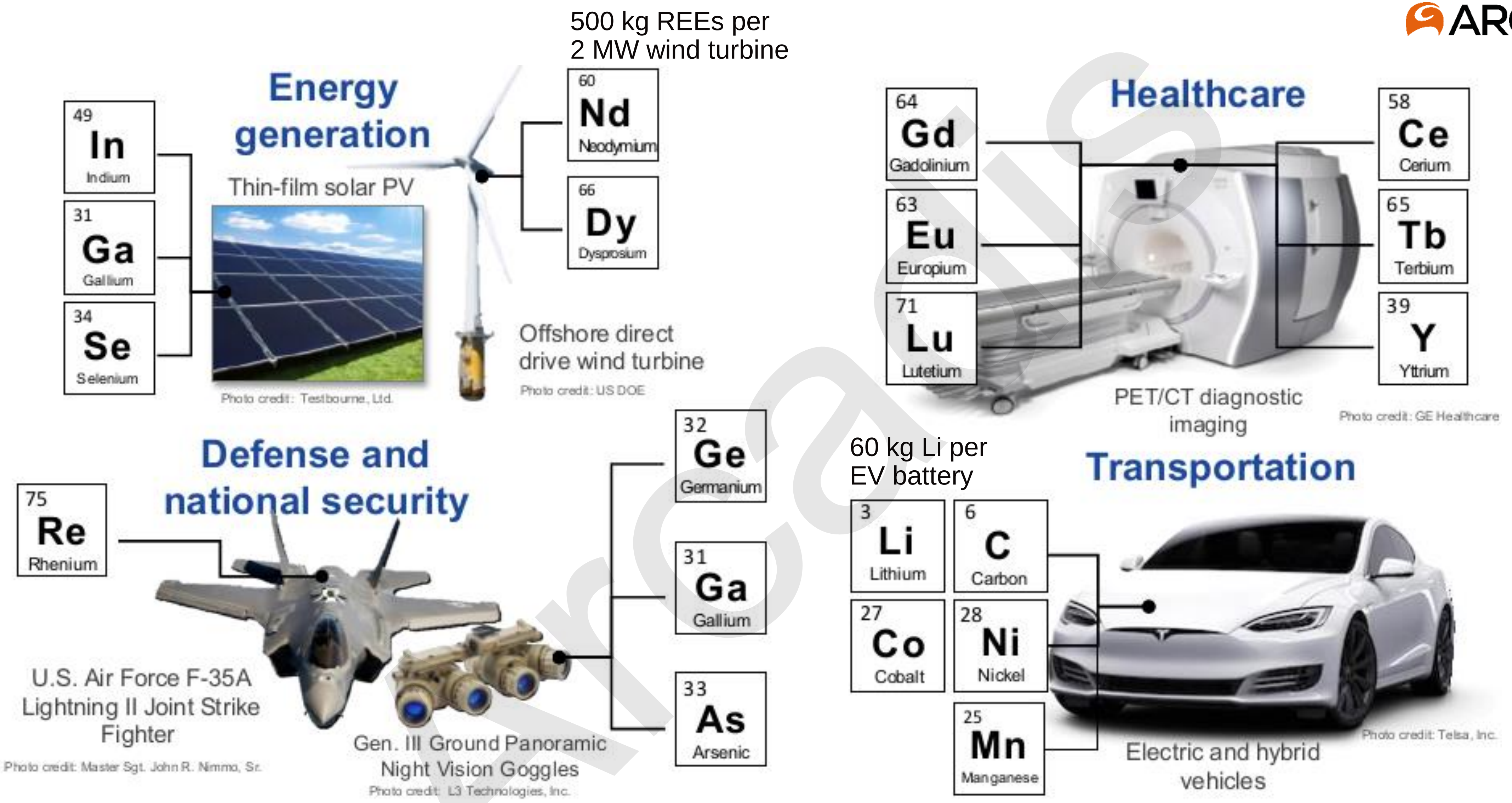


Policy paper

Resilience for the Future: The UK’s Critical Minerals Strategy

Updated 13 March 2023

The UK’s list of 18 critical minerals	
Antimony	Bismuth
Cobalt	Gallium
Graphite	Indium
Lithium	Magnesium
Niobium	Palladium
Platinum	Rare Earth Elements
Silicon	Tantalum
Tellurium	Tin
Tungsten	Vanadium



