Using Spent Brewery Grain to Suppress Acid Rock Drainage from Historic Tailings

James Gusek, Tahne Corcutt (B2C), and Lee Josselyn

Linkan ENGINEERING

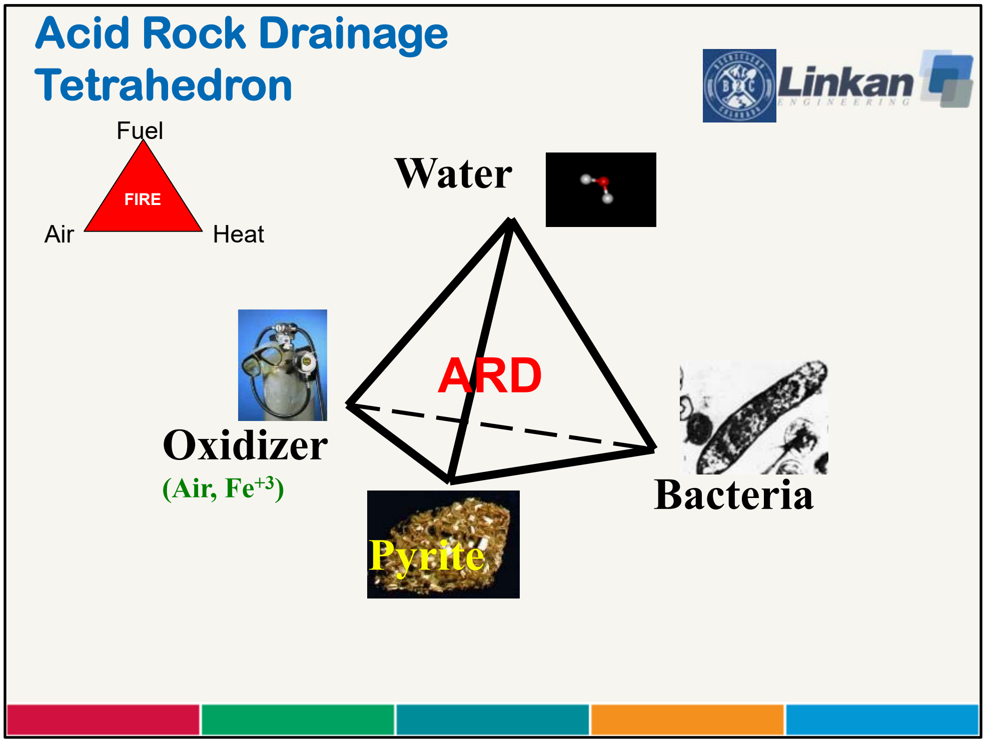
Solutions for the World of Water

Thanks for inviting us to participate. I'd like to acknowledge my co-authors Tahne Corcutt and Lee Josselyn.

OUTLINE

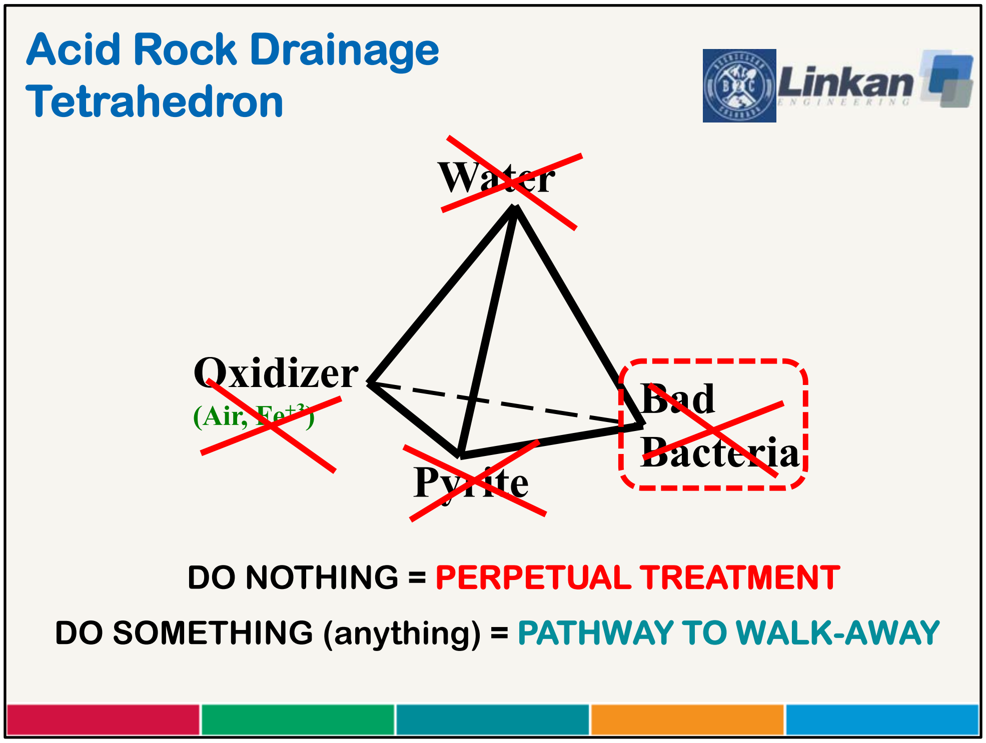
- ARD Suppression Background
  - ARD Tetrahedron
  - How Bactericides Work
  - Why Use Spent Brewery Grain?
- The Site
- The Test
  - Sample Collection
  - Test Setup
- Results
- ProofPassive test kits

