NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

Organic Covers on Tailings: Effects and Economic Returns

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- Domtar and St. Mary's Paper
- Terratec Environmental
- Black Lake Environmental

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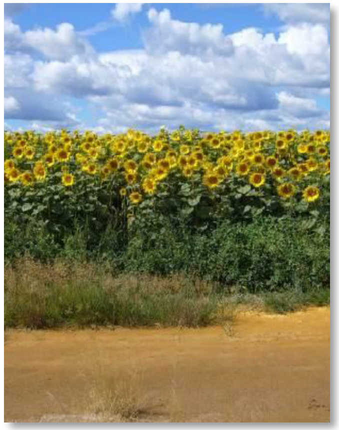
Outline

- Introduction
  - Background and NRCan rationale
- Study site location and description
  - Brief history of the study plots
- Observations on tailings
  - Mineralogy, geochemistry, microbiology
- Biomass recovery
  - Preliminary economic analysis
- Conclusions and future research plans

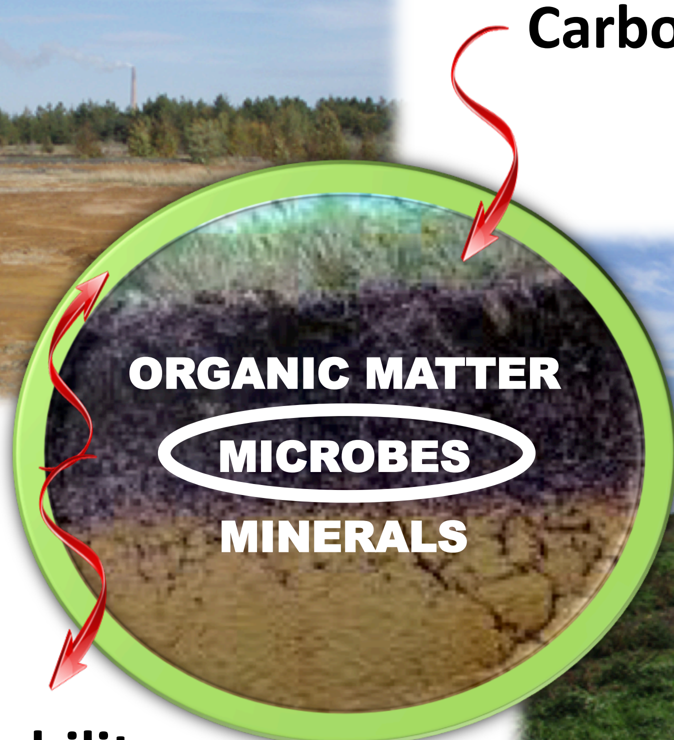
Background and NRCan Rationale

- Green Mines Green Energy Program (2005-2013)
  - Demonstrate use of organic residuals
  - Economic production of feedstock for fuels?
  - Mixed success, depending on the crop
- Mining Value from Waste (current)
  - Reprocessing/repurposing of Canadian mine wastes
  - Remove value and reduce liability
  - Partnering with industry and academia
- Minimize water use in tailings management
- Improved closure economics ($10's of millions)



How Do We Define Successful Reclamation?

Carbon sequestration?



