CENE 486 FINAL PRESENTATION

CORN COB BIOSORBENT RESEARCH (CORN CORPS.)

April 26th, 2019

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Project Purpose

- Identify if ground corn cobs can remove heavy metals (cadmium) from drinking water
- Biosorbent: biological material that is used to remove contaminants from aqueous solution
- Health effects of cadmium: nausea/vomiting, muscle cramps, sensory disturbances, kidney failure [1]
- Untreated and nitric-acid treated corn to increase sorption potential

- Technical Advisor/Client: Dr. Fethiye Ozis
- NASA Space Grant research (2017-18)
  - *Inconclusive yet promising Isotherm adsorption model*
    - Removal efficiencies between 9 and 51%

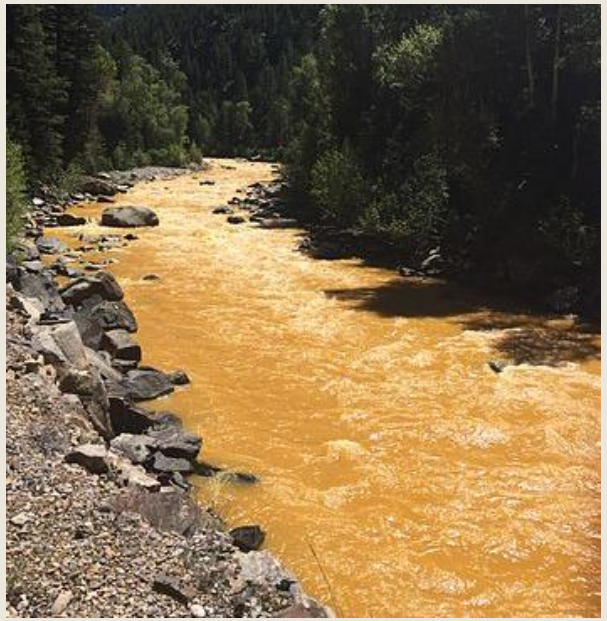


Figure 1. Gold King Mine Spill 2015

Figure 2. Cadmium metal and cadmium in batteries

Research Plan – Major Tasks

Task 1.0 – Experimental Methods

Task 2.0 – Isotherm Development

Task 3.0 – Prototype Development

Task 4.0 – Pilot Testing and Scale-up

Task 5.0 – Cost-Benefit Analysis

Task 6.0 – Team Management

Task 1.0. Experimental Methods

- Task 1.1. Biosorbent Preparation
- Task 1.2. Isotherm Development

Task 1.1. Corn Biosorbent Preparation

Figure 1. Sweet corn cobs purchased from local grocers

Figure 2. Corn cobs cut into two-inch sections

Figure 3. Dried corn cobs after being placed in drying oven for 24 hours at 100˚C

Task 1.1. Corn Biosorbent Preparation

Figure 4. Kernels removed from dried corn cobs

Figure 5. Dried corn cobs pulverized in a food processor

Figure 6. Pulverized corn passed through No. 60 sieve (250 microns)

Task 1.1. Nitric Acid Treatment

Figure 7. Corn treated with nitric acid and centrifuged

Figure 8. Acidic pH of treated corn after centrifuging

Figure 9. Neutral pH of treated corn after titrating with base

Final Corn Biosorbent Material

Untreated Corn

Acid-treated Corn

Figure 10. Final Corn Biosorbent Material Used for Testing

Task 1.2. Experimental Matrix

Table 1: Original experimental matrix

Experiment	Initial Concentration (µg/L)	Treated	Number of Replicates
Cd-1	10	No	3
Cd-2	20	No	3
Cd-3	35	No	3
Cd-4	50	No	3
Cd-5	75	No	3
Cd-6	10	Yes	3
Cd-7	20	Yes	3
Cd-8	35	Yes	3
Cd-9	50	Yes	3
Cd-10	75	Yes	3

Task 1.2. Batch Reaction Methods

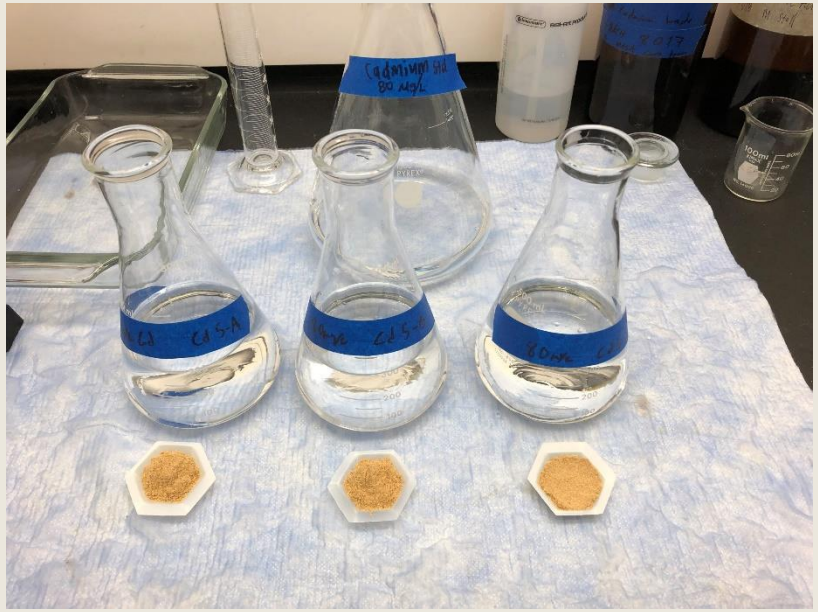


Figure 11. One gram of corn added to three identical flasks containing a known concentration of cadmium solution

Figure 12. Samples placed on rotary shaker table for 90 minutes

Figure 13. Solid corn filtered out of solution

Task 1.2. Untreated Corn – Method

Figure 16. Reagent Preparation

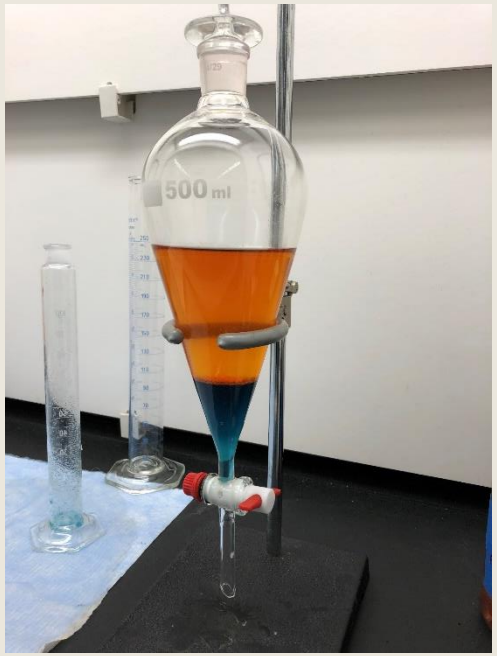


Figure 17. Reagents added to filtrate

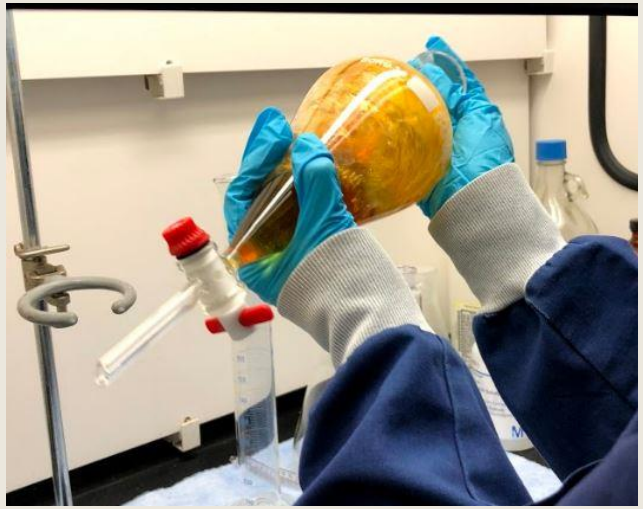


Figure 18. Separatory funnel shaking

Figure 20. Final Sample

Figure 19. Liquid Separation

Task 1.2. Untreated Corn – Results

Table 2. Final cadmium concentration and removal efficiencies after 90 minute batch reaction

Prep'd Initial Conc (ug/L)	Final C Sample A (ug/L)	Final C Sample B (ug/L)	Final C Sample C (ug/L)	Average Final C (ug/L)	Removal Efficiency (%)
10	2.58	X	1.28		
20	2.58	3.56	4.86		
35	10.27	11.46	11.14		
50	X	9.84	11.46		
75	24.79	18.18	17.96		