We're basically going to cover four main topics: a bit of ARD Suppression background, a look at the site, how we tested the concept of using brewery waste to suppress acid rock drainage, and the test results. **and - full disclosure, a little commercial at the end.**

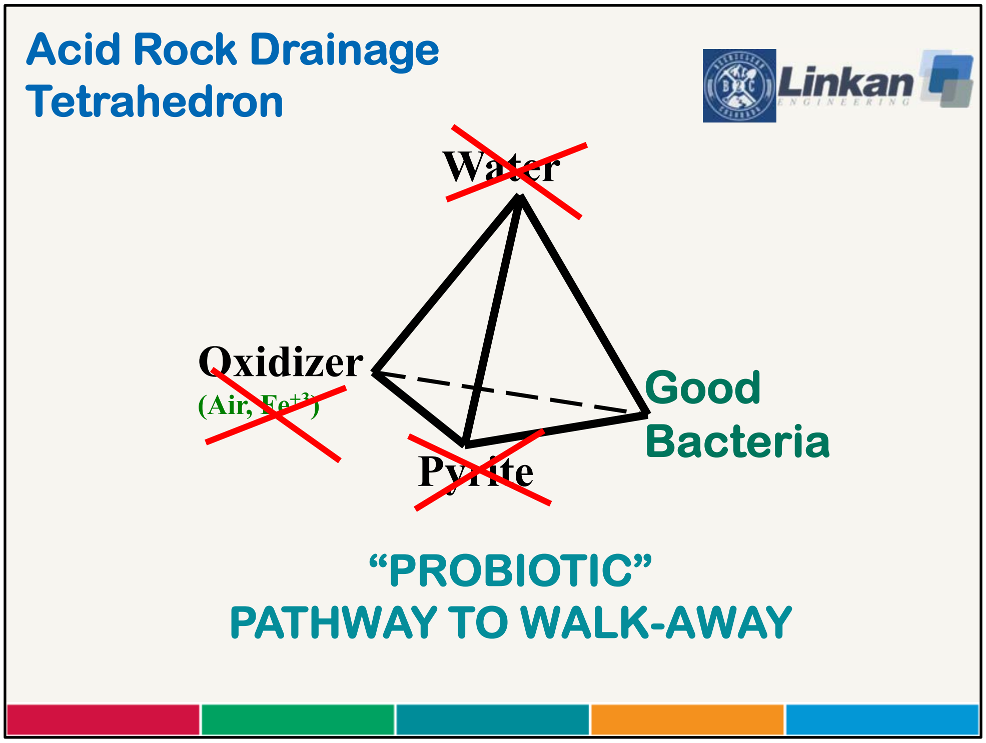


Before we get started, we need to understand that ARD formation is analogous to the combustion triangle we all learned in elementary school. Cut off the air, fuel or heat supplies and you won't have a fire. **(CLICK)**

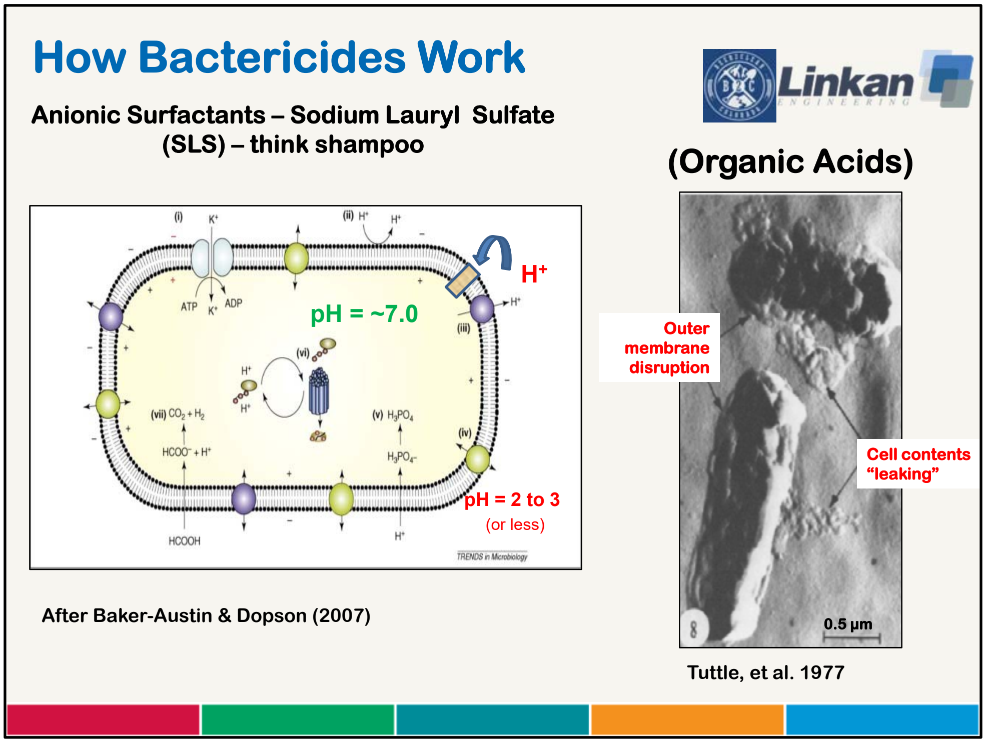
ARD formation is similar, you need pyrite (of course), air, water and not fully appreciated, bacteria: acidithiobacillus ferro-oxidans . Cut off one or more corners of the ARD tetrahedron, and ARD kinetics is greatly suppressed. But if you cut off the bacteria corner, you can slow the kinetics of ARD formation by 3 orders of magnitude (**that's a thousand times slower**).