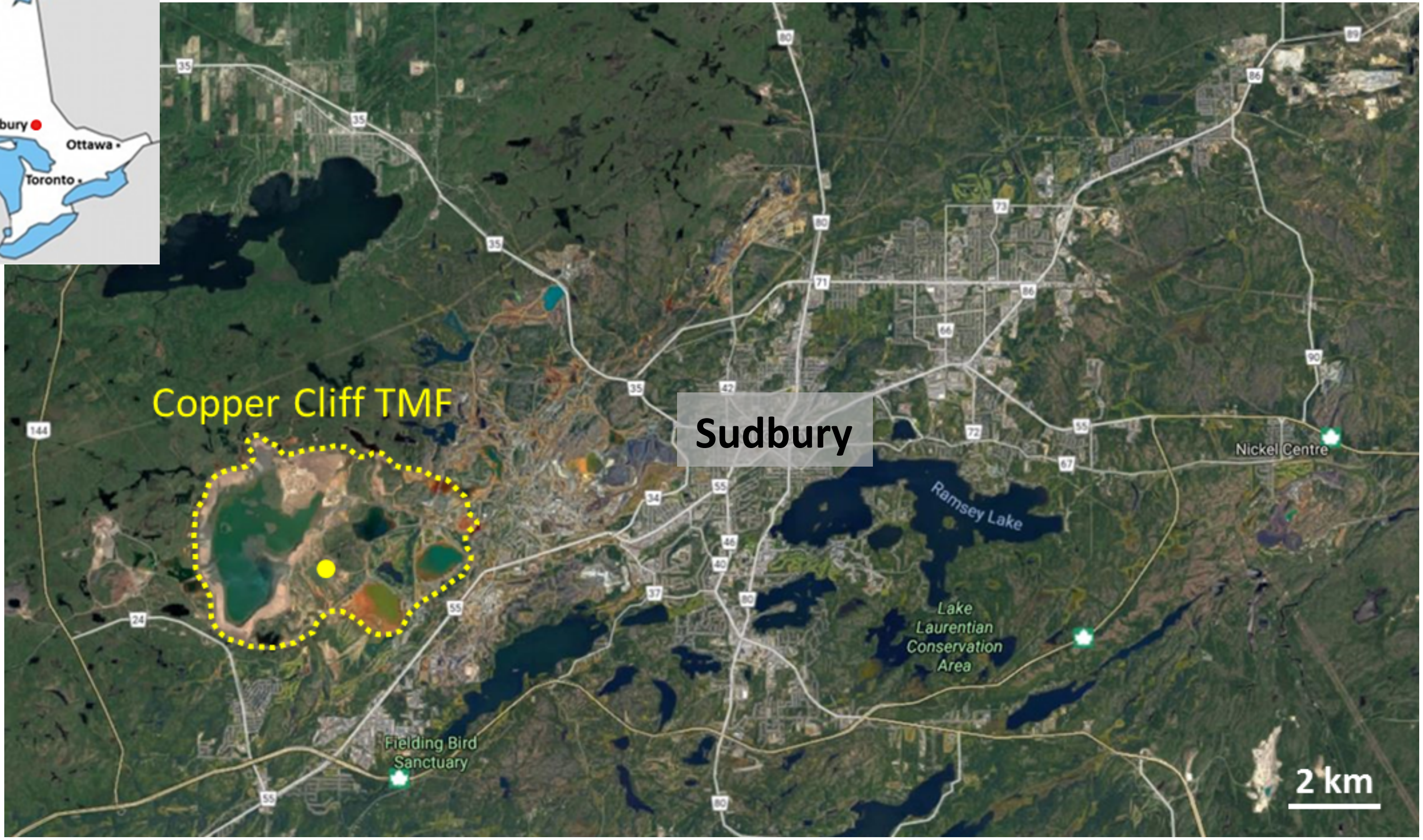
Ecosystem productivity, diversity and sustainability?

Geochemical stability of the tailings?

Economic benefits?

Study Site (Sudbury, Ontario)

- 2500 ha impoundment, about half are active
- Different reclamation strategies have been considered



Study Plots – A Brief History

Control

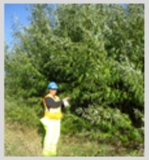
- Oxidized tailings, 40 cm deep
- No cover or vegetation; pH 2.5
- Last tailings discharged: 1993

St. Mary's

- Established: 2008
- paper mill biosolids, 1 m
- corn & canola

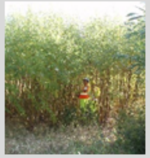
Domtar (Thin)

- Established: 2011
- paper mill biosolids, 30-50 cm
- hybrid willows



Domtar (Thick)

- Established: 2009
- paper mill biosolids, 1 m
- corn & canola, willows (2011)