Overall average removal efficiency was approximately 76%

Task 1.2. Untreated Corn – Method Issues

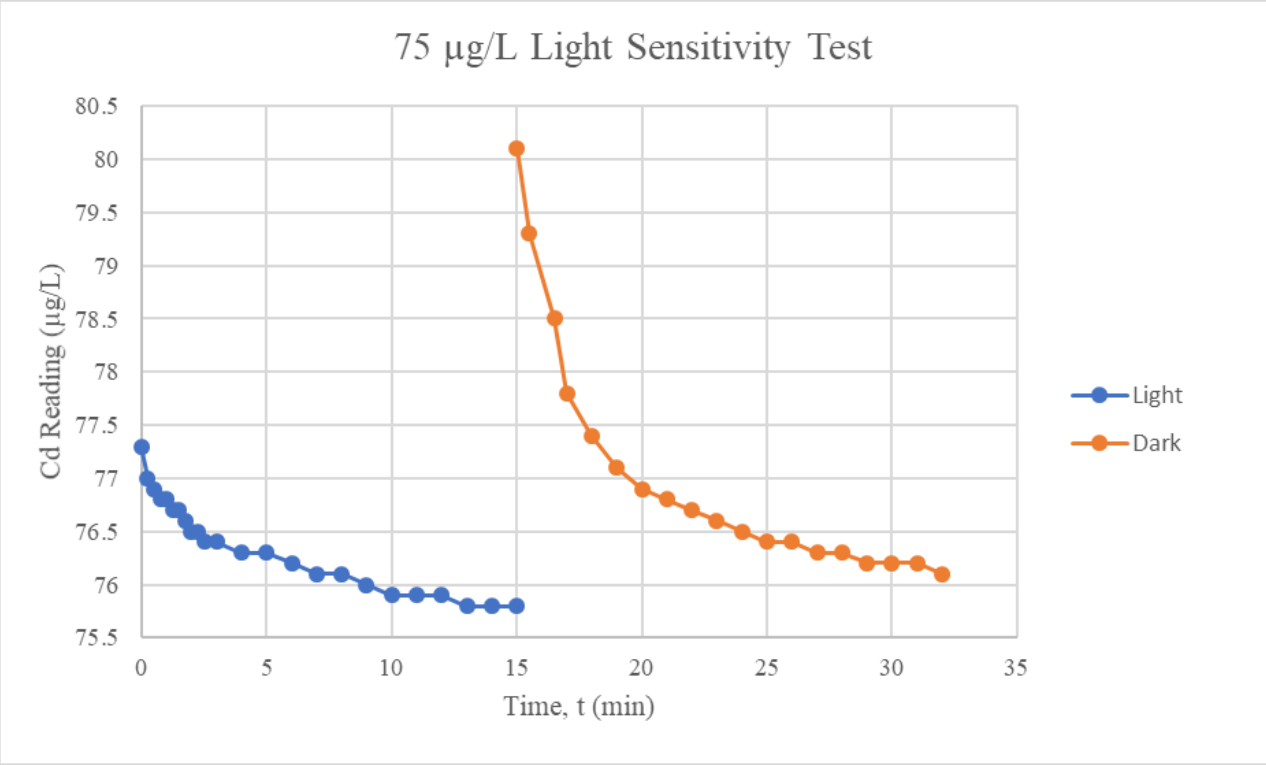


Figure 19. Cadmium readings change over time in DR 3900

Figure 20. Dissolved solids are present

Task 1.2. Treated Corn – Method Issues

Figure 21. Cloudiness of samples interferes with cadmium readings

Task 1.2. Treated Corn – Method

- Subcontracted to Western Tech
  - *Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis*

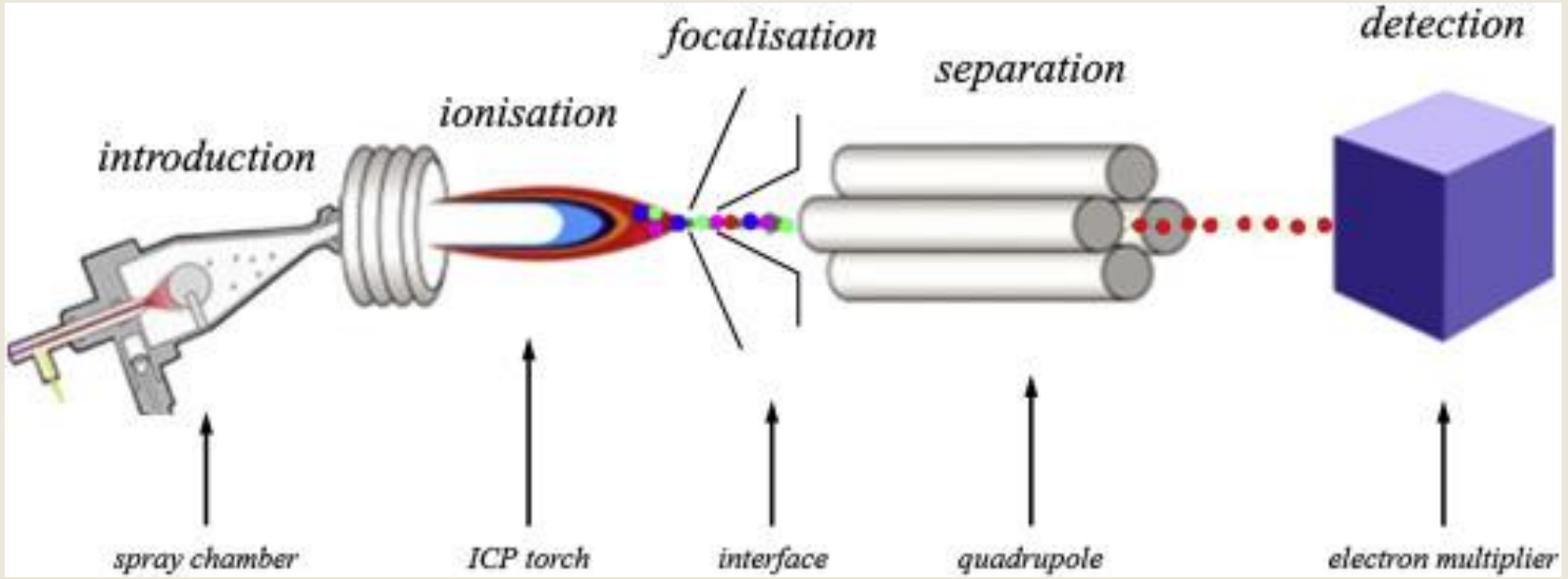


Figure 23. ICP-MS Diagram [2]

Task 1.2. Treated Corn – Analysis

Table 3. Treated Corn Experimental Matrix

Test No.	Initial Conc. (ug/L)	Replicates
Cd-1	10	2
Cd-2	20	2
Cd-3	35	2
Cd-4	50	2
Cd-5	75	2
Method Blank	0	1

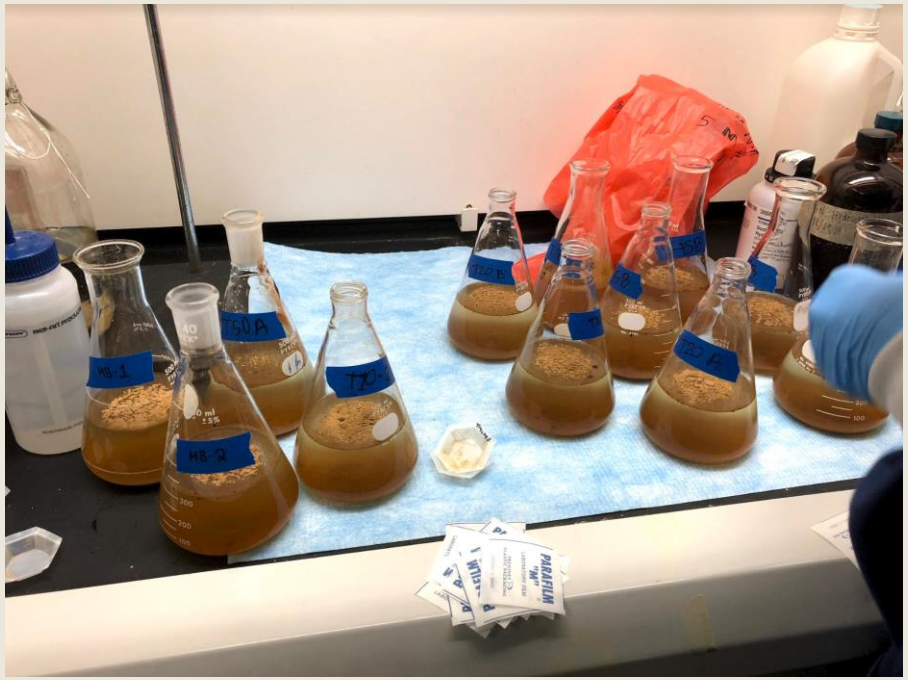


Figure 24. Treated Corn Sample Preparation

Task 1.2. Treated Corn – Results

Table 4. Final cadmium concentration and removal efficiencies after 90 minute batch reaction

Initial Conc (ug/L)	Sample A Final Conc (ug/L)	Sample B Final Conc (ug/L)	Average Final Conc (ug/L)	Removal Efficiency (%)
8.47	ND	ND	N/A	
25.6	ND	1.05	1.05	
35.4	1.28	1.35	1.315	
48.4	1.43	1.92	1.675	
70.6	2.2	2.11	2.155	

