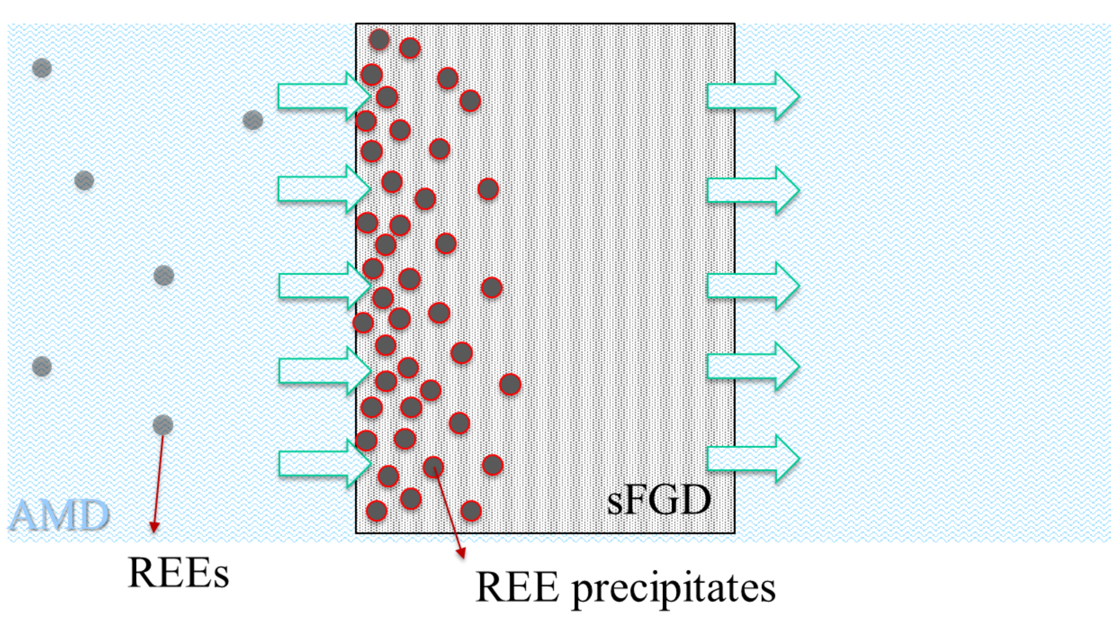
Concentrating Rare Earth Elements in Acid Mine Drainage Using Coal Combustion By-products through Abandoned Mine Land Reclamation

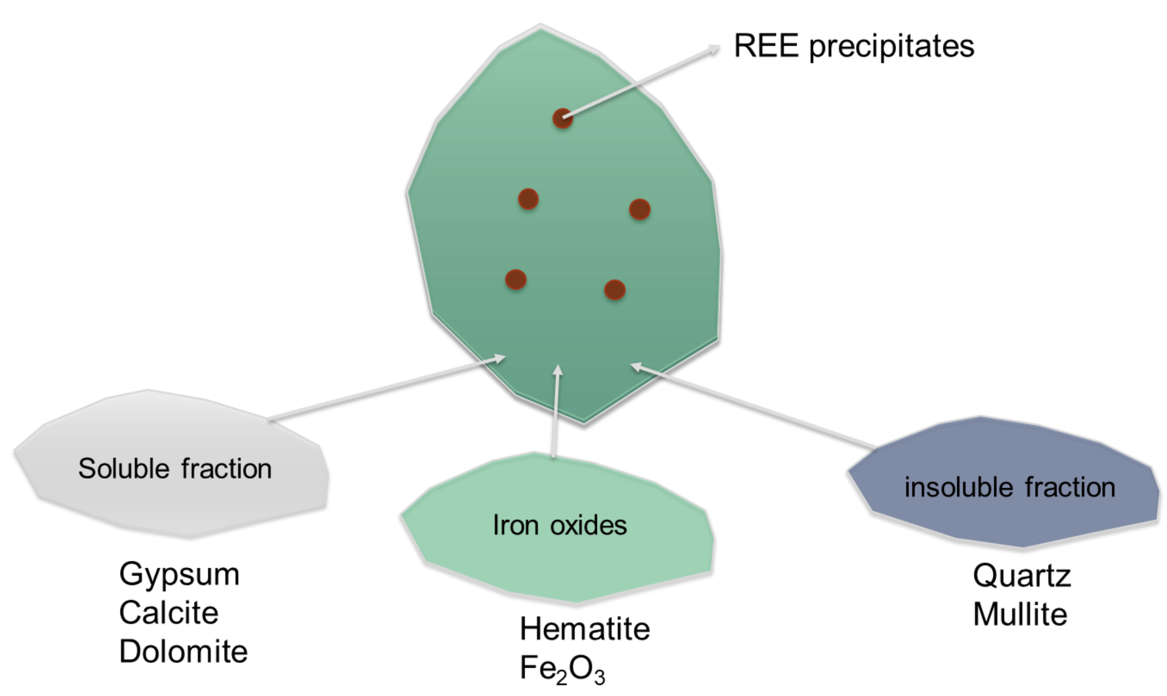
Chin-Min Cheng, Tarunjit Butalia, Jeff Bielicki, John Lenhart
Department of Civil, Environmental, and Geodetic Engineering