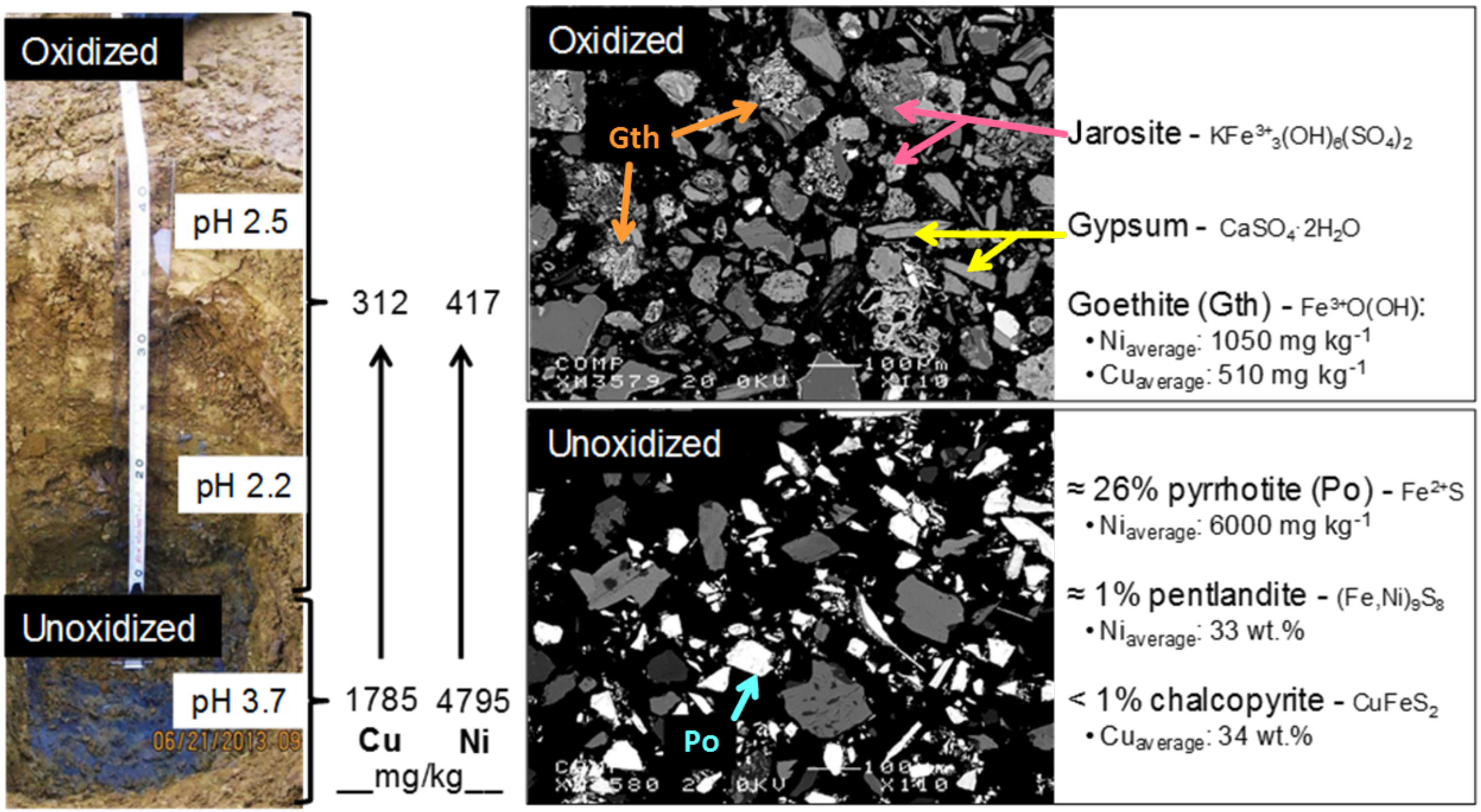


Biosolids

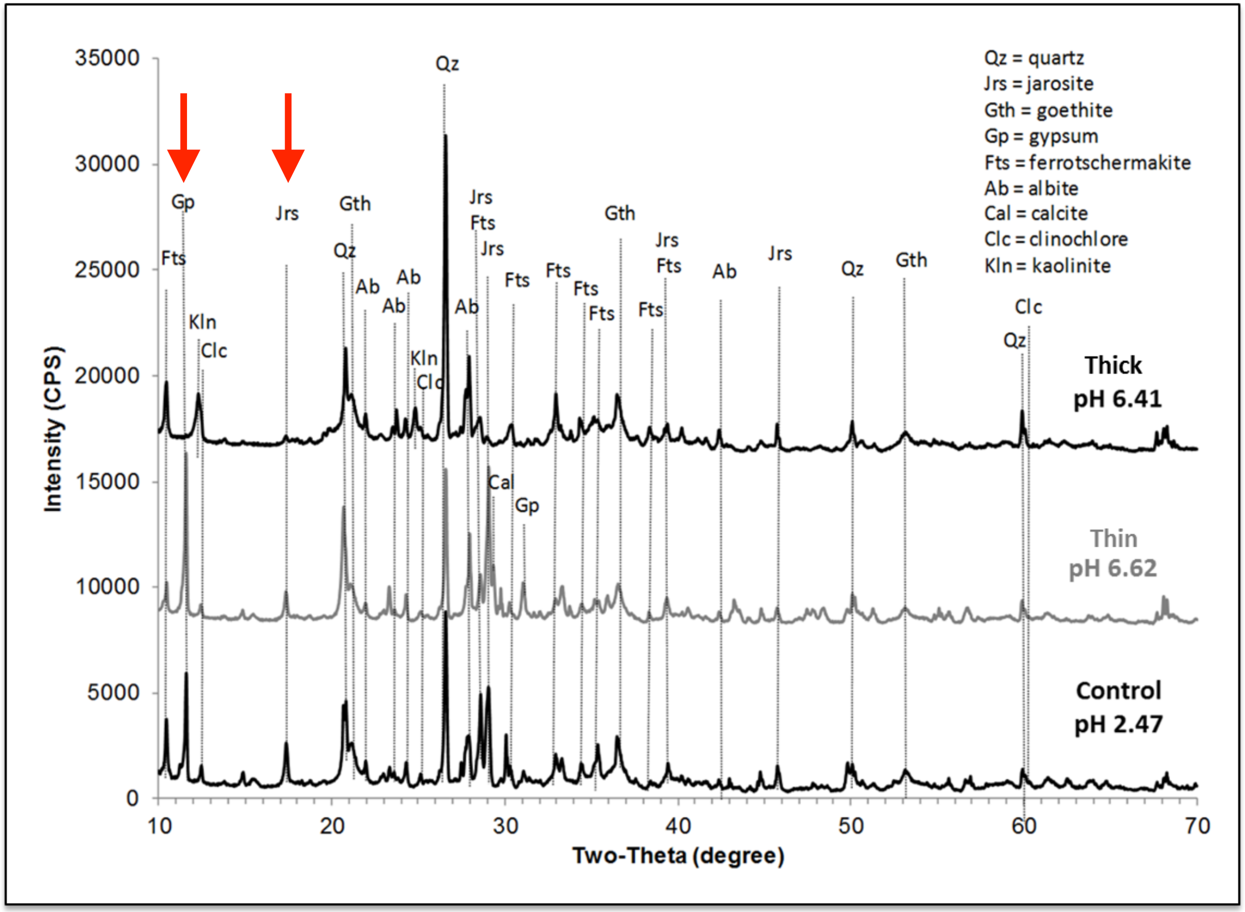
- Established 2014
- Municipal biosolids
- 10 cm, mixed; hay, quackgrass