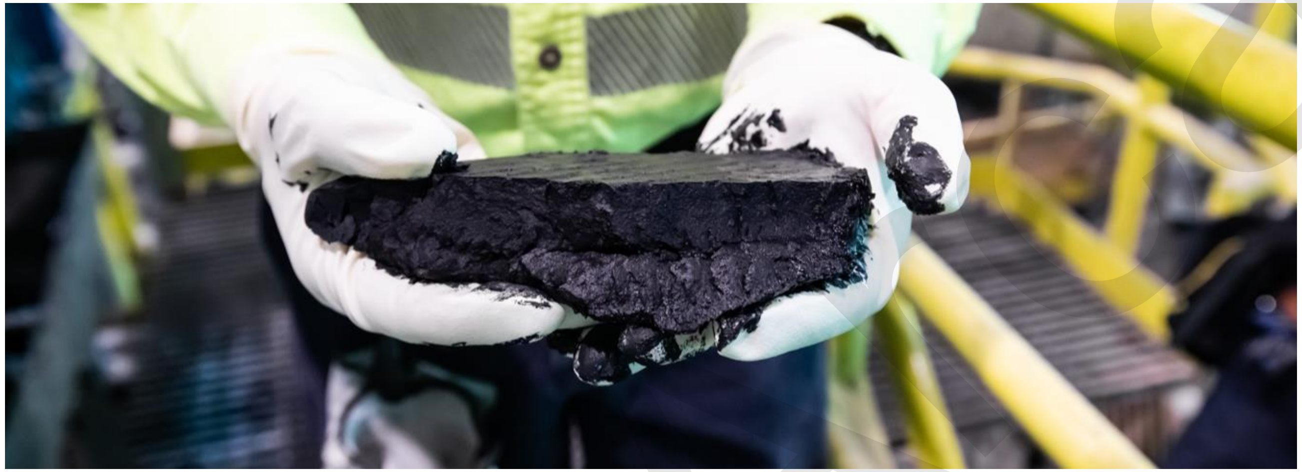
From: Nassar, USGS, 2020

Secondary Sources of Critical Minerals - Photovoltaics

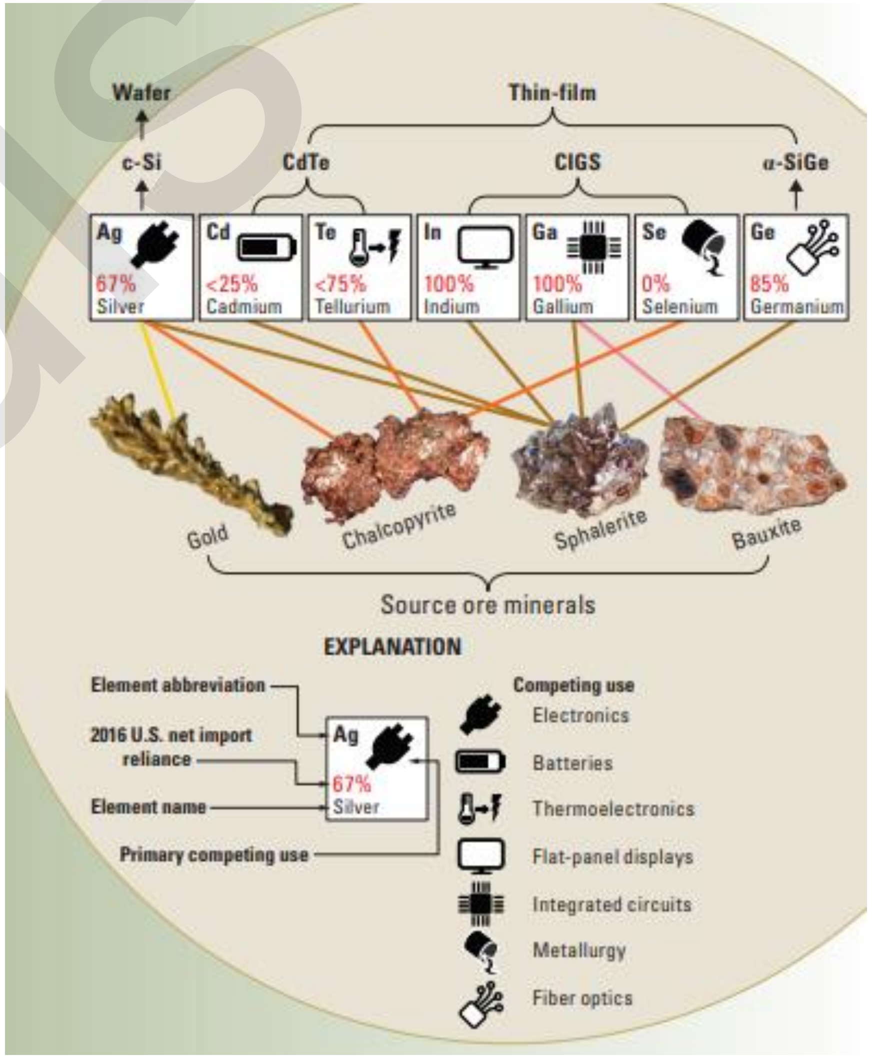
- Photovoltaics (PVs) use elements for which a **primary source** (**conventional resource - ore**) is often not readily available

- **Secondary sources** (**unconventional resources**) are therefore the focus for supply of Cd, Te, In, Ga, Se, and Ge