It’s not enough to kill the bad bacteria, just killing the bacteria leads to short term control but you need to something, right?



We need to replace/displace them with good bacteria. With apologies to Jamie Lee Curtis and the folks who make Activia, think of this as a "probiotic" pathway to walking away from perpetual ARD treatment.



How can a microbe survive in low pH water? It has evolved an oily “cloak” that keeps the ARD out and it uses proton pumps to keep the protoplasm circum-neutral. The shampoo destroys the cloak and the ARD floods in, killing the bug – it basically stews in its own juices and it’s hard to evolve an adaptive strategy. **[CLICK]**

Unlike the soap, organic acids just weaken the cell membrane so that the contents leak out – kind of like stabbing someone in an artery. Humic acids generated by plants in the root zone are a sustainable source of bactericides. Vegetation is a gift that keeps on giving.

Organic Amendments

- Spent brewery grain (Lindsay et al., 2010)
- Waste milk & dairy products (Jin et al., 2008)
- Organic acids (Tuttle, et al., 1977)
- Composted sewage sludge (Pichtel & Dick, 1990)
  - Composted paper mill sludge (ditto)
  - Pyruvic acid (ditto)
  - Water-soluble extract from composted sewage sludge (ditto)

So organic amendments work too – a lot of these are considered waste. But the mechanism is a little different from shampoo. As you'll see, we focused mostly on the spent brewery grain but have included some milk and shampoo cells for comparison.

Why Use Spent Brewery Grain?

It looks like a soggy granola bar – it can hold a LOT of moisture – very difficult to dry it out.

Brewery grain has a lot going for it; it's everywhere, research a decade ago shows it can suppress ARD; it helps to grow plants on mine wastes and using it to reclaim mine land helps to further close a loop.

When my co-author Tahne heard me talk about this during my 2018 presentation in Creede, she thought it was a great concept (and here we are).

Tahne’s connections on the Western Slope of Colorado lead to the identification of our test site. With the cooperation of the landowners, we embarked on collecting preliminary samples for characterization in 2019.

The Site – Atlas Tailings, Ouray County, Colorado

- 3.1 tons/kt pyritic sulfur in "red" tailings adjacent to Sneffels Creek
- Paste pH 3.4, no alkalinity
- Planned reclamation by Colorado Div. of Mining, Reclamation & Safety (DRMS) & Trout Unlimited
- Lead and potential cadmium, silver, & zinc loading in Sneffels Creek
- Suspected *Anglesite* ($PbSO_4$) presence (*Galena* weathering product)
- Elevation 10,700 ft. / 3,262 meters
- Mixed ownership (public/private)

The tailings only have 3.1 tons of pyritic sulfur per kiloton – that's only 0.31%: not much. But because of the lack of alkalinity, the tailings have a paste pH of 3.4 and exhibit elevated amounts of lead with other heavy metals.

I never saw this in the information on the site, but I suspect that one source of lead in the red tailings is the mineral Anglesite, which is a galena or lead sulfide weathering product. Any geochemists out there? Does this make sense?

Sampling/ Tailing Collection

Team members Jim Gusek, Jeff Litteral (DRMS), and Tahne Corcutt work together at the Atlas Mill site near Ouray.

Samples were collected in the fall and early winter of 2019.

B2C Engages Local Communities

Ouray High School students help to transport fifteen cubic feet (1,150 pounds) of tailing material from the Atlas Mill site to the Beer2Clear lab.

Future engineers & scientists?

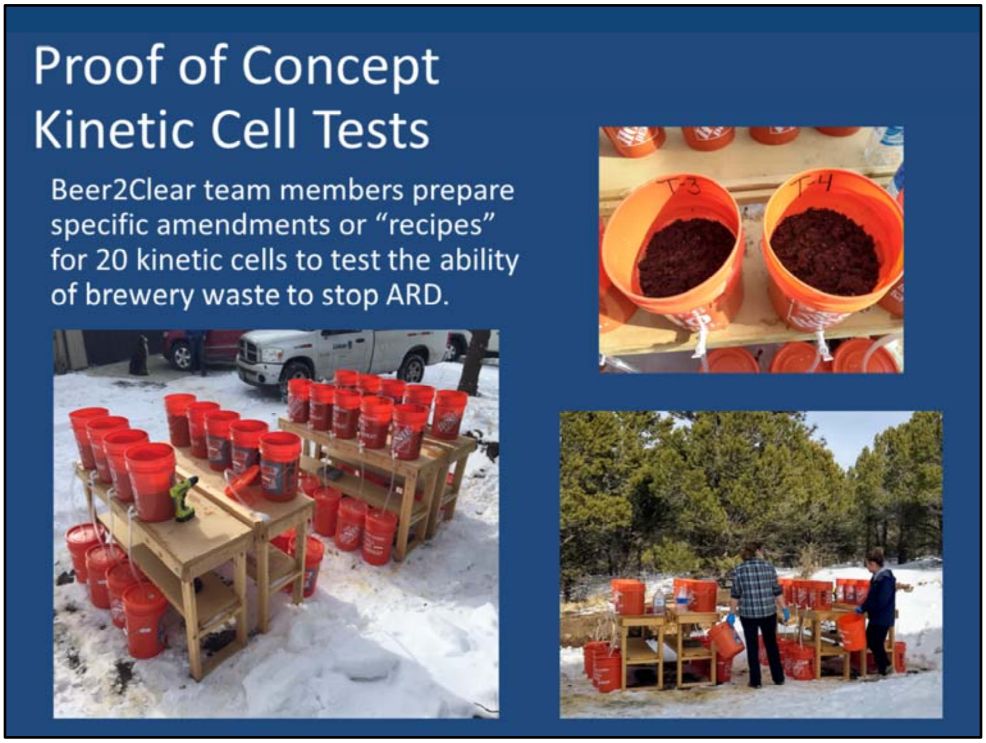
Tahne had some great help from the students at Ouray High School Science Program and their teacher, Beth Lakin. Excuse me, but you say you need a permission slip from your parents to do **WHAT?**