Control Tailings

- Silt loam texture < 200 µm
- TOC = 0.18% N < 0.05% P = 0.03% K = 0.56%

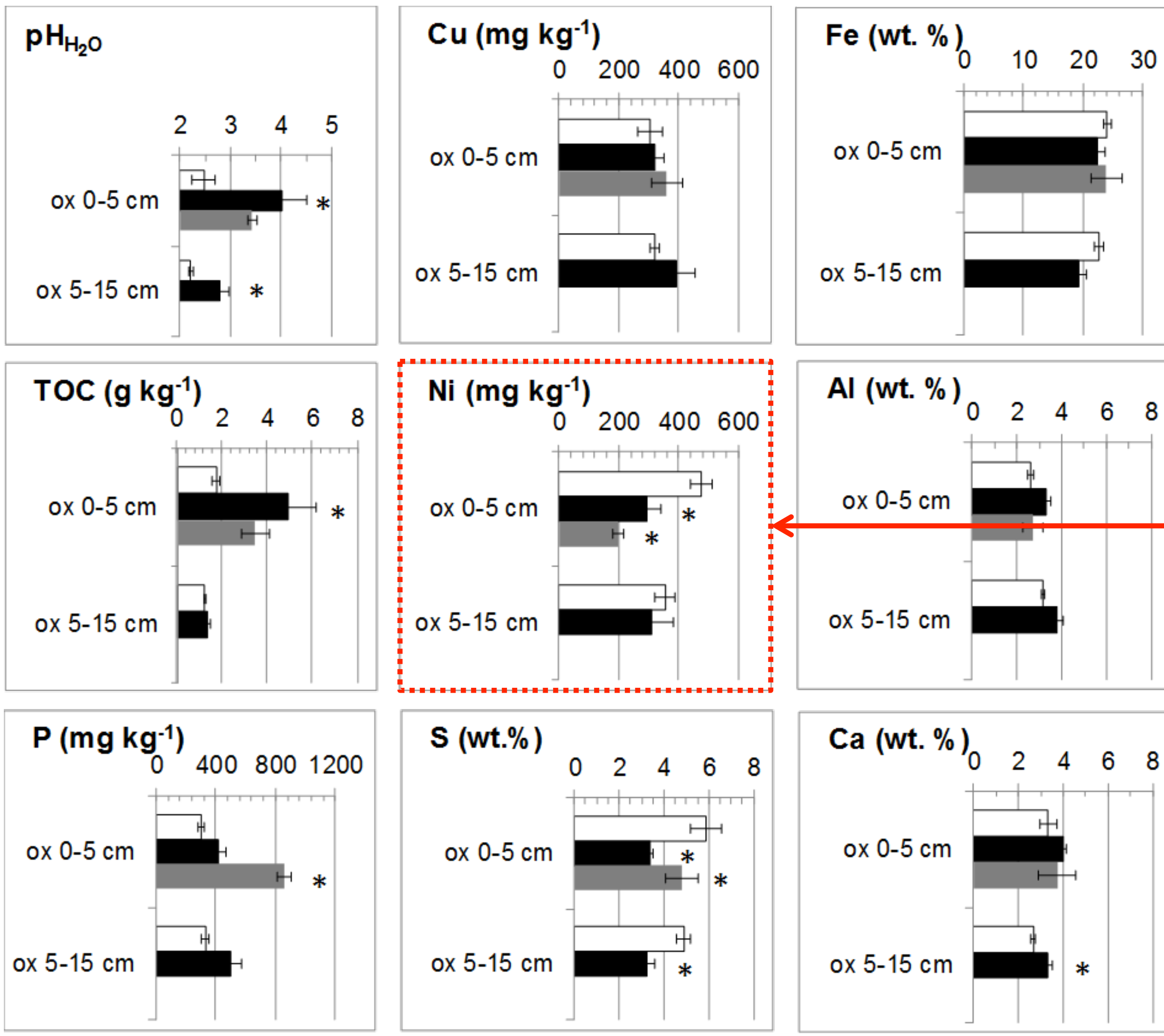


Cover Effects on Tailings Mineralogy



Loss of gypsum (Gp) and jarosite (Jrs) under thick cover

Cover Effects on Tailings Geochemistry



Control
Thick
Thin

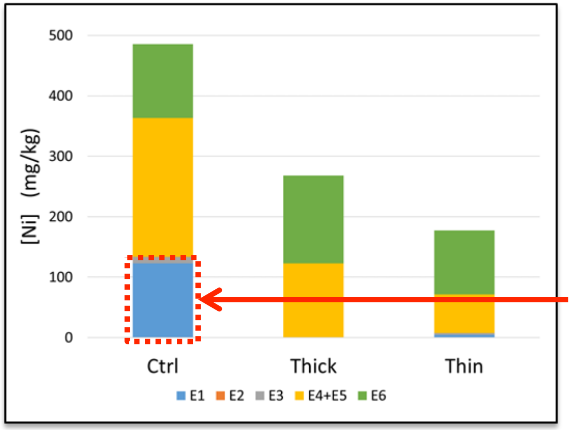
Decreased Ni in covered systems

Cover Effects on Ni Mobility

Sequential Extractions