- Ga currently is derived as a byproduct of lead-zinc, and processing of bauxite ore, along with extraction from residues of zinc (sphalerite) processing (USGS, 2017)



- Te is recovered from copper anode slimes, a byproduct of smelting copper (Rio Tinto, 2022)



From: National Minerals Information Center, 2017

Water Treatment at UK Abandoned Coal Mines

ARCADIS

In 2016, 64 pumping stations were operated by the Coal Authority

(some pumped waters are used for heating)

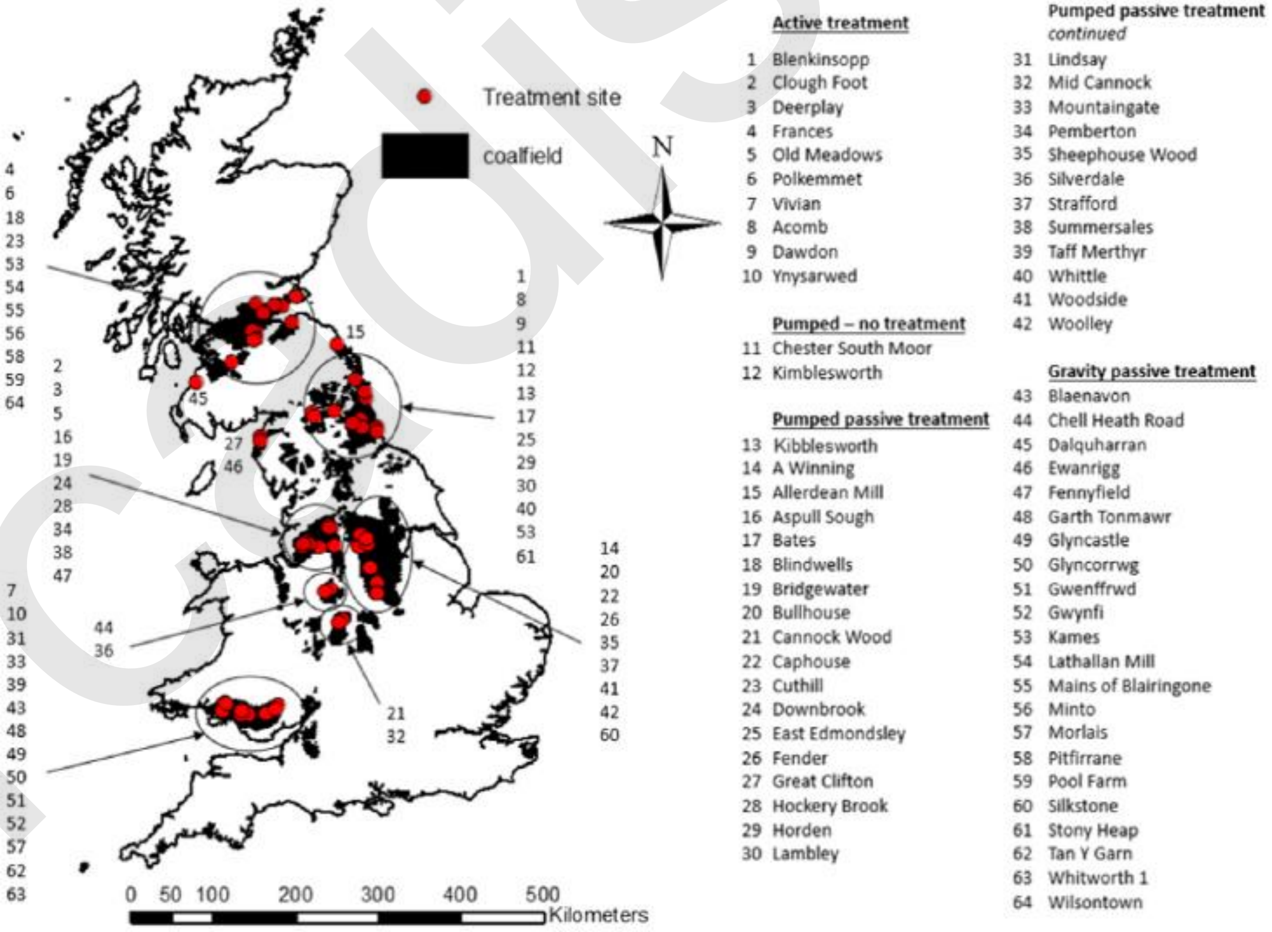


Fig. 1. Coal mine water pumping and treatment sites in Great Britain.