Overall average removal efficiency was approximately 97%

1.2. Comparison of Equilibrium Concentrations

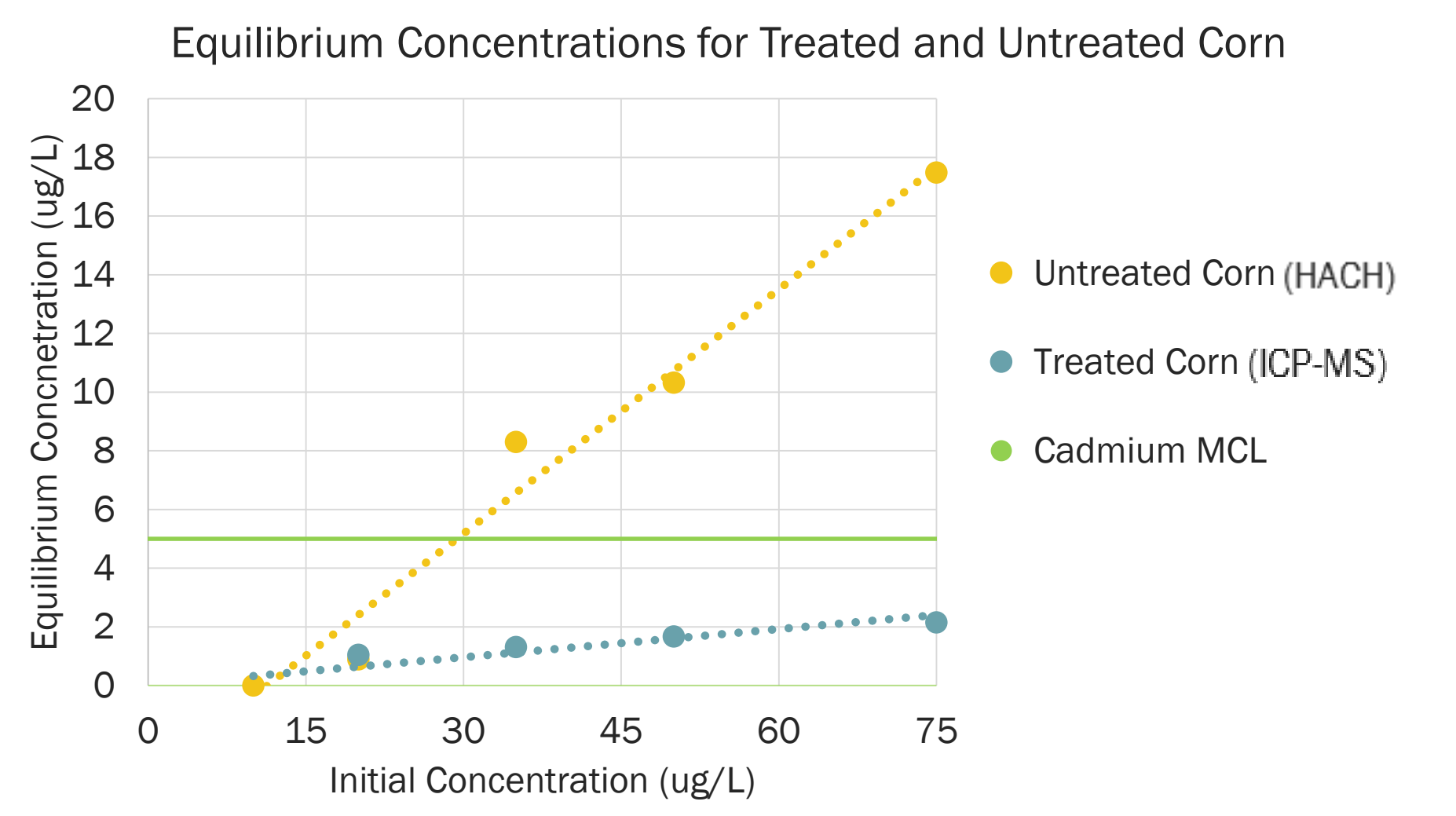


Figure 25. Equilibrium concentrations for treated and untreated corn

Task 2.0. Isotherm Development

Task 2.0. Untreated Corn Isotherm

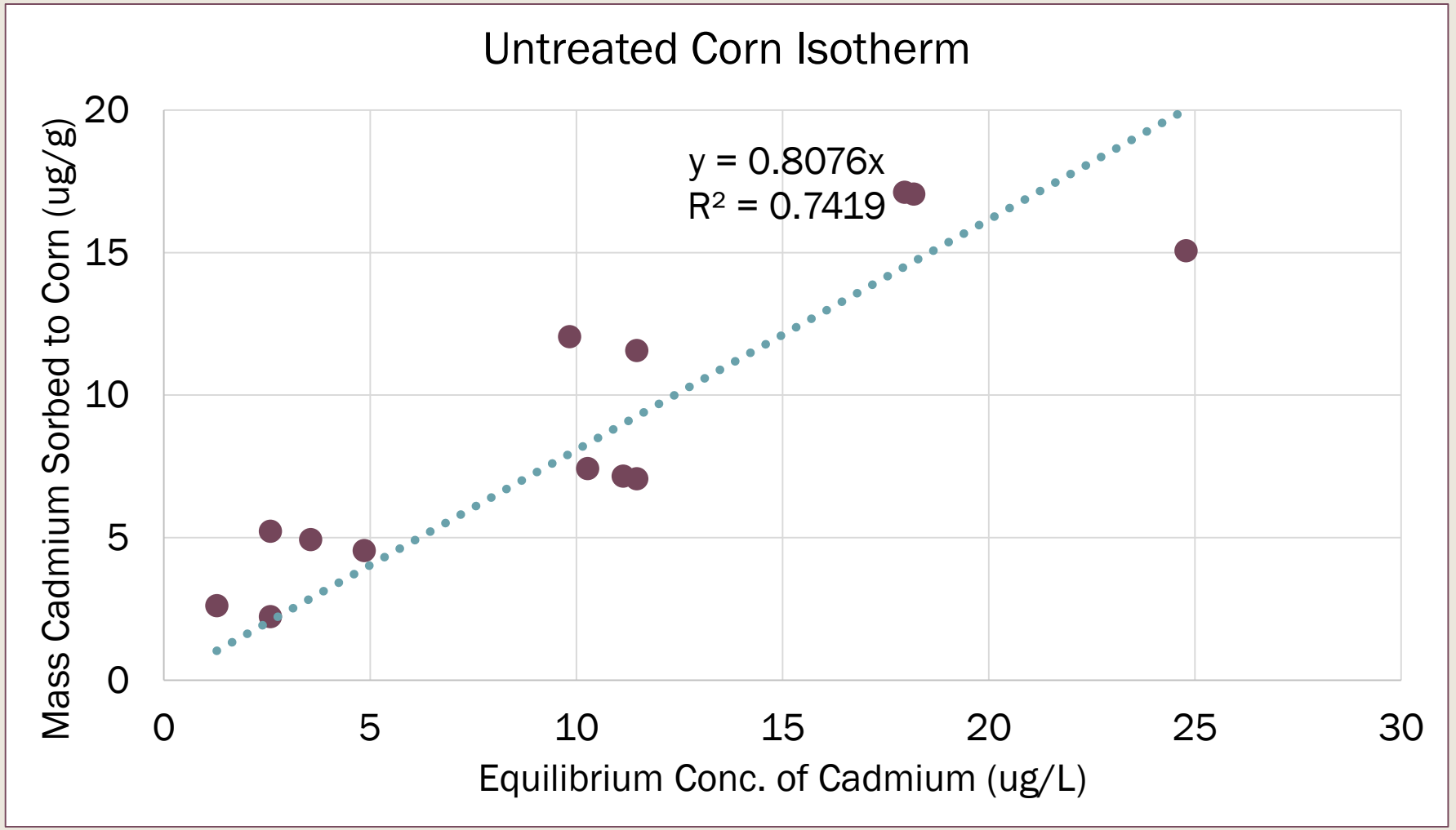


Figure 26. Isotherm for treated corn following cadmium batch reaction

Task 2.0. Treated Corn Isotherm

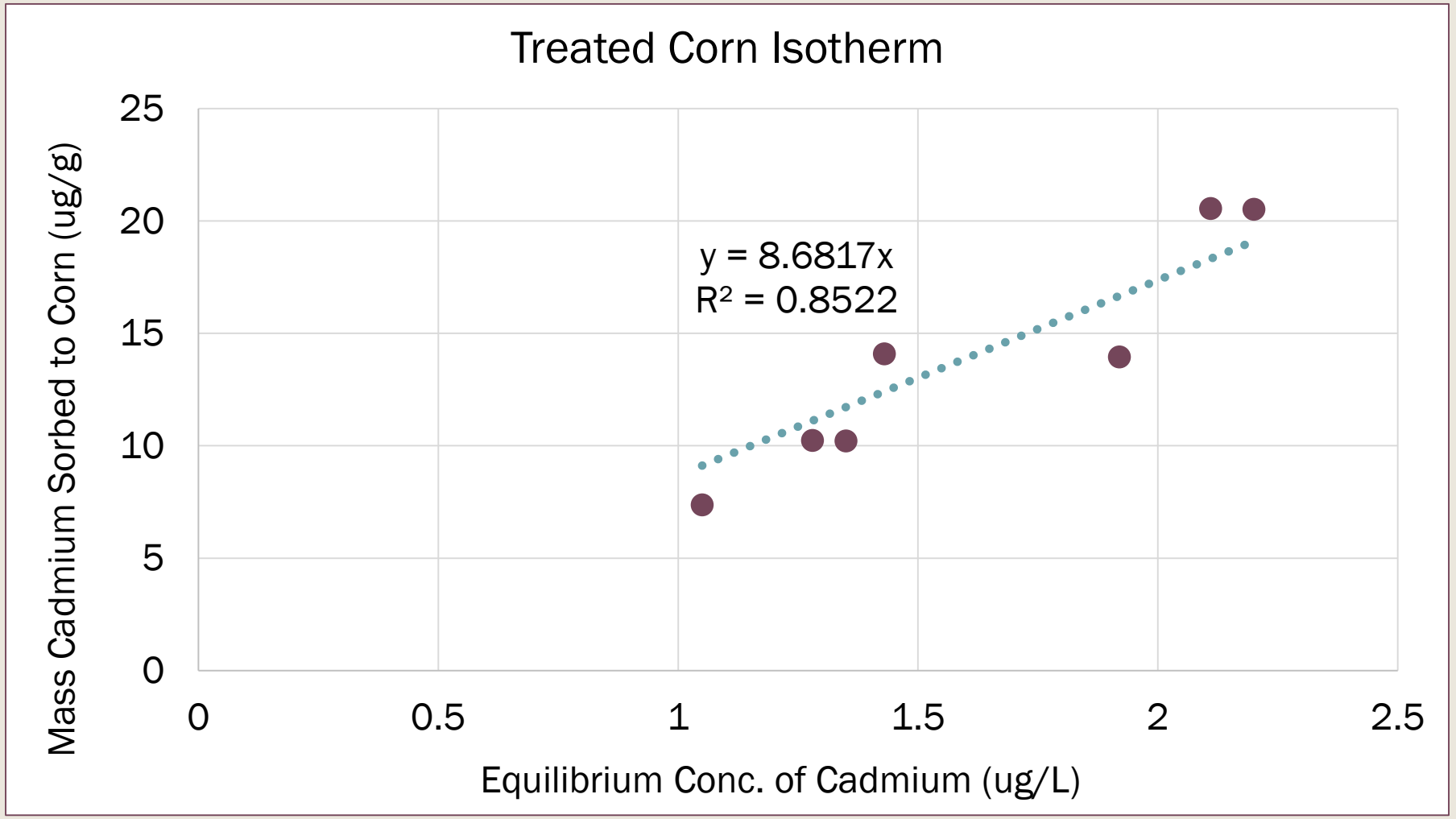


Figure 27. Isotherm for treated corn following cadmium batch reaction

Task 3.0. Prototype Design

Task 3.0. Prototype Considerations

Table 5. Untreated prototype parameters

UNTREATED		
y = 0.8076x		
Parameter	**Quantity**	**Units**
Influent Concentration	75	ug/L
Effluent Concentration	5	ug/L
Δ Concentration	70	ug/L