Test Setup
(based on lab screening)

Test #	Red Atlas Tailings (kg)	Brewery Waste (BW)	Milk	Ag Lime	Manure Inoculant	Veg. Cover	Buffered SLS Rinse	Logic
1	20							**Control**
2	20					X		**Control w/veg**
3	20	Low % BW			X	X	Yes, but only if pH <5.5	BW in entire soil column, low concentration, no lime
4	20	Med % BW			X	X	Yes, but only if pH <5.5	BW in entire soil column, medium concentration,no lime
5	20	High % BW			X	X	Yes, but only if pH <5.5	BW in entire soil column high concentration , no lime
6	20	Low % BW		X	X	X		BW in entire soil column, low concentration, w/lime
7	20	Med % BW		X	X	X		BW in entire soil column, medium concentration, w/lime
8	20	High % BW		X	X	X		BW in entire soil column high concentration w/lime
9	20	Low % BW	X	X	X	X		BW in entire soil column, low concentration w/milk & lime
10	20	Med % BW	X	X	X	X		BW in entire soil column, med. concentration w/milk & lime
11	20	High % BW	X	X	X	X		BW in entire soil column high concentration w/milk & lime
12	20		X	X	X	X		No BW, just milk & lime **(Non-BW semi-control)**
13	20	Low % BW		X	X	X	Yes, but only if pH <5.5	BW in just upper soil column, low concentration, w/lime
14	20	Med % BW		X	X	X	Yes, but only if pH <5.5	BW in just upper soil column, medium concentration, w/lime
15	20	High % BW		X	X	X	Yes, but only if pH <5.5	BW in just upper soil column, high concentration w/lime
16	20						X	Once, week 0 to test SLS longevity
17	20	**Sodium Lauryl Sulfate Rinse**					X	Week 0 and whenever pH drops to <5.5 (multiple applications)
18	20					X	X	Once, week 0 to test SLS longevity with vegetation
19	20					X	X	Week 0 and whenever pH drops to <5.5 (multiple applications)
20	**0**					**X**		**Background – no tailings with vegetation**

Based on some preliminary lab screening results (click), we developed an ambitious suite of kinetic test cell recipes. Most of the test cells involved various amounts of brewery waste, milk, and sodium lauryl sulfate. We had three controls, one of which was a bucket filled with native soil. Most, but not all of the test cells had a vegetative cover that was provided by a native seed mix planted in a biotic soil medium.

Over the space of several days, the mixtures were prepared in Tahne's garage "lab" and the mixtures were placed in the test units.

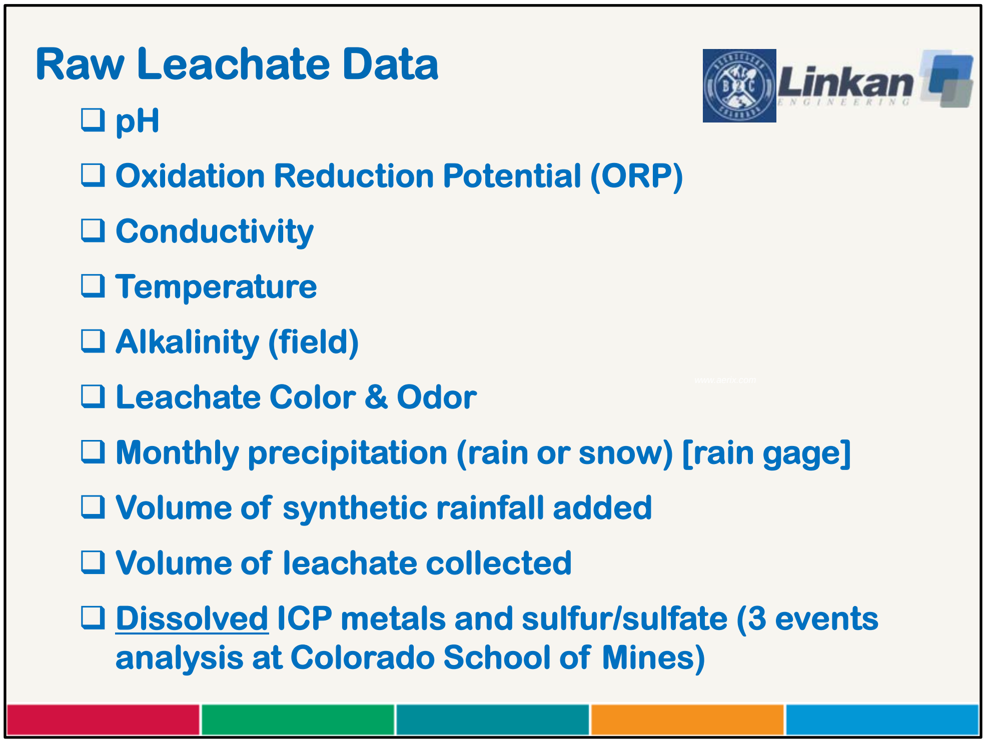


The 20 KCTs were assembled in Tahne's back yard in January of 2020. Initially, they were concerned about the brewery waste attracting the local deer herd but they seemed to lose interest once the brewery waste was mixed with tailings.