From: Bailey et al., International Journal of Coal Geology, 2016

Example of Trace Element Content of UK Coal

ARCADIS

Parkgate Seam, Thoresby Colliery, UK Coal Mining Ltd. (Nat grid ref E461578, N374957)				
Depth (cm)	Sample	Section	Thickness (cm)	Description
		Roof 2		Mudstone, light grey, 30cm exam.
		Roof 1	10	Mudstone, dark grey
185cm	I		25	Bright coal
	H		20	Bright coal, occassional pyritic lenses
	G		1	Interleaved bright coal & mudstone
	F		39	Bright coal
	E		39	Banded dull and bright coal
	D		10	Dull coal
	C		1	Mudstone, very carbonaceous
	B		25	Bright coal with pyritic lenses
	A		25	Bright coal with pyritic lenses
		Floor		Seatearth mudstone, light grey, 3cm exam.

Bright Banded Dull Fusain Cannel — <15% Ash; Inferior bright, Inferior banded, Inferior dull — <15.1-40.0% Ash; Dirt — >40% Ash

From Spears and Tewalt, 2009

Parameter	Units	Median	Average	Standard deviation
Si	wt.%	0.96	1.66	1.92
Al	wt.%	0.65	1.15	1.42
Ca	wt.%	0.17	0.22	0.18
Mg	wt.%	0.038	0.054	0.06
Na	wt.%	0.21	0.2	0.07
K	wt.%	0.072	0.186	0.31
Fe	wt.%	0.682	1.055	0.99
Ti	wt.%	0.03	0.049	0.07
P	wt.%	0.0006	0.0025	0.004
S	wt.%	1.76	2.13	1.12
525 °C Ash	%	6.05	8.79	8.14
Remnant moisture	%	1.72	1.75	0.44
As	ppm	11.6	31.3	45
Ba	ppm	84.0	100	63
Be	ppm	1.45	1.65	0.82
Bi	ppm	0.09	0.12	0.10
Cd	ppm	0.04	0.05	0.03
Cl	ppm	5850	6120	1810
Co	ppm	2.35	3.38	2.3
Cr	ppm	8.90	14.8	18
Cs	ppm	0.280	0.79	1.23
Cu	ppm	30.0	39.0	28
Ga	ppm	2.01	3.26	3.1
Ge	ppm	5.52	9.31	10.4
Hg	ppm	0.087	0.174	0.21
Li	ppm	10.0	29.1	62
Mn	ppm	24.4	30.1	23
Mo	ppm	2.81	3.39	2.7
Nb	ppm	0.780	1.17	1.3
Ni	ppm	24.1	40.0	51
Pb	ppm	12.8	23.5	23
Rb	ppm	3.70	9.8	16
Sb	ppm	1.69	2.29	1.8
Sc	ppm	2.14	3.15	3.0
Se	ppm	1.45	2.33	2.1
Sn	ppm	1.07	1.45	1.1
Sr	ppm	35.0	46.0	35
Te	ppm	0.07	0.07	0.03
Tl	ppm	0.33	0.73	1.0
U	ppm	0.78	1.09	0.8
V	ppm	25.1	35.0	27
Y	ppm	4.60	5.84	4.5
Zn	ppm	7.61	8.44	3.4

Element	Parkgate	Harworth	Eggborough	East Midlands
Hg	7.2			
Tl	40			17
Pb	875	390	406	322
As	1440	1346	1070	1029
Se	78	38	27	97
Mo	96	128	98	107
Cd	0.9			
Ni	1870	525	337	309
Sb	53	26	20	
Zn	97	564	455	21
Co	72			
Cu		885		315

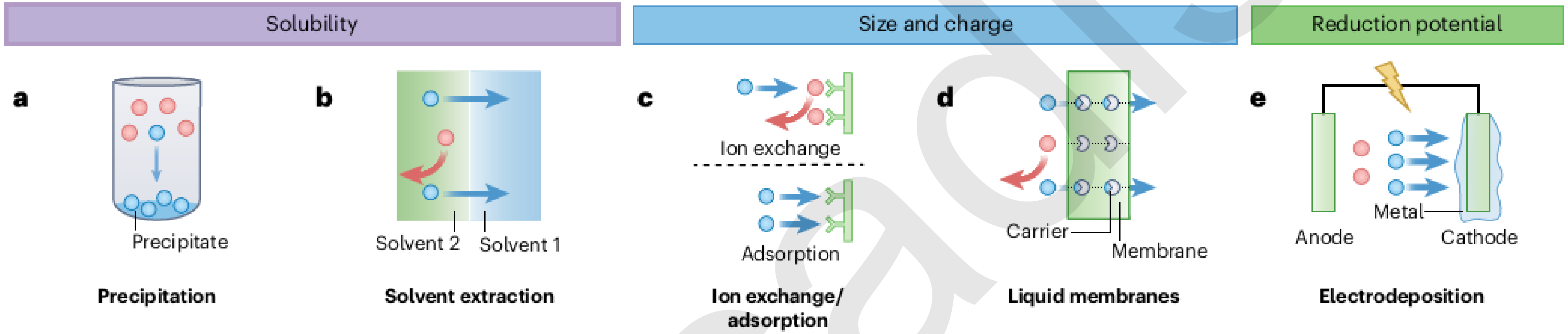
Table above shows concentration of trace elements in pyrite mineral in coal (pyrite causes AMD)