Mass Corn/Volume	17.3	g/L

Table 6. Treated prototype parameters

TREATED		
y = 8.6817x		
Parameter	**Quantity**	**Units**
Influent Concentration	75	ug/L
Effluent Concentration	5	ug/L
Δ Concentration	70	ug/L
Mass Corn/Volume	1.61	g/L

Treated corn is approximately 11 times more effective at removing cadmium than untreated corn

Task 3.0. Prototype Setup

- Treated corn used for prototype (11x more effective)
- Supplies
  - *Cole Parmer MasterFlex L/S Peristaltic pump*
  - *3/8” Vinyl tubing*
  - *Column: 1” diameter by 8” long*

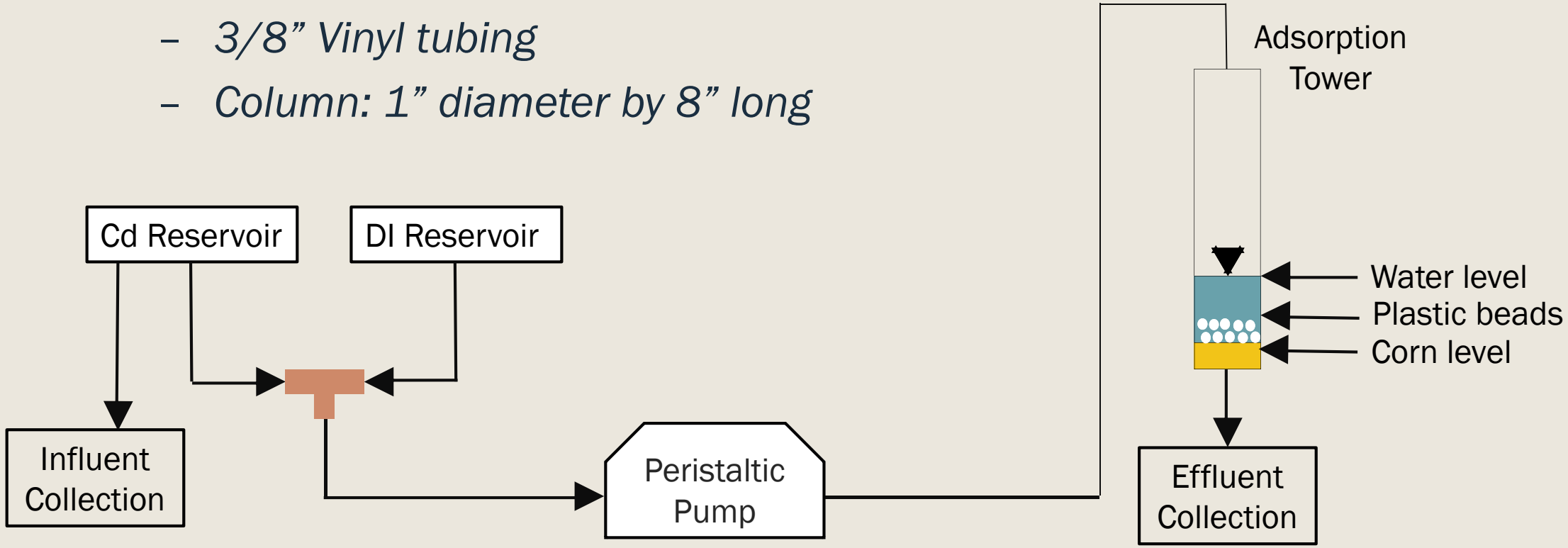


Figure 28. Schematic of prototype design

Task 3.0. Prototype Setup

Figure 29. Actual prototype setup

Task 3.0. Prototype Parameters

- 2.5 g of corn
- 1.5 L of 75 ug/L Cd
- 36.6 mL/min
- Empty bed contact time 21 seconds