Vegetative Cover
(not too successful)

- ❑ Junegrass - 0.9 PLS/ac.
- ❑ Needle & Thread Grass - 18 PLS/ac.
- ❑ Galletagrass – 9 PLS/ac.
- ❑ Muttongrass – 1.5 PLS/ac.
- ❑ Un-vegetated Tests
  - o #1 Control
  - o #16 SLS one application
  - o #17 SLS multi-applications (pH driven)

We used a seed mix that was similar to the one that DRMS would be using on the site **but multiplied it times THREE**. Three test cells did not receive seed. Vegetation establishment wasn't very successful. However, the plant growth media on the surface may have prevented oxygen exchange. We've had this problem on other projects.



So, what did we measure? Field parameters were pH, ORP, conductivity, temperature and alkalinity. Tahne took notes of leachate appearance and we semi-tracked the water balance in and out the test cells. Due to the dry weather, she had to add synthetic rain to generate leachate. This was a pro-bono test; Tahne submitted three samples to the Colorado School of Mines for analysis via ICP/AES. Her biggest challenge was filtering some of the high organic content leachates.

So let's look at some of the data.

Results – July Sampling Event

Kinetic Cell Test	pH (s.u.)	Oxidation Reduction Potential (ORP) (mv)	Conductivity (µS/cm)	Alkalinity mg/L (@pH>6.0)	Leachate Volume (mL)	Comments
1 Control	5.56	262	246	0	200	Orange Leachate
2 Control +Veg	7.40	223	140	25	750	"Weak Tea"
3 Low BW no lime	7.48	227	98	40	700	Clear Leachate
4 Med. BW no lime	7.19	257	1,298	35	450	"Weak Tea"
5 High BW no lime	8.5	165	6,008	270*	500	"Black Tea"
6 Low BW w/lime	7.4	247	652	30	350	"Weak Tea"
7 Med BW w/lime	7.63	245	2,480	45	400	"Weak Tea"
8 High BW w/lime	8.42	184	1,876	240	500	"Strong Tea"
9 #6 + milk	7.38	238	500	20	850	"Weak Tea"
10 #7 + milk	8.35	189	2,780	250	300	"Weak Tea"
11 #8 + milk	8.14	193	5,936	240	400	"Black Tea"
12 No BW milk& lime	7.34	242	198	30	350	Clear Leachate
13 ½ BW w SLS	7.73	223	374	55	550	"Strong Tea"
14 ½ BW w SLS	7.13	251	618	50	700	"Strong Tea"
15 ½ BW w SLS	7.32	235	1,224	80	950	"Black Tea"
16 SLS once no veg	5.35	334	172	0	300	Orange Leachate
17 SLS multi no veg	5.78	277	220	0	200	"Weak Tea"
18 SLS once w/veg	6.49	271	100	15	525	"Weak Tea"
19 SLS multi w/veg	6.61	272	94	15	750	Clear Leachate
20 Baseline	8.13	174	3,072	180	550	"Weak Tea"

#5 - * Max'd out alkalinity test

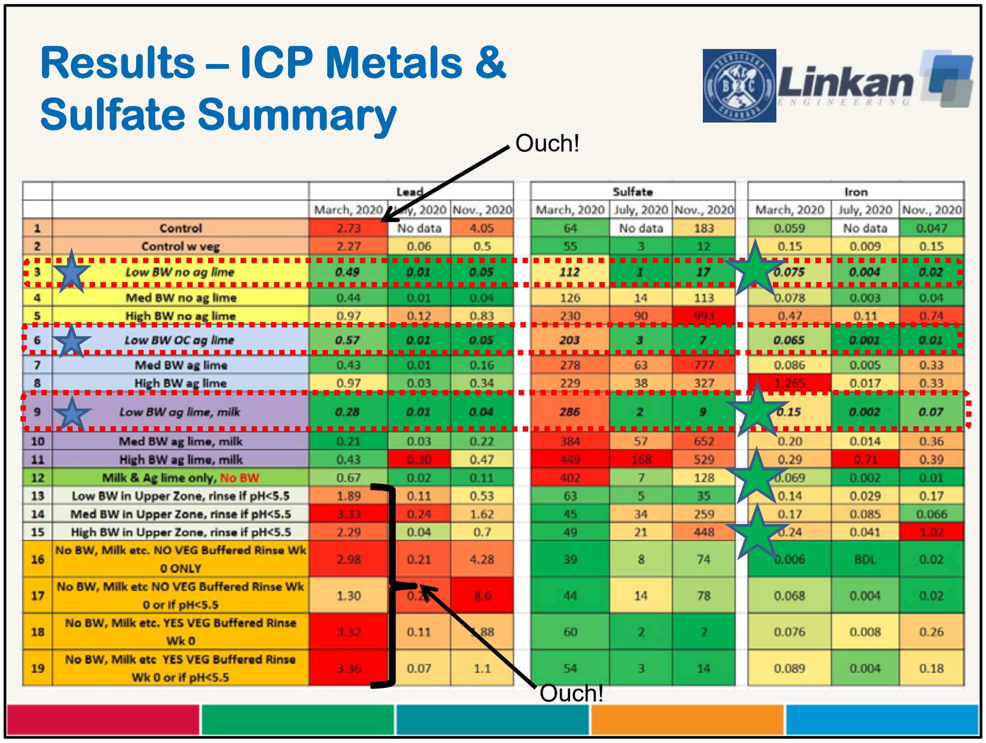
So here are the field measurements from the July event. Lots of data here but let's first focus on "clear leachate" KCTs: #3, #12, and #19. They all have consistently very low conductivity values, circum-neutral pHs and modest alkalinity increases. You can look at the data more closely at your leisure if you download the presentation.. The "clear leachate cells compare favorably with the control plus vegetated cell (#2) - **High Alkalinity and conductivity correlation with high organics.** Now let's fast forward to the end of the test.