Table (left) shows trace element content in Parkgate bulk coal

Example of potential value associated with REEs in a 500 gpm mine water seep (US), with 75% recove

Rare Earth Element	Concentration (mg/L)	Mass Recovered, kg per year (75% recovery)	Price, rare earth oxide (US dollars/kg)	Value (rare earth oxide, US dollars, per year)
Dy[a]	2	14,922	$158	$2,357,691
Er[a]	1	7,461	$53	$395,435
Eu[a]	0.5	3,731	$13	$48,496
Ga[a]	1.5	11,192	$76	$850,559
Ho[b,c]	0.5	3,730	$100	$373,052
La[a]	0.75	5,595	$1	$5,595
Nd[c,d]	2.5	18,652	$138	$2,574,061
Pr[a]	0.35	2,611	$133	$347,311
Tb[a]	0.3	2,238	$1,300	$2,909,808
Y[a]	10	74,610	$12	$895,325
Yb[c,d]	1	7,461	$15	$111,915
	Total Mass Recovered:	152,205	**Total Value:**	$10,869,252

Recovery Concepts – AMD Water at Abandoned Coal Mines



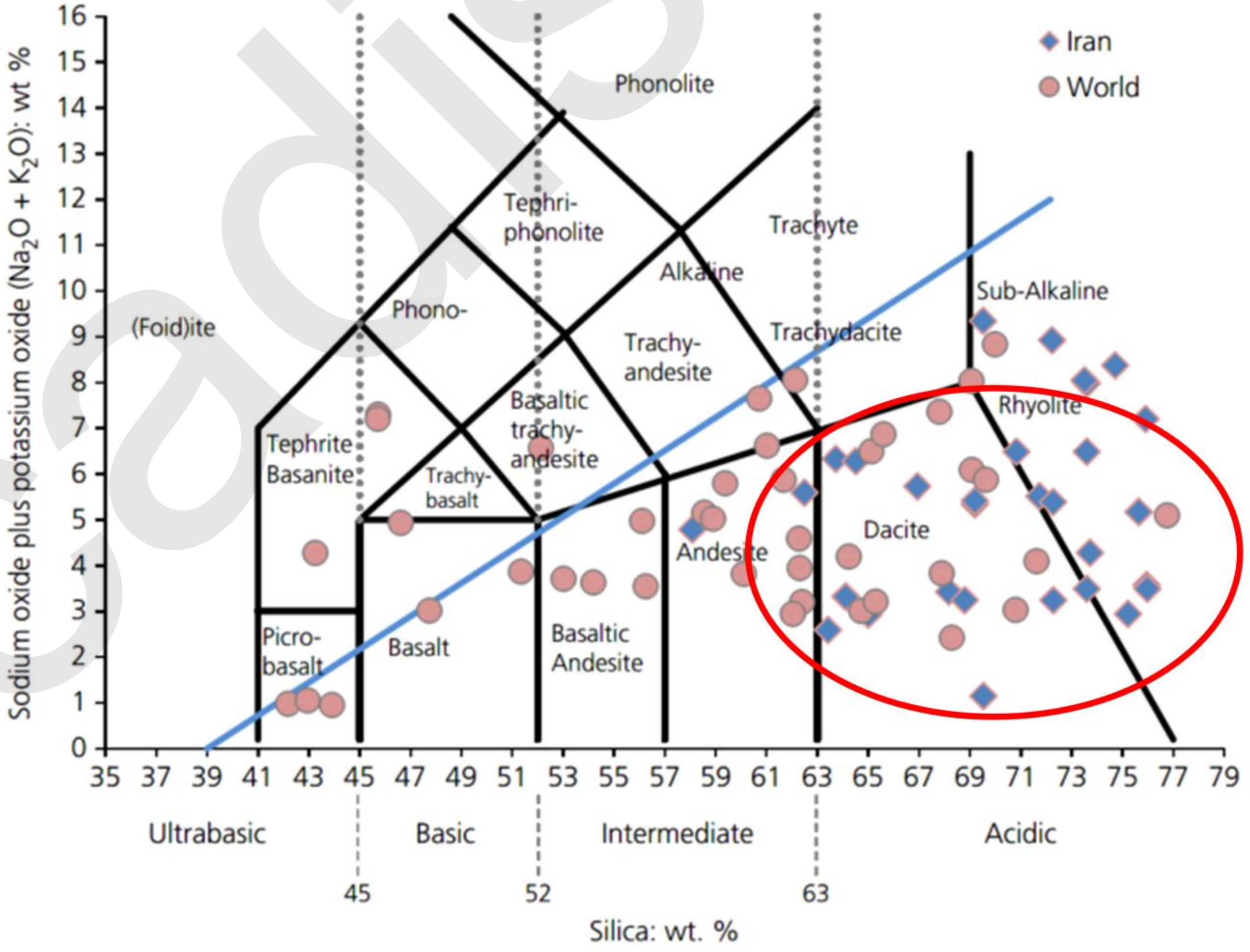
From: DuChanois et al., 2022

a. Precipitation based upon solubility (saturation index) and pH
b. Recovery into a solvent that provides physical separation of target CM/REE from aqueous phase
c. Interaction with solid resin through anion or cation exchange
d. Association with a carrier molecule that transport target CM/REE across a membrane
e. Electrochemical reduction and deposition onto a cathode