Figure XX. Corn and bead layer

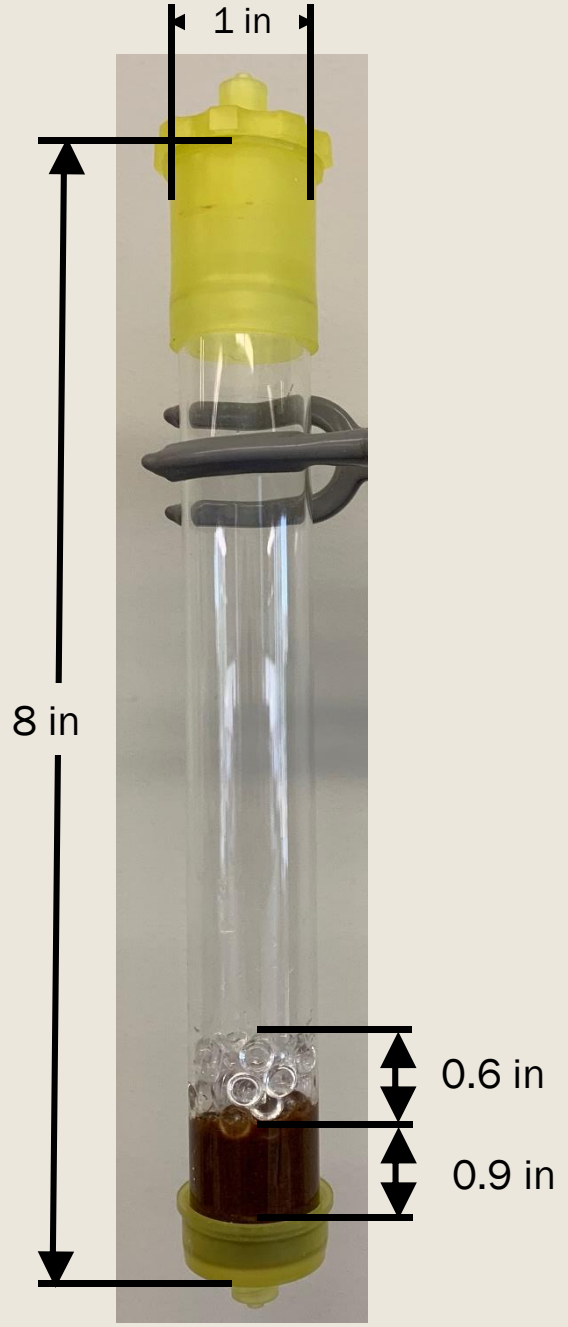


Figure XX. Prototype dimensions

Task 4.0. Pilot Testing and Scale-up

Task 4.0. Breakthrough Curve

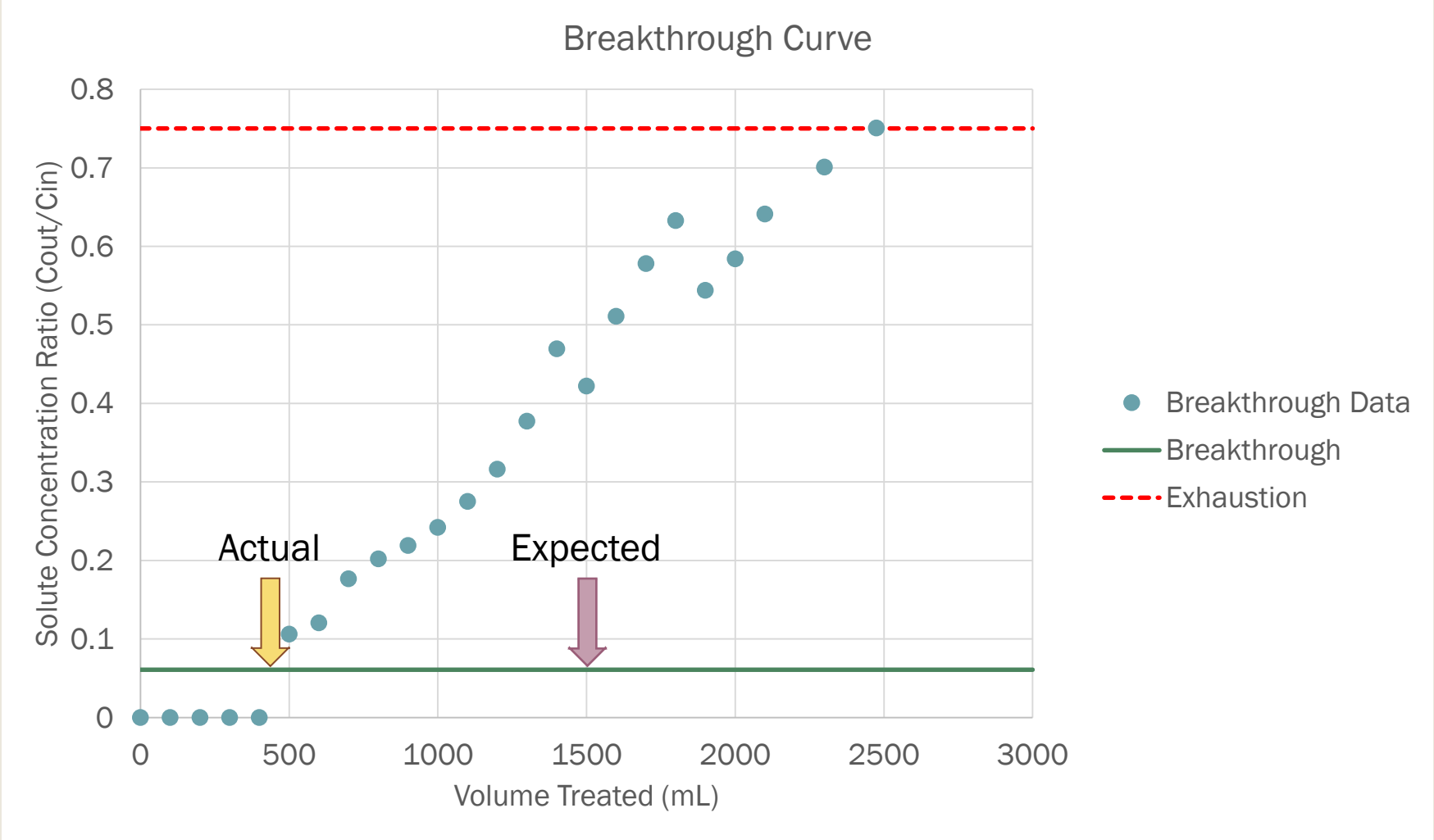


Figure 31. Breakthrough curve from prototype test

Task 4.0. Breakthrough Curve

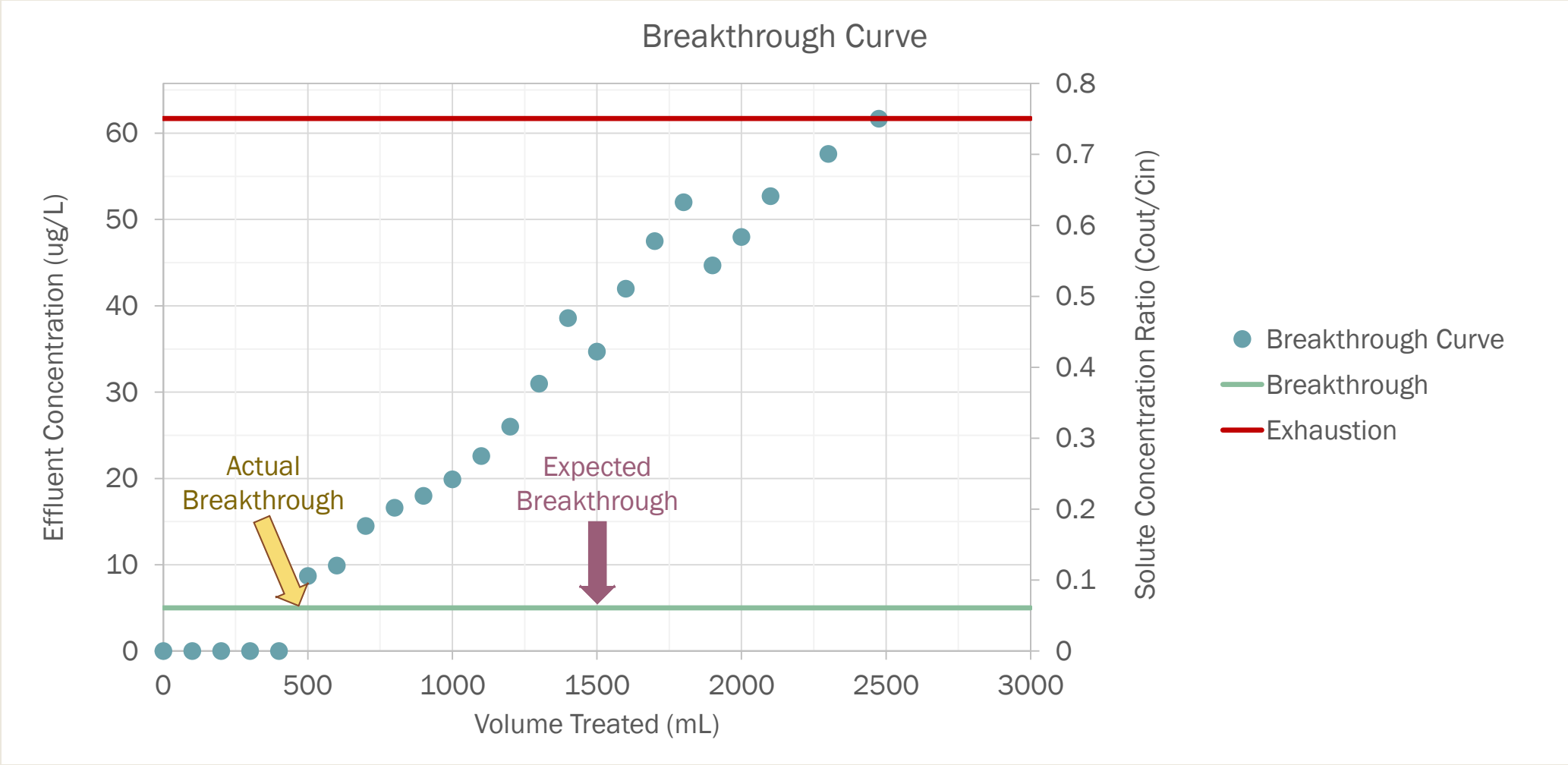
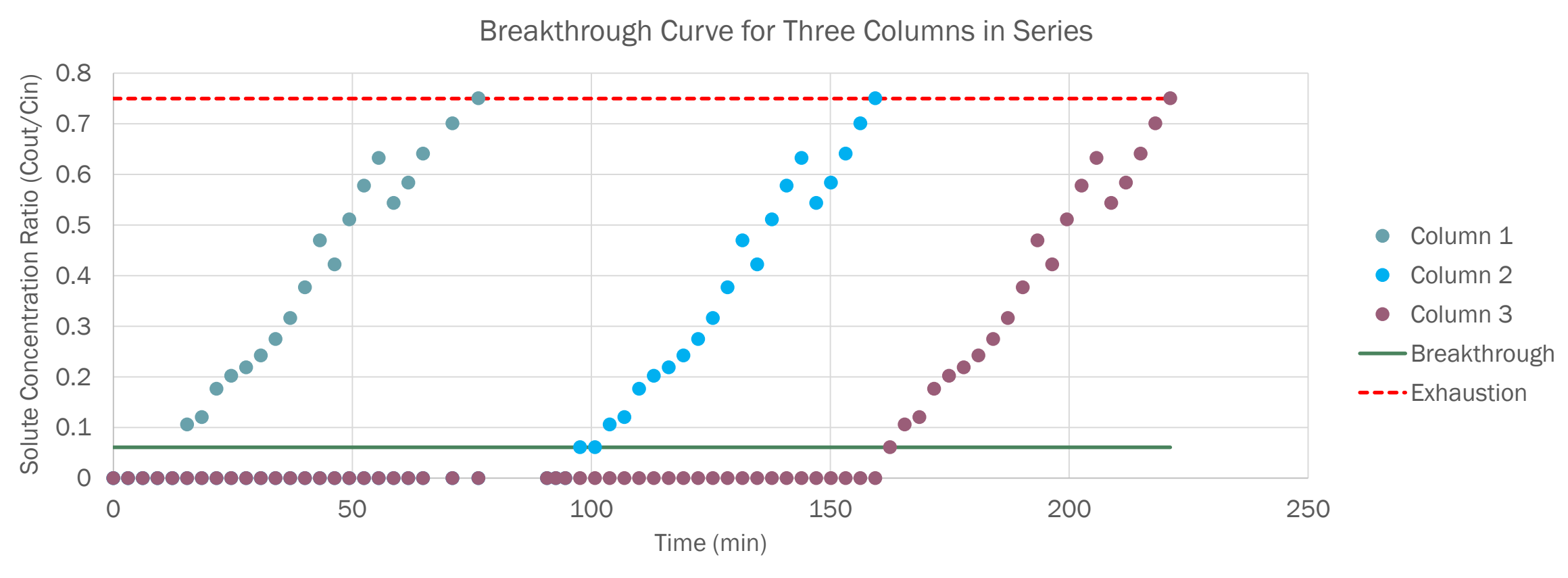
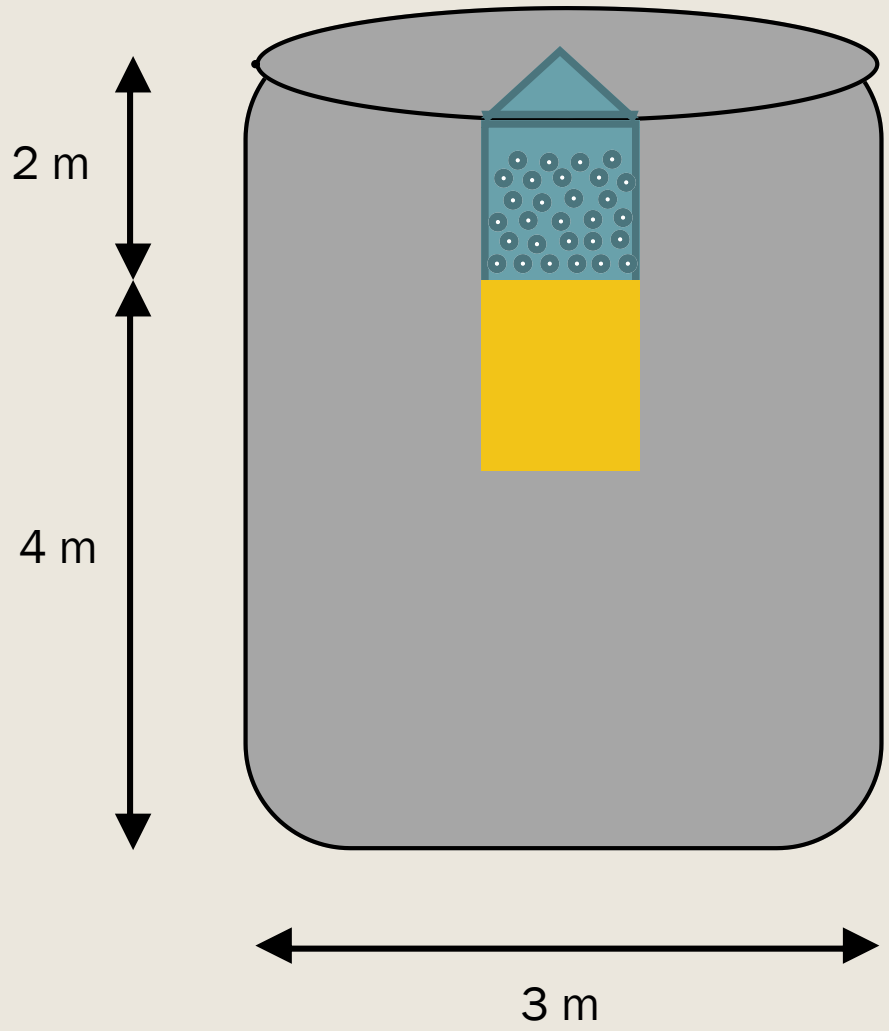


Figure 31. Breakthrough curve from prototype test

Task 4.0. Breakthrough Curve



Task 4.0 Scale-Up



Final Design Parameters

- Design Flow Rate: 50,000 gal/day
- Bed Volume (Corn Only): 27 m^3
- Total Vessel Volume: 41 m^3
- Loading Rate: 1.2 $m^3/(m^{2*}hr)$
- Empty Bed Contact Time: 3.4 hrs
- Mass of Corn Required: 6,480 kg
- Change Out Period: 30 days
- Bogart

Task 5.0. Cost Benefit Analysis

-Task 5.1. Feasibility Assessment

-Task 5.2. Assessment of Benefits

Task 5.1. Feasibility Assessment

Table 7. Cost Analysis per kg of Treated Corn

Cost analysis of treated Corn Cob Bio sorbent (treated) per 1000 kg				