Two-Step Process

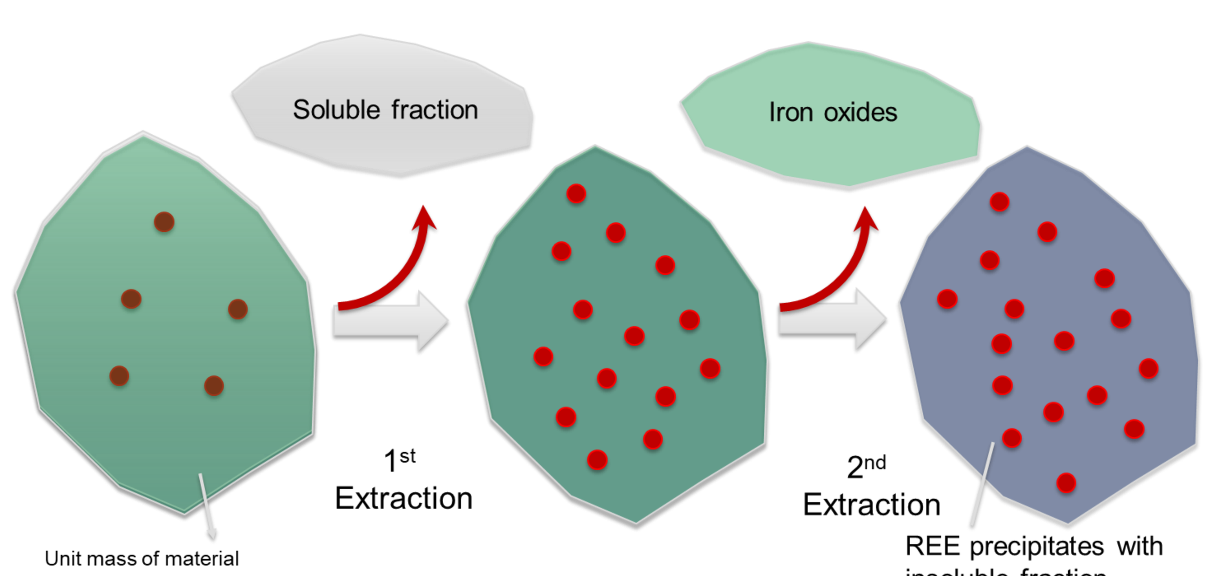
- Recover rare earth elements in acid mine drainage (AMD) using stabilized flue gas desulfurization material (sFGD)



Spent sFGD Material



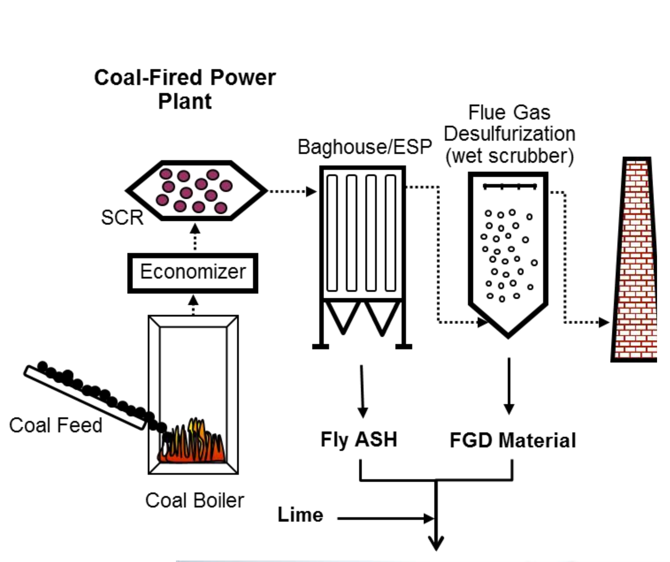
- Concentrating recovered REEs using a selective extraction process to produce feedstock with >2wt.% T-REEe