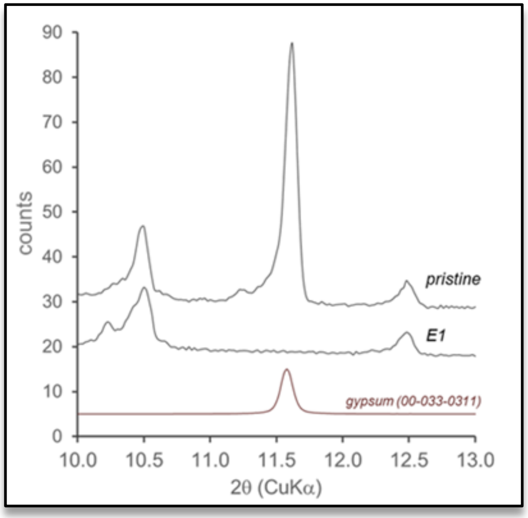
Target Phases

E1: soluble, exchangeable, carbonates
E2: labile organics, volatile sulfides
E3: amorphous, oxyhydroxides
E4 + E5: crystalline, recalcitrant sulfides
E6: residuals



Bulk of lost Ni from the most labile pool

X-Ray Diffraction

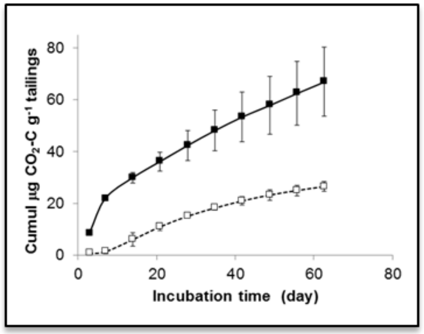


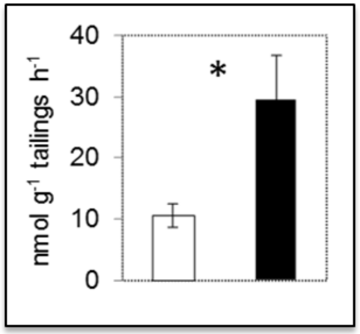
* EPMA indicated no Ni associated with gypsum