	Material	Unit cost	Amount	Net price
	Corn Cob Waste (kg)	$0.22	1,000 kg	$222
Grinding	kWh	$0.12	11 kWh	$1
Treatment	Nitric (per L)	$0.002	6,667 L	$13,022
	Sodium hydroxide (per L)	$0.017	133 L	$2,227
Drying	kWh	$0.12	1402 kWh	$168
Total cost per 1000 kg				$15,418

Task 5.1. Feasibility Assessment

Table 8. Cost Analysis per kg of Untreated Corn

Cost Analysis of treated Corn Cob Biosorbent (untreated) per 1000 kg				
	Material	Unit cost	Amount	Net price
	corn cob waste (kg)	$0.22	1000 kg	$222
Grinding	kWh	$0.12	11 kWh	$1
	Total cost per 1000 kg			$223

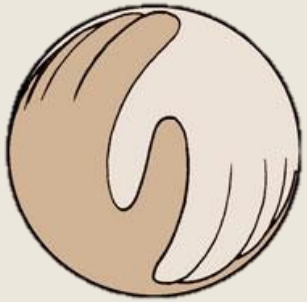
Task 5.1. Feasibility Assessment

Table 9. Corn Biosorbent Compared to Granulated Activated Carbon

Comparison of Adsorbents			
	Corn Cob biosorbent (treated)	Corn Cob biosorbent (untreated)	GAC
Cost per kg	$15.42	$0.22	$14.33
Removal Efficiency	96%	76%	86%
kg of corn required to treat 1000 L of 75 ug/L Cd water	1.6	13.0	2.4
Cost to treat 1000L at 75 ug/L	$24.86	$2.85	$34.86