Objectives

- Validate the effectiveness and feasibility of the integrated rare earth recovery/ concentrating process
- Determine mechanisms controlling the rare earth recovery
- Quantify the associated economic and environmental benefits
- Evaluate the full-scale application

sFGD Material



Stabilized FGD material

- Hannebachite ($CaSO_3$ 0.5 H_2O); Portlandite ($Ca(OH)_3$); Hematite (Fe_2O_3); Magnetite (Fe_3O_4); Quartz (SiO_2); Mullite ($3Al_2O_3$ $2SiO_2$); and Maghemite (Fe_2O_3)

			sFGD Material
Mercury	Hg	μg/kg	318
Phosphorus	P	mg/kg	228
Potassium	K	mg/g	1.43
Calcium	Ca	mg/g	166
Magnesium	Mg	mg/g	9.83
Sulfur	S	mg/g	108
Aluminum	Al	mg/g	12.3
Boron	B	mg/kg	290
Copper	Cu	mg/kg	<0.5
Iron	Fe	mg/g	39.7
Manganese	Mn	mg/kg	58
Molybdenu	Mo	mg/kg	3.51
Sodium	Na	mg/g	5.4
Zinc	Zn	mg/kg	34.8
Arsenic	As	mg/kg	23.8
Barium	Ba	mg/kg	168
Beryllium	Be	mg/kg	<0.11
Cadmium	Cd	mg/kg	0.803
Cobalt	Co	mg/kg	8.10
Chromium	Cr	mg/kg	28.6
Lithium	Li	mg/kg	133
Nickel	Ni	mg/kg	18.6
Lead	Pb	mg/kg	6.05
Antimony	Sb	mg/kg	4.33
Selenium	Se	mg/kg	<3
Silicon	Si	mg/g	0.25
Strontium	Sr	mg/kg	248
Thallium	Tl	mg/kg	44.3
Vanadium	V	mg/kg	<1.2
Decimal percent of total by dry		%	60.4
pH		S.U.	9.7
Hydrogen ion concentration		mole/L	1.99×10^{-10}
pyritic sulfur		%	0.07
total sulfur		%	14.27
Potential acidity		tons of $CaCO_3$ per 1000 tons	2.2
Neutralization potential		tons of $CaCO_3$ per 1000 tons	84.77
Calcium carbonate deficiency		tons of $CaCO_3$ per 1000 tons	-82.57

AMD from Unreclaimed AMLs



- Historical environmental problem
  - Over 6,000 recorded abandoned underground mines and 119,000 acres of unreclaimed surface mined lands in Ohio
  - Approximately 1,200 miles of streams are adversely impacted by acid mine drainage (AMD) from abandoned mine lands (AMLs)
  - About 4,000 miles of streams in the Appalachian Region
  - Between 5,000 to 10,000 miles of streams in the western US regions
- Reclaiming AMLs faces significant financial challenge

Using CCRs in AML Reclamation



- Ohio Coal Development Office, Ohio Dept. Natural Resources, and American Electric Power
- Full-scale demonstration project
  - Over 1.8 million tons of FGD gypsum, sFGD, and fly ash
  - Environmental monitoring has been carried out for over seven years and is on going
  - Cheng et al. (2016)

Using sFGD in Reclamtion of AMD-producing AML

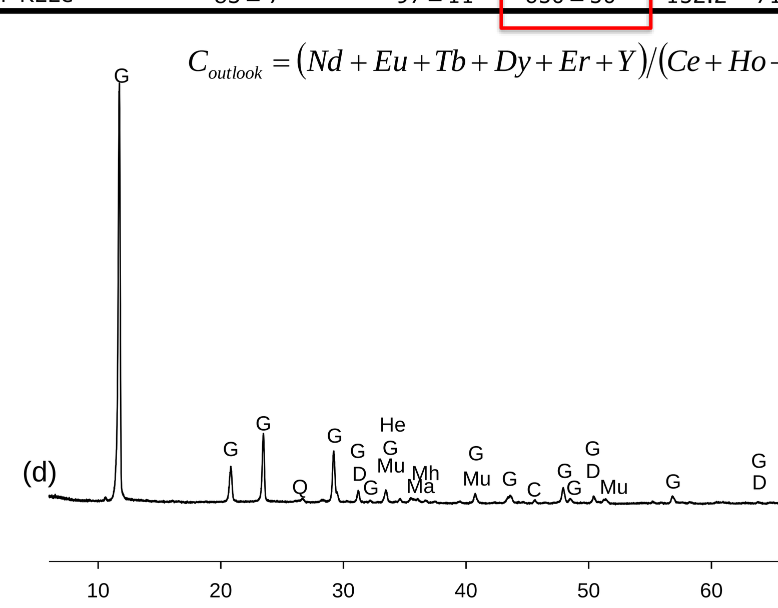
- Potential of using sFGD material to reclaim AMD producing AMLs
  - High Alkalinity
  - Low permeability
  - Combining source control and passive treatment approaches