Results – November Sampling Event

Kinetic Cell Test	pH (s.u.)	Oxidation Reduction Potential (ORP) (mv)	Conductivity (µS/cm)	Alkalinity mg/L (@pH>6.0)	Leachate Volume (mL)	Comments
1 Control	5.54	348	106	0	1000	Orange leachate
2 Control +Veg	7.10	246	46	15	500	Clear leachate
3 Low BW no lime	7.63	152	206	35	1200	Green leachate
4 Med. BW no lime	6.21	272	268	10	25	Weak tea
5 High BW no lime	5.97	280	1,598	0	200	Weak tea
6 Low BW w/lime	7.12	225	18	20	1000	Clear leachate
7 Med BW w/lime	6.61	235	110	15	450	Weak tea
8 High BW w/lime	6.6	219	248	10	1350	Weak tea
9 #6 + milk	8.05	150	62	10	1200	Green leachate
10 #7 + milk	5.96	248	88	0	700	Weak tea
11 #8 + milk	7.35	248	30	20	1900	Clear leachate
12 No BW milk& lime	7.22	286	164	30	350	Green leachate
13 ½ BW w SLS	6.70	293	62	15	200	Weak tea
14 ½ BW w SLS	7.08	197	1,394	30	1000	Orange leachate
15 ½ BW w SLS	6.52	215	1,854	30	100	Green leachate
16 SLS once no veg	5.06	355	144	0	200	Orange leachate
17 SLS multi no veg	5.52	333	86	0	300	Orange leachate
18 SLS once w/veg	7.1	238	36	20	4000	Weak tea
19 SLS multi w/veg	7	246	22	15	1500	Weak tea
20 Baseline	7.32	272	194	40	600	Clear leachate

So here are the field measurements from the November event.

Again we have a few cells producing clear leachate and a lot of cells, including the Control, producing orange leachate Lot's of data here but let's first focus on "clear leachate" KCTs: #6 and #11. They all have consistently very low conductivity values, circum-neutral pHs and modest alkalinity increases. The "clear leachate cells compare favorably with the control plus vegetated cell (#2) suggesting that vegetation alone isn't a bad idea. We have some interesting "green" leachate observed in 3, 9, and 15 – this is suspected to be ferrous iron. Now let's look at the ICP metals and sulfate. (click)