Task 5.2. Assessment of Benefits

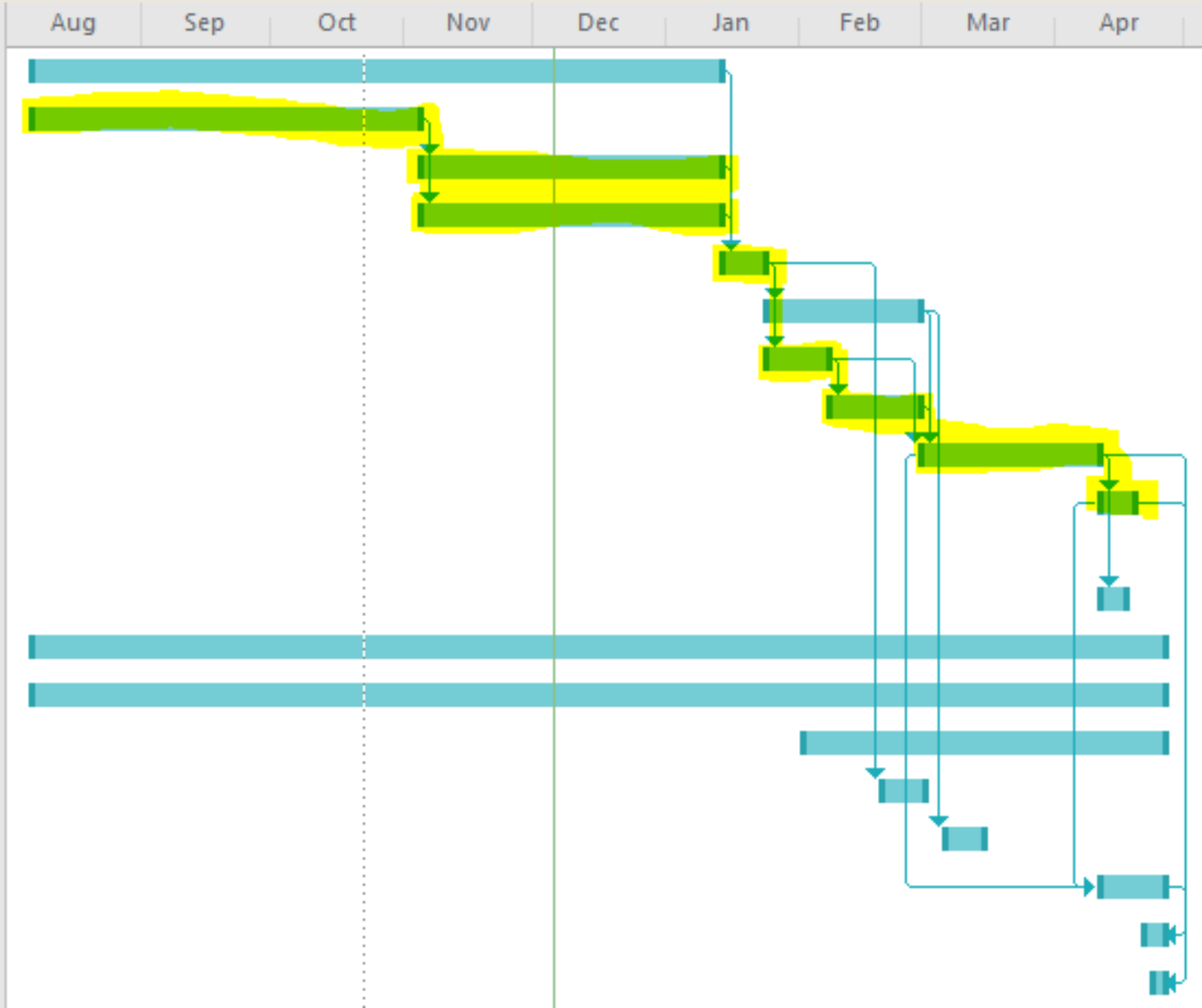
- Environmental
  - ✓ *Cleans heavy metal-contaminated water worldwide (drinking and non-drinking water sources)*
  - ✓ *Diverts waste corn cobs from landfills*
  - ❖ *Contaminated corn may be disposed of in a hazardous waste landfill*
- Economic
  - ✓ *Lowers the price of water purification*
  - ✓ *Provides more income to corn producers*
- Social
  - ✓ *Empowers rural communities to purify their water*
  - ❖ *Some people are allergic to the proteins in corn*



Task 6.0. Team Management

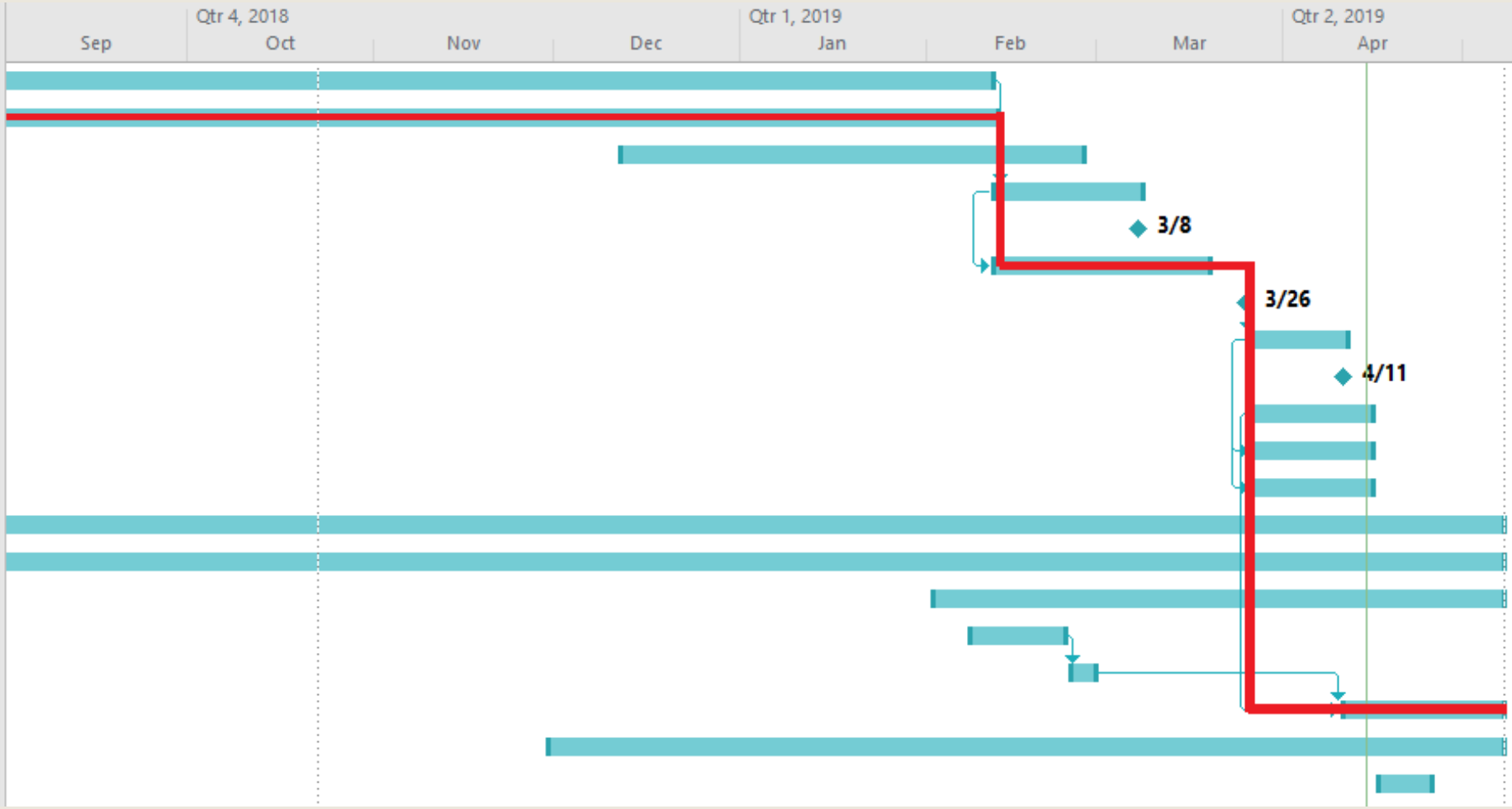
Original Gantt Chart

Task Name	Duration
Task 1.0 Experimental Methods	**115 days**
Task 1.1 – Corn Biosorbent Preparation	65 days
Task 1.2 – Cadmium Testing	51 days
Task 1.3 – Lead Testing	51 days
Task 2.0 - Isotherm Development	**8 days**
Task 3.0 – Prototype Design	**26 days**
Task 3.1 Design Calculations	11 days
Task 3.2 Prototype Development	15 days
Task 4.0 – Pilot Testing and Scale-up	**30 days**
Task 5.0 – Cost Benefit Analysis	**6 days**
Task 5.1 – Feasibility Assessment	4 days
Task 5.2 – Assessment of Potential Benefits	4 days
Task 6.0 – Project Management	**189 days**
Task 6.1 – Professional/Team Interactions	189 days
Task 6.2 – Project Deliverables	61 days
Task 6.2.1 30% Report	8 days
Task 6.2.2 60% Report	7 days
Task 6.2.3 Final Report	11 days
Task 6.2.4 Website	5 days
Task 6.2.5 Final Presentation	3 days



Final Gantt Chart

Task Name	Duration
Task 1.0 Experimental Methods	**135 days**
Task 1.1 – Corn Biosorbent Preparation	136 days
Task 1.2 – Cadmium Testing	55 days
Task 2.0 - Isotherm Development	**19 days**
Completed Isotherm Model	*0 days*
Task 3.0 – Prototype Design	**27 days**
Fully Constructed Prototype	*0 days*
Task 4.0 – Pilot Testing and Scale-up	**12 days**
Completed Breakthrough Curve	*0 days*
Task 5.0 – Cost Benefit Analysis	**14 days**
Task 5.1 – Feasibility Assessment	14 days
Task 5.2 – Assessment of Potential Benefits	14 days
Task 6.0 – Project Management	**197 days**
Task 6.1 – Professional/Team Interactions	197 days
Task 6.2 – Project Deliverables	69 days
Task 6.2.1 30% Report	12 days
Task 6.2.2 60% Report	4 days
Task 6.2.3 Final Report	19 days
Task 6.2.4 Website	114 days
Task 6.2.5 Final Presentation	7 days