* Loss of Ni is probably due to desorption

Cover Effects on Tailings Microbiology

Activity

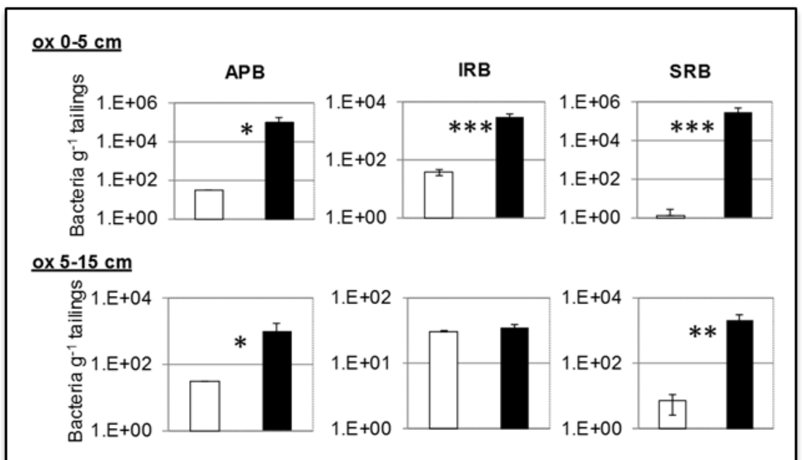




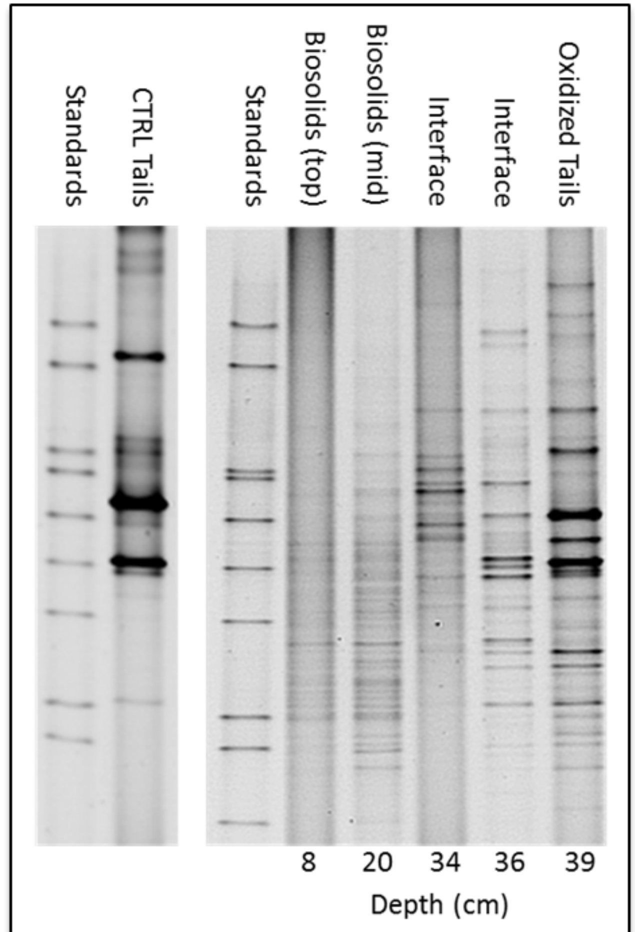
Control

Thick

Enumeration



Biodiversity

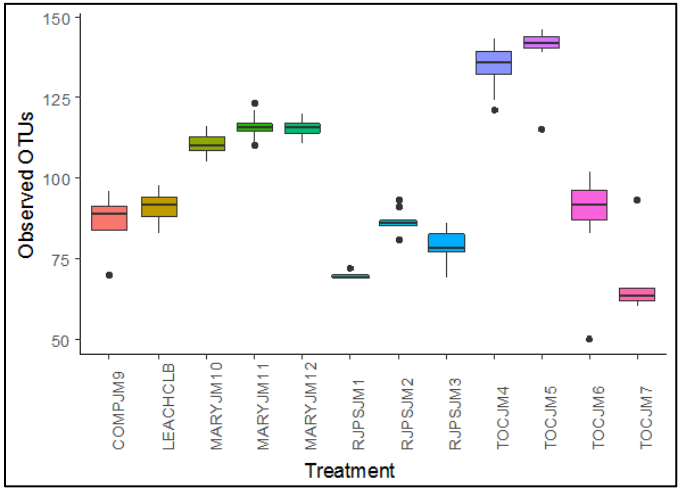


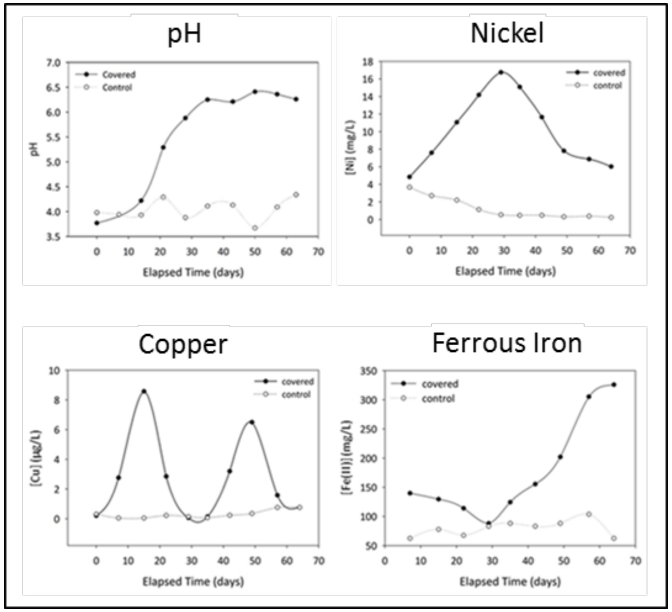
Biosolids
no excisions

Interface
Pseudobact. cellulosolvens
Cellulomonas spp.