Critical Minerals: UK Example

Confidential Global Green Cement Company

- **Global Prospecting**
- **Geology and Minerology**
  - Volcanic rhyolitic ignimbrites and dacites
  - SiO_2 - greater than 70%
  - Non-devitrified (glassy and amorphous) SiO_2 greater than 10% (now targeting >25%)
  - Age – less than 2.5M years (Pliocene through Quaternary)
- **Surface exposure**
- **Potential Reserve Size (30M to 100M tonnes)**
- **Proximity to Protected Lands (preserves and national parks)**
- **Proximity to deep water port facilities (15-meter channel draft)**
- **Proximity to energy grid**
- **Proximity to roads and rails**
- **Existing mining permits for resource material**
- **Country’s political stability**



Titan ArcGIS Platform

Tentative Exploration Areas - Iceland

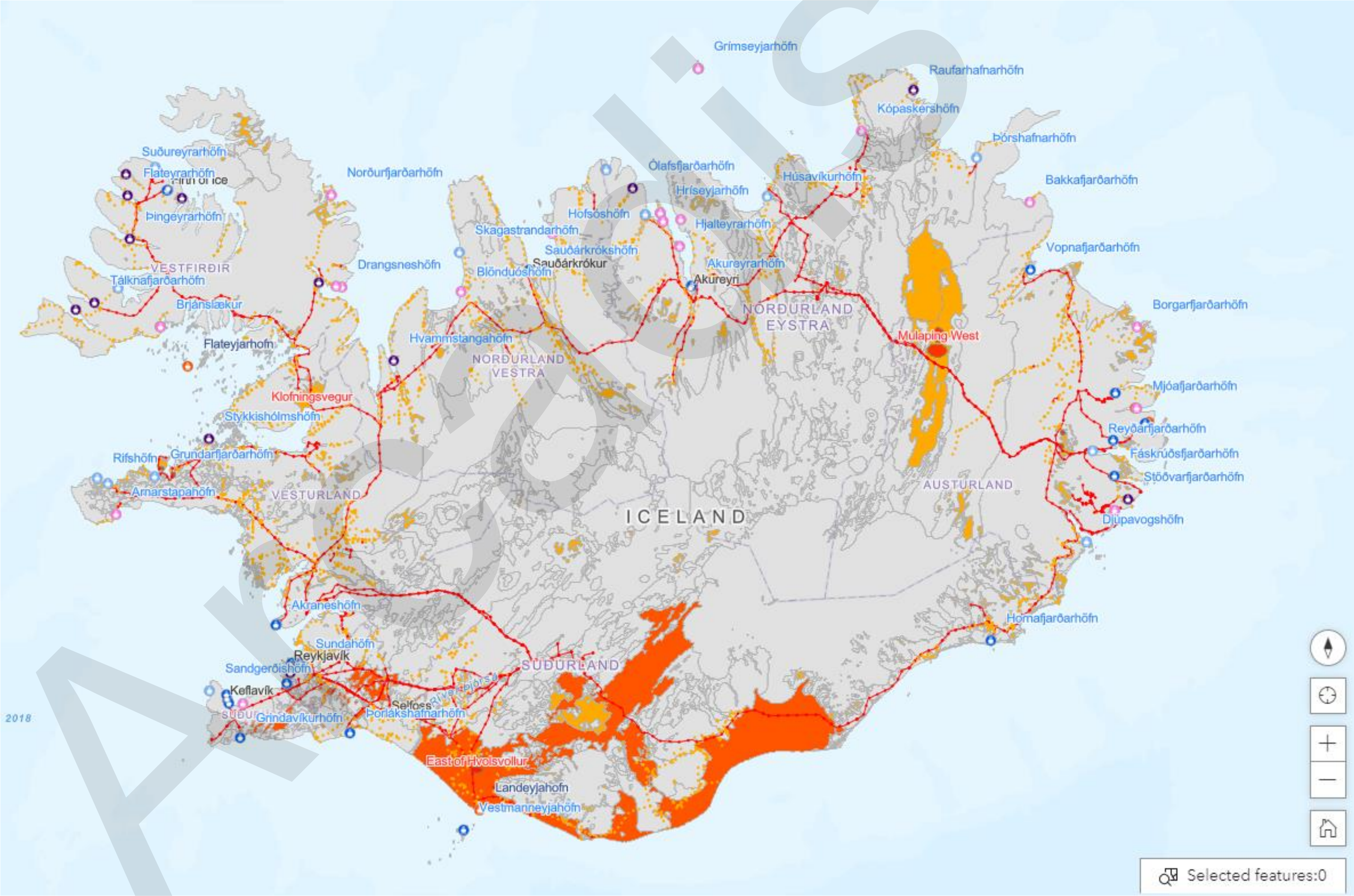
Interpreted Geological Map (Iceland)

Description

Interpretation of the geological map of Iceland - Scale: 1:600.000, considering the distribution of different rock types and their potential for pozzolanic exploitation.