- Laboratory Testing

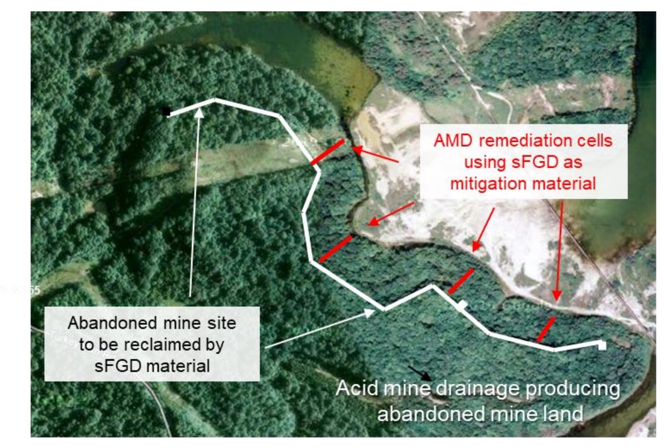

$C_{outlook}$=2

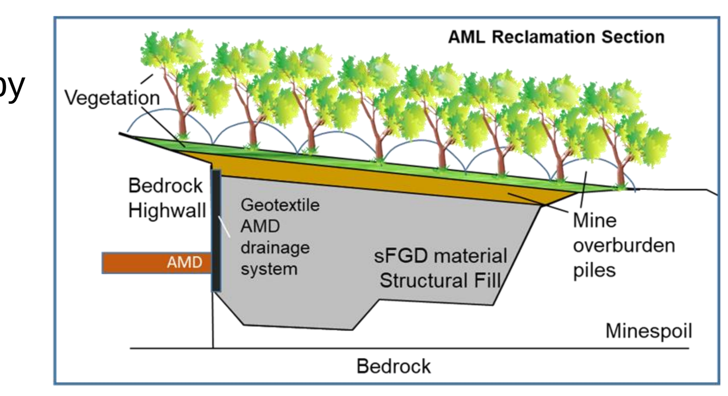
	sFGD			AMD Sludge			Coal Ash
	S-20 (L/S=20,Bench)	S-21 (L/S=30, Bench)	S-8 (L/S=147, Column)	Site A	Site B	US Coal	Appalachian Basin Coal
Ce Cerium	18.9 ± 0.4	23.2 ± 0.4	139 ± 7	26.0	160.0	21	192.09
Dy Dysprosium	0.56 ± 0.10	0.7 ± 0.2	27.8 ± 1.7	9.0	34.0	1.9	16.41
Er Erbium	2.7 ± 0.2	3.07 ± 0.13	15.1 ± 0.9	5.0	19.0	1.0	9.46
Eu Europium	0.27 ± 0.06	0.35 ± 0.04	7.3 ± 0.4	2.0	6.0	0.4	3.55
Gd Gadolinium	4.6 ± 0.3	5.21 ± 0.15	44 ± 3	9.0	34.0	1.8	18.43
Ho Holmium		0.05 ± 0.11	2.5 ± 0.2	2.0	7.0	0.35	3.34
La Lanthanum	8.5 ± 1.1	10.1 ± 1.2	39 ± 3	8.0	59.0	12	89.46
Lu Lutetium	0.27 ± 0.08	0.15 ± 0.03	1.48 ± 0.05	0.6	2.0	0.14	1.25
Nd Neodymium	11.0 ± 0.4	12.4 ± 0.9	113 ± 7	16.0	90.0	9.5	82.93
Pr Praseodymium	17 ± 7	19 ± 8	53 ± 8	3.0	19.0	2.4	21.62
Sc Scandium	3.781 ± 0.018	4.63 ± 0.10	7.3 ± 0.4	6.0	9.0	4.2	38.47
Sm Samarium	3.93 ± 0.05	5.5 ± 0.5	37.9 ± 1.6	5.0	23.0	1.7	17.66
Tb Terbium	1.1 ± 0.2	1.1 ± 0.2	7.2 ± 0.4	2.0	6.0	0.3	2.81
Tm Thulium			0.73 ± 0.04	0.6	2.0	0.15	1.35
Y Yttrium	7.43 ± 0.11	9.1 0.3	132 ± 9	54	230.0	8.5	95.37
Yb Ytterbium	1.461 ± 0.003	1.70 ± 0.09	9.0 ± 0.6	4.0	14.0	0.95	8.37
T-REEe	83 ± 7	97 ± 11	650 ± 50	152.2	714	66.3	602.6