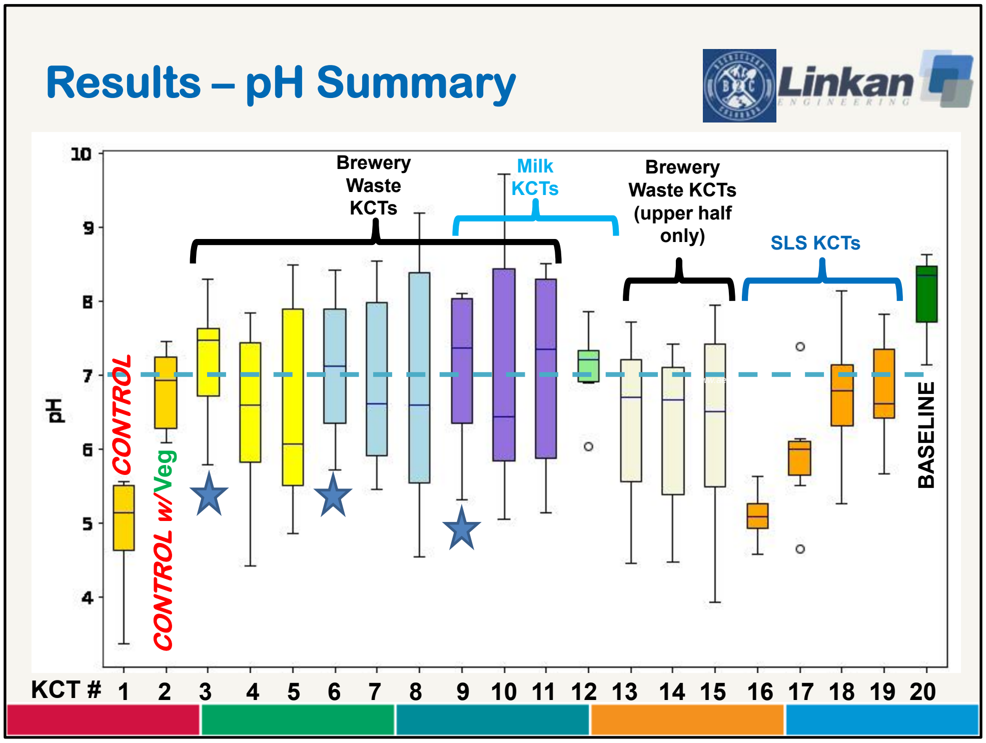
		Lead			Sulfate			Iron		
		March, 2020	July, 2020	Nov., 2020	March, 2020	July, 2020	Nov., 2020	March, 2020	July, 2020	Nov., 2020
1	Control	2.73	No data	4.05	64	No data	183	0.059	No data	0.047
2	Control w veg	2.27	0.06	0.5	55	3	12	0.15	0.009	0.15
3	*Low BW no ag lime*	***0.49***	***0.01***	***0.05***	***112***	***1***	***17***	***0.075***	***0.004***	***0.02***
4	Med BW no ag lime	0.44	0.01	0.04	126	14	113	0.078	0.003	0.04
5	High BW no ag lime	0.97	0.12	0.83	230	90	993	0.47	0.11	0.74
6	*Low BW OC ag lime*	***0.57***	***0.01***	***0.05***	***203***	***3***	***7***	***0.065***	***0.001***	***0.01***
7	Med BW ag lime	0.43	0.01	0.16	278	63	777	0.086	0.005	0.33
8	High BW ag lime	0.97	0.03	0.34	229	38	327	1.265	0.017	0.33
9	*Low BW ag lime, milk*	***0.28***	***0.01***	***0.04***	***286***	***2***	***9***	***0.15***	***0.002***	***0.07***
10	Med BW ag lime, milk	0.21	0.03	0.22	384	57	652	0.20	0.014	0.36
11	High BW ag lime, milk	0.43	0.30	0.47	449	168	529	0.29	0.71	0.39
12	Milk & Ag lime only, No BW	0.67	0.02	0.11	402	7	128	0.069	0.002	0.01
13	Low BW in Upper Zone, rinse if pH<5.5	1.89	0.11	0.53	63	5	35	0.14	0.029	0.17
14	Med BW in Upper Zone, rinse if pH<5.5	3.33	0.24	1.62	45	34	259	0.17	0.085	0.066
15	High BW in Upper Zone, rinse if pH<5.5	2.29	0.04	0.7	49	21	448	0.24	0.041	1.02
16	No BW, Milk etc. NO VEG Buffered Rinse Wk 0 ONLY	2.98	0.21	4.28	39	8	74	0.006	BDL	0.02
17	No BW, Milk etc NO VEG Buffered Rinse Wk 0 or if pH<5.5	1.30	0.2[illegible]	8.6	44	14	78	0.068	0.004	0.02
18	No BW, Milk etc. YES VEG Buffered Rinse Wk 0	3.32	0.11	[illegible].88	60	2	2	0.076	0.008	0.26
19	No BW, Milk etc YES VEG Buffered Rinse Wk 0 or if pH<5.5	3.36	0.07	1.1	54	3	14	0.089	0.004	0.18

Here's where the distinctions start to emerge. The two controls (#1 & #2) released a LOT of lead at startup (CLICK) and so did the low BW cells (#13, 14, & #15) and the SLS cells (#16 to #19) **[CLICK]**

No 2 with the vegetation was still leaching lead at the end of the test.

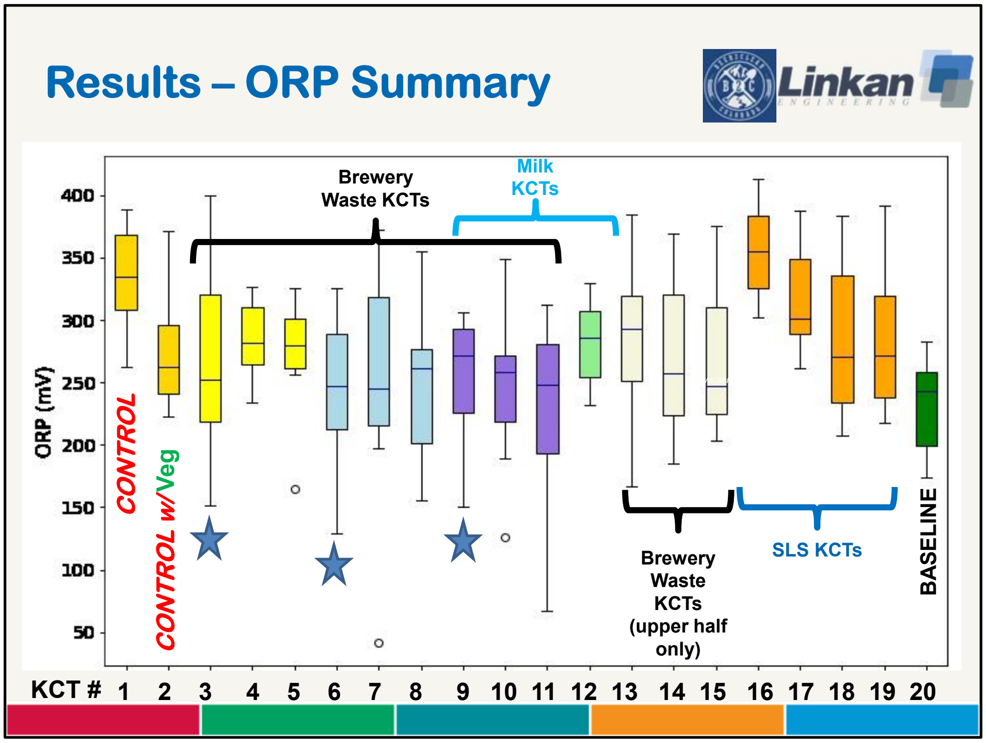
Most of the BW cells (with the exception of the #5 High BW) released very little lead at startup. No. 3 is looking pretty good (CLICK) with low lead, low sulfate & iron (virtually zero pyrite oxidation). #6 (CLICK) is not that far behind (click). #9 rounds out the favorites with respect to lead, sulfate, and iron concentrations. **Click.** The green stars are the cells that produced green leachate. This is probably ferrous iron – only #15 with the high BW exhibited really high iron but #5 leachate was "weak tea" in color in the final sampling event.