Level of Interest/Potential

- High Interest
- Medium Interest
- Low Interest



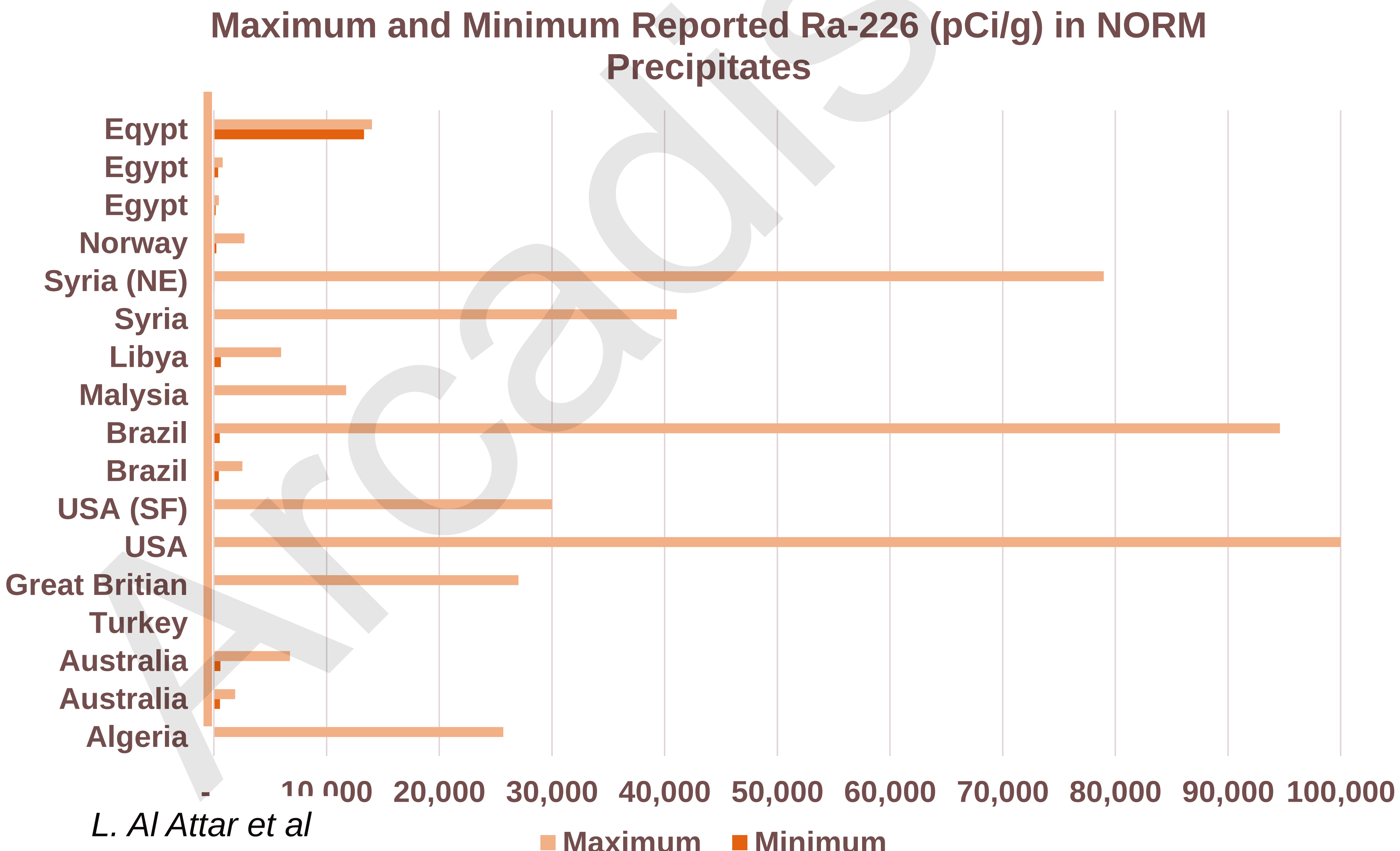
Green Cement Prospecting:Overall Onward Project Plan Follows Systematic and Logical Progression