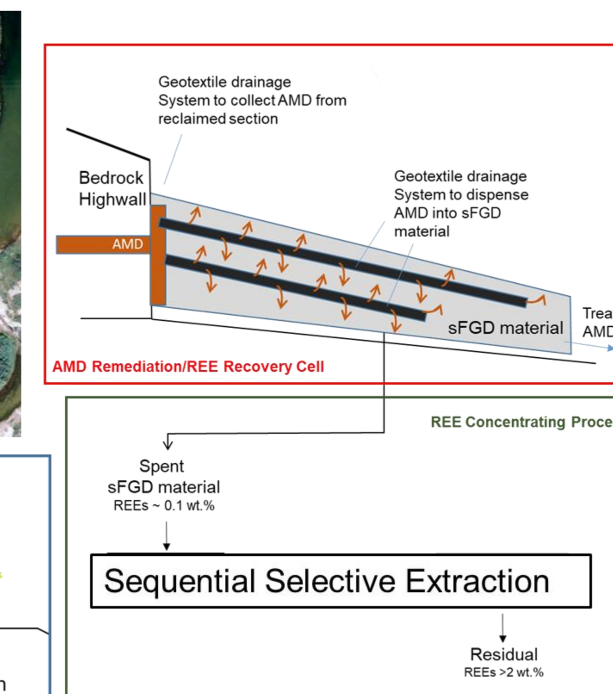
$$C_{outlook} = (Nd + Eu + Tb + Dy + Er + Y)/(Ce + Ho + Tm + Yb + Lu)$$