Staffing Plan

Table 10: Task Matrix

Task	SENG Hours	ENG Hours	LAB Hours	Total
Task 1.0 Experimental Methods	0	0	190	190
Task 1.1 Corn Biosorbent Preparation			36	36
Task 1.2 Cadmium Testing			71	71
Task 1.3 Lead Testing			83	83
Task 2.0 Isotherm Development	1	11	0	12
Task 3.0 Prototype Design	8	14	0	22
Task 3.1 Design Calculations	1	9		10
Task 3.2 Construction Drawings	1	5		6
Task 3.3 Construction	6			6
Task 4.0 Pilot Testing and Scale-up	2	12	109	123
Task 5.0 Cost Benefit Analysis	1	11	0	12
Task 5.1 Feasibility Assessment	0.5	5.5		6
Task 5.2 Assessment of Benefits	0.5	5.5		6
Task 6.0 – Project Management	113	153	0	266
Task 6.1 Professional/Team Interactions	108			108
Task 6.2 Project Deliverables		79		79
Task 6.2.1 30% Report		16		16
Task 6.2.2 60% Report		20		20
Task 6.2.3 Final Report	5	10		15
Task 6.2.4 Website		20		20
Task 6.2.5 Final Presentation		8		8
TOTAL	**125**	**201**	**299**	**625**

Legend

Classification	Code
Senior Engineer	SENG
Engineer	ENG
Lab Technician	LAB

Billed Hours

Table 11: Project billable hours

Task	SENG Hours	ENG Hours	LAB Hours	Task total
Task 1.0 Experimental Methods	0	18	308.5	326.5
Task 1.1 Corn Biosorbent Preparation	0	10	103	113
Task 1.2 Cadmium Testing	0	8	205.5	213.5
Task 2.0 Isotherm Development	0	7	0	7
Task 3.0 Prototype Design	0.5	72.5	8	81
Task 4.0 Pilot Testing and Scale-up	0	27.5	11.5	39
Task 5.0 Cost Benefit Analysis	2	21.5	0	23.5
Task 5.1 Feasibility Assessment	0	13.5	0	13.5
Task 5.2 Assessment of Benefits	2	8	0	10
Task 6.0 Project Management	153	108.5	0	261.5
Task 6.1 Professional/Team Interactions	91	32.5	0	123.5
Task 6.2 Project Deliverables	62	76	0	138
Task 6.2.1 30%	30.5	2.5	0	33
Task 6.2.2 60%	23.5	9	0	32.5
Task 6.2.3 Final Report	1.5	27.5	0	29
Task 6.2.4 Website	0	32	0	32
Task 6.2.5 Presentation	6.5	5	0	11.5
TOTAL HOURS	**328**	**274.5**	**164**	**738.5**

Legend

Classification	Code
Senior Engineer	SENG
Engineer	ENG
Lab Technician	LAB

113.5 hours over

Actual Cost of Engineering Services

Table 12: Total Projected Project Cost

1.0 Personnel			
Classification	**Hours**	**Rate, $/hr**	**Cost**
SENG	125	120	$15,000
ENG	201	90	$18,090
LAB	299	55	$16,445
Total		**$49,535**	
2.0 Supplies			
Item	**Quantity**	**Cost Each**	**Cost Total**
Syringe Pump	1	300	$300
Cadmium Reagents	56	6.80	$381
Lead Reagents	63	7.52	$474
Acrylic Plexiglass (2'x6')	1	14	$14
Corn Cobs	60	1	$60
Ninja Food Processor	1	20	$20
PPE	4	90	$360
Lab Rental Fee	45 days	286/day	$12,870
Total		**$14,479**	
3.0 Subcontracting			
Subcontractor		**Cost**	
Engineering Fabrication Shop		$50.00	
Total		**$50.00**	
Project Total			
$64,064			

Actual Cost of Engineering Services

Table 13: Total Projected Project Cost

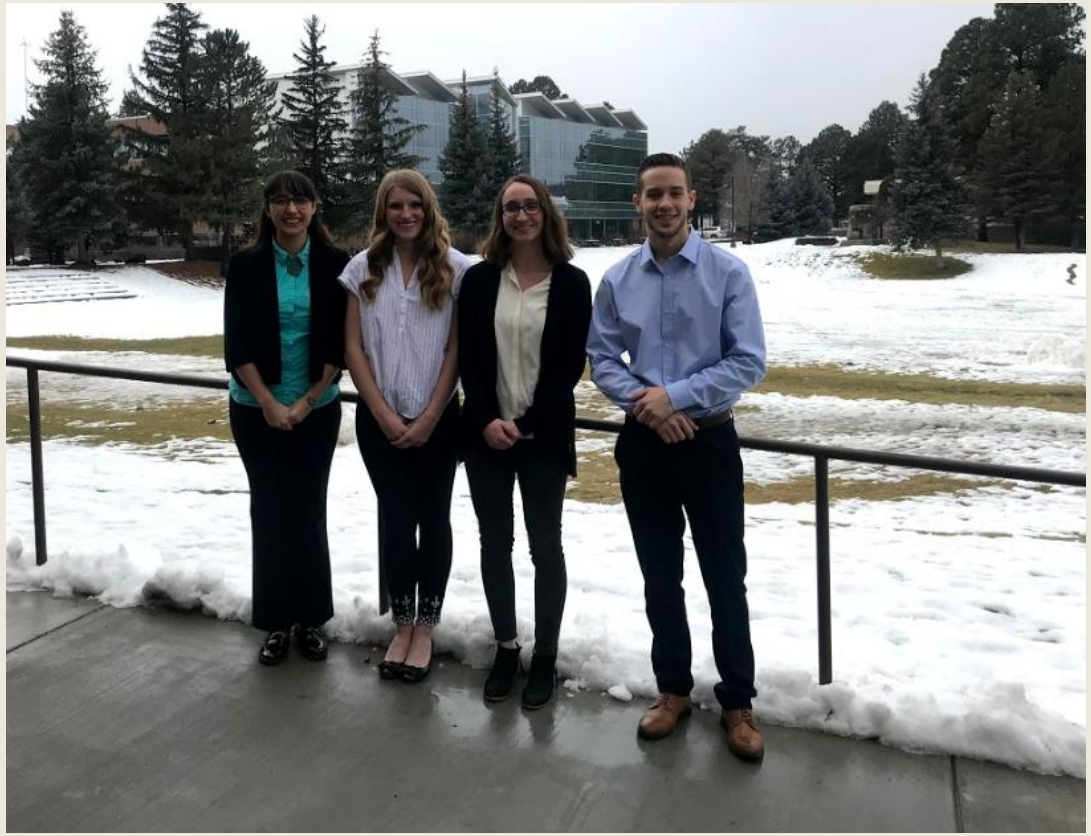
1.0 Personnel			
Classification	Hours	Rate, $/hr	Cost
SENG	164	120	$19,680
ENG	274.5	90	$24,705
LAB	328	55	$18,040
Total	**$62,425**		
2.0 Supplies			
Item	Quantity	Cost Each	Cost Total
Cadmium Reagents	36	6.8	$245
Corn Cobs	60	1	$60
Ninja Food Processor	2	20	$40
PPE	4	90	$360
Lab Rental Fee	41	286/day	$11,726
Total	**$12,430**		
3.0 Subcontracting			
Subcontractor	Cost		
Western Technologies Inc.	$659		
Total	**$659**		
Project Total			
$ 75,515			

$11,451 over budget

Conclusion

- Treated corn yielded higher removal efficiency, but there is great promise for untreated corn
- Possible replacement for GAC

- Additional research
  - *Possible regeneration of biosorbent*
  - *Refinement of corn treatment process*
  - *Further breakthrough testing*
    - Untreated corn
    - Varying conditions (e.g. pH, concentration, contaminants)
    - Three columns in series testing
  - *Test the adsorption of other contaminants*



References

1] EPA, "National Primary Drinking Water Regulations," 2018. [Online]. Available: https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

[2] M. Aceto, "The Use of ICP-MS in Food," in Advances in Food Traceability Techniques and Technologies, Alessandria, 2016, pp. 137-164.

[3] M. Karnib, A. Kabbani, H. Holail and Z. Olama, "Heavy Metals Removal Using Activated Carbon, Silica and Silica Activated Carbon Composite," Energy Procedia, vol. 50, pp. 113-120, 2014.

All other photos and work displayed in this presentation are original and were either photographed or produced by the Corn Corps.

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NAU Environmental Health and Safety

Western Technologies, Inc.