The Control exhibited orange leachate and elevated lead throughout the test.



The raw pH data can be used as an indicator of how steady the pH values were through the test. **In many instances, it took several months for the pH to increase.** Some of the pH peaks were associated with higher amounts of organic carbon either in the form of Brewery waste or milk. This might have been due to alkalinity generated by sulfate reducing bacteria.

The SLS cells didn't do as well as the brewery waste; stopping pyrite oxidation didn't prevent the mobilization of the stored acidity.



Lastly, let's look at the Oxidation reduction potential. We had some really low observations as show by some of the outliers (dots) Lower values are good as pyrite is less likely to oxidize.

Our favorites so far are #3, #6, and #9 and they all have low ORPs comparatively.

Potential Winners

Linkan Engineering

Kinetic Cell Test	pH (s.u.)	Oxidation Reduction Potential (ORP) (mv)	Conductivity (μS/cm)	Alkalinity mg/L (@pH>6.0)	March Lead (mg/L)	July Lead (mg/L)	November Lead (mg/L)	Comments
1 Control	5.54	348	106	0	2.73	No data	4.05	Orange Leachate
2 Control + Veg	7.10	246	46	15	2.27	0.06	0.5	Clear Leachate
3 Low BW in the entire mass, no lime	7.63	152	206	35	0.49	0.01	0.05	Green Leachate
6 Low BW in the entire mass w/lime	7.12	225	18	20	0.57	0.01	0.05	Clear Leachate
9 Low BW in the entire mass w/lime & milk	8.05	150	62	10	0.28	0.01	0.04	Green Leachate
20 Baseline native soil with vegetation	7.32	272	194	180	No data	No data	No data	Clear Leachate

Nov., 2020 Final Field Data

Our three potential winners are Numbers 3, 6, and 9 which had the lowest brewery waste amounts among their respective clusters. This goes to show that too much of a good thing (brewery waste or milk) may not be appropriate in all situations. If there was more pyrite present in the Atlas Tailings, **or they were not as weathered**, perhaps other mixtures would have been better.

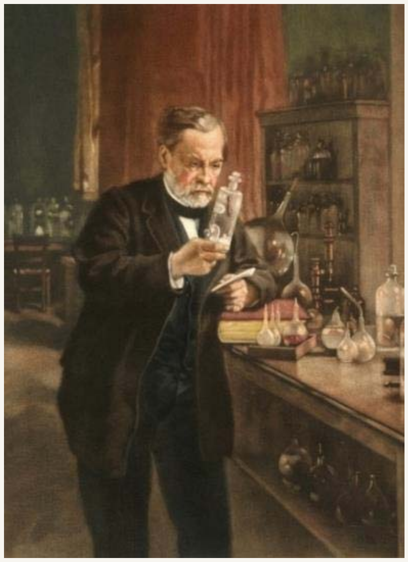
End Game “By the Book”

- TCLP Testing (failed for lead content)
- 1,500 lbs. of tailings
- Four 55-gallon drums disposed responsibly
- Clean Management Environmental Group
- $3,000 price tag for disposal

No good deed goes unpunished. For a variety of reasons, we couldn’t return the materials back to the site or find a new home for them. They failed the TCLP test for lead. Tahne arranged with the Clean Management Environmental Group and spoke very highly of them.

Many thanks to our collaborators. Be sure to check out the **Colorado Boy Brewery** the next time you're in western Colorado.

Cheers!



"Chance favors the prepared mind"
L. Pasteur

jim.gusek@linkan.biz
tcorcutt@gmail.com
lee.josselyn@linkan.biz

Thanks for your attention – I hope your mind is a little more prepared now, especially as you down your next beer (cheers!)

Does anyone in the audience know the connection that Louis Pasteur had with beer? Sorry, no prizes except bragging rights.

Answer: Pasteur observed that by holding beer at between 131°F and 149°F (55°C–60°C) for a short time, the growth of beer spoilage organisms was inhibited, and the beer could be rendered palatable for up to 9 months. ... This is the basis of the process of pasteurization. (www.beer&brewing.com)

"When the only tool in your toolbox is a hammer, everything looks like a nail". When I started my career in passive treatment, I thought that biochemical reactors (BCRs) could solve almost any mining influenced water (MIW) problem. Fast forward a few decades and the reality is that the passive treatment design toolbox contains more options. If you're or a co-worker are confronted with the question as to whether passive treatment processes could work at your site, perhaps Linkan Engineering can help. We've condensed our experience into a simple customized ProofPassive test kit that we'd ship to you with clear instructions geared to guide you in assessing the basics of passively treating your MIW.   In the process, you'll have Linkan's expertise supporting you every step of the way.

The ProofPassive test kit results could provide you with data to make an informed decision about adopting this technology in closing your mine site.