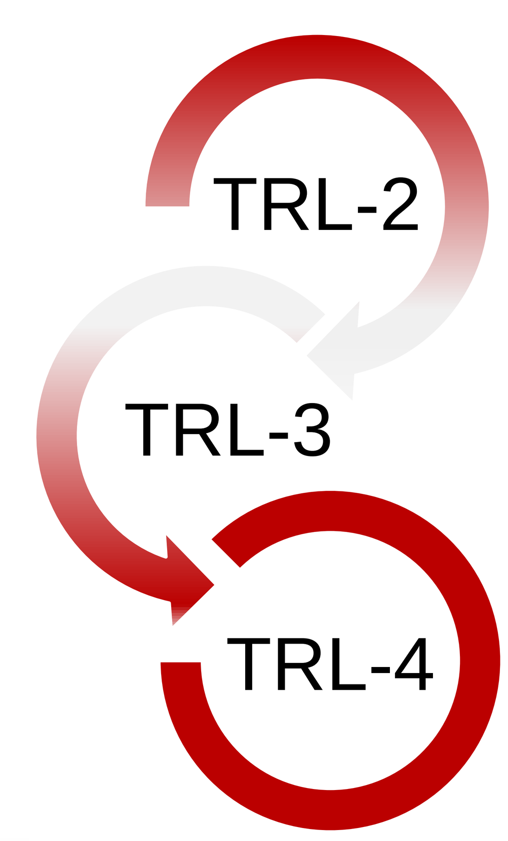
AML Reclamation 2.0







Tasks

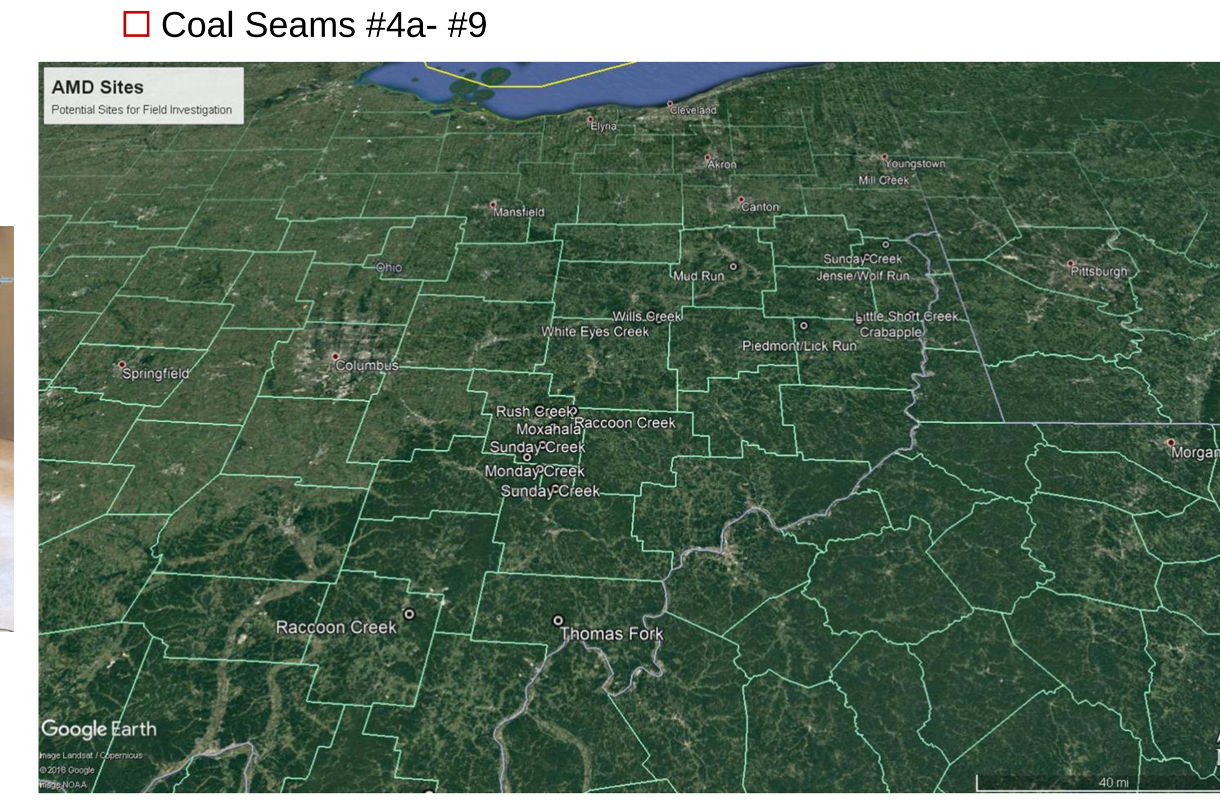


Carry out analytical and laboratory-scale studies to validate the proposed process
- Conducting column tests to maximize the retention of rare earths in sFGD
- Analyze the mineral and elemental compositions of the spent sFGD
- Apply sequential extraction to concentrate REE in spent sFGDs

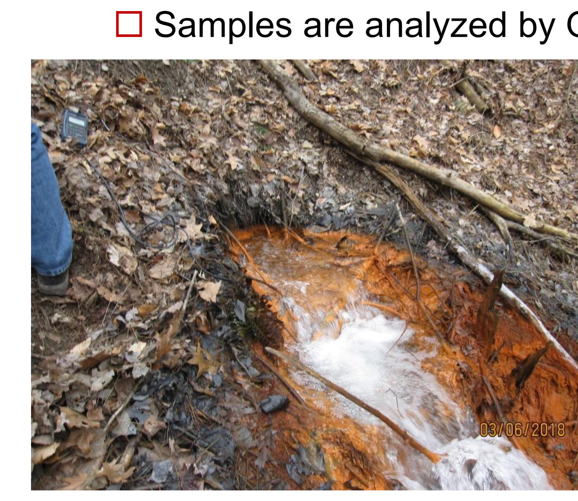
Integrate basic technological components for next phase pilot-scale study
- Field Investigation
- Techno-economic analysis and life-cycle assessment for full-scale applications
- Propose potential site for pilot-scale Study

Current Progress

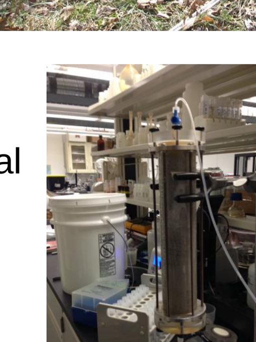
- Collaborate with ODNR and select over 20 AMD discharges
  - Most from underground mines
  - Coal Seams #4a- #9



- Field Investigation
  - Collecting AMD samples from discharging points
  - Measuring flow rates
  - Samples are analyzed by OSU's STAR lab and TERL.




- Column Test
  - AMD with high recovery potential
  - At least two sFGD materials
  - Percolation conditions
  - Geochemical models

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