Phase 0 Initial Planning	Phase 1 Desktop Exploration		Phase 2 Field Investigation	Phase 3 Target Evaluation	
Criteria Development, Country Specific Targets	**1A Desktop Study**	**1B Remote sensing**	**Field Investigations**	**Drilling and Sampling**	**GIS Model Development**
• Spain • Portugal • Canary Islands • Azores • Iceland	• Geological maps • Geomorphological maps • Legislation • Protected areas • Closed/active quarries • Active companies • Thesis, articles & papers • Mining concessions • Logistics • Utility supplies	• Regional • Detailed	• Azores • Canary Islands • Iceland		• Data Plotting • Kriging • Mine Modeling

Green Cement Prospecting: New Scope for Caribbean, Central and South America

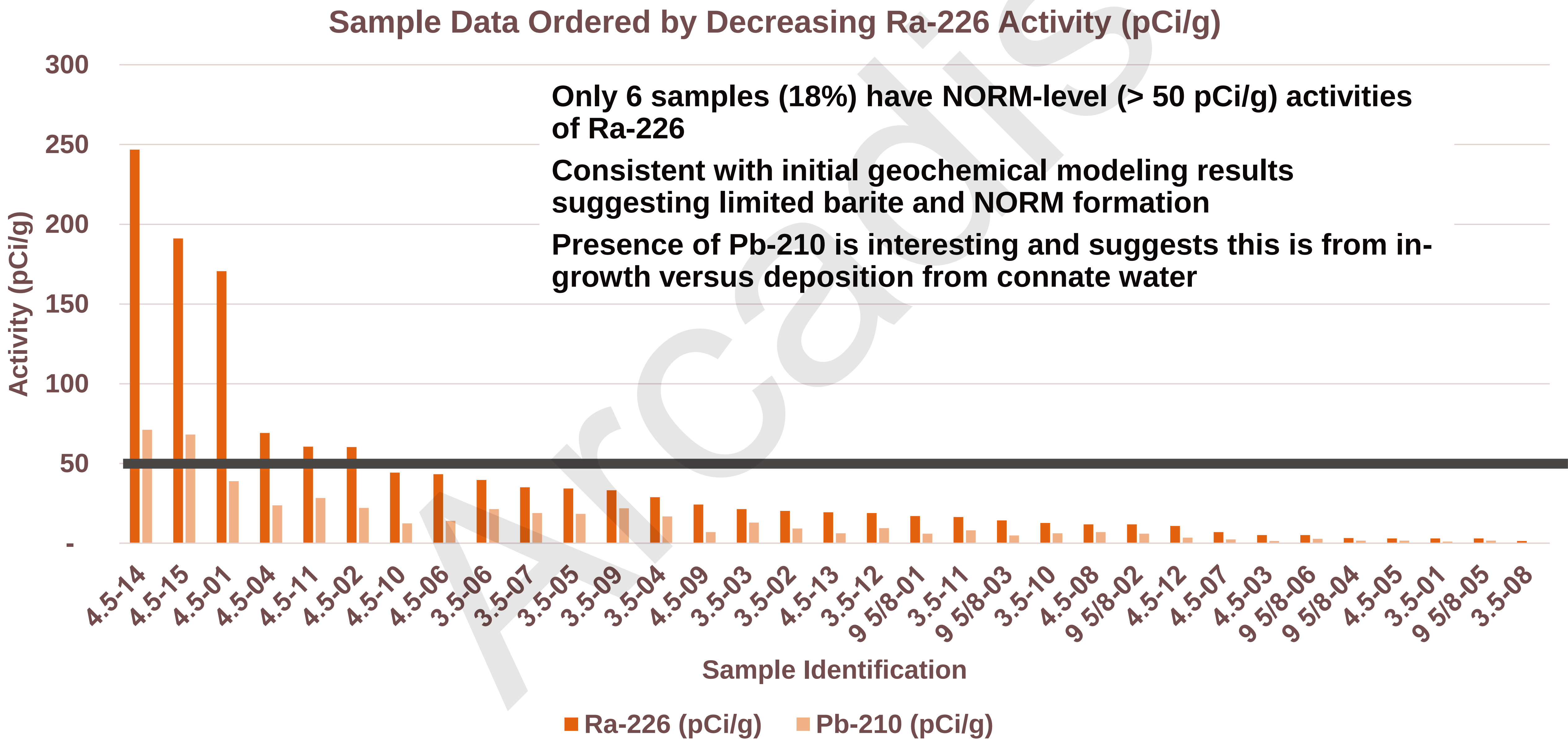
Target Areas of the Americas

Confidential Upstream O&G – Australia: Assessing Naturally Occurring Radioactive Materials in Produced (Connate) Water



L. Al Attar et al

Upstream O&G: Presence of Only Comparatively Modestly NORM Impacted Material



Only 6 samples (18%) have NORM-level (> 50 pCi/g) activities of Ra-226

Consistent with initial geochemical modeling results suggesting limited barite and NORM formation

Presence of Pb-210 is interesting and suggests this is from in-growth versus deposition from connate water

Arcadis.

Improving quality of life.