Tailings
Desulfovibrio desulfuricans
Desulfococcus multivorans
Geobacter metallireducens
Leptospirillum ferrooxidans
L. ferriphilum

Municipal Biosolids (Early Data)



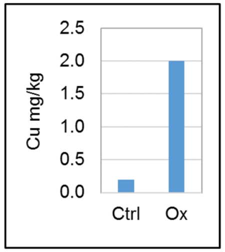


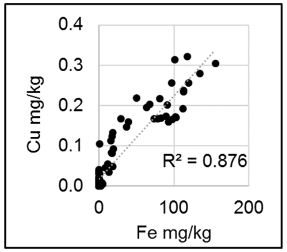
* *greater proportion of heterotrophic bacteria*

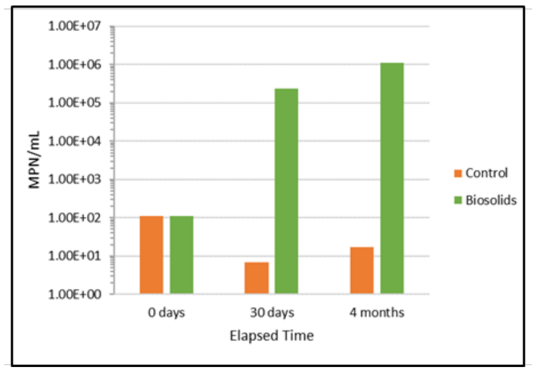
* *less dominance of AMD-associated microbes*

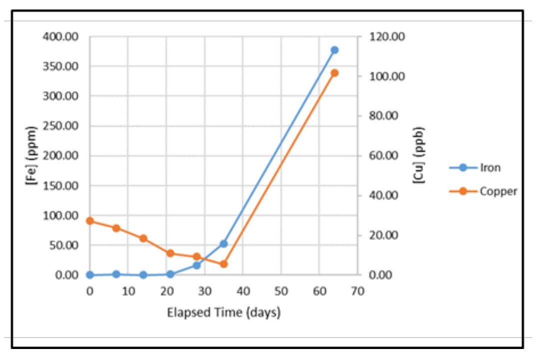
- Rapid return of microbial biodiversity within the tailings
- Leachate pH is improved, from ~ 4 to 6
- Ni leaching observed again, and a bimodal release of Cu

Municipal Biosolids (Early Data)









- Organic acids enhanced release of Cu at pH 6.0
- Biosolids stimulated growth of iron-reducing bacteria by orders of magnitude
- Cu release was concurrent with onset of microbial iron reduction

Conclusions (Paper Mill Waste)

- Reclamation of Cu-Ni tailings with paper mill waste looks promising:
  - increased pH
  - increased nutrient availability
  - increased microbial activity and biodiversity
  - reduction of water-soluble metals

- Remobilization of Ni was observed
  - It may only be a concern if the Ni is not re-adsorbed within the impoundment; associated costs to treat would be incremental

Conclusions (Municipal Biosolids)

- In the lab, municipal biosolids promoted:
  - rapid return of microbial biodiversity (also seen in the field)
  - increased effluent pH, decreased redox potential
  - *remobilization of Ni and Cu from oxidized tailings*
- Questions and concerns remain:
  - long-term impacts and performance
  - mobilization of Ni and Cu (complexation?)
  - high nutrient loads (esp. nitrogen species)
  - emerging organic contaminants
  - regulatory requirements

Hybrid Willows – Rapid Reclamation

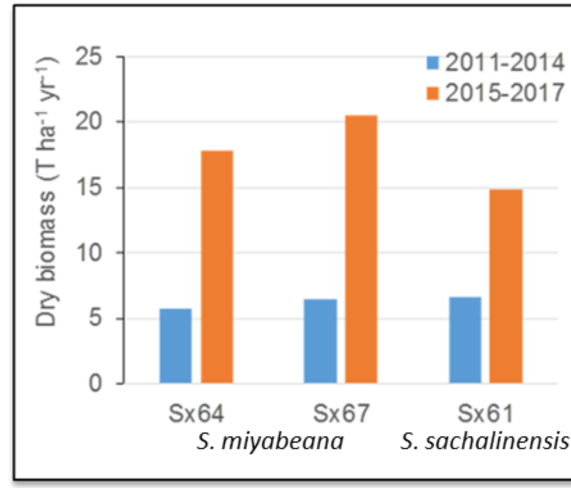
2011

2014

2016

2017

Willow Harvest



Average yield:
12 dry t ha^{-1} yr^{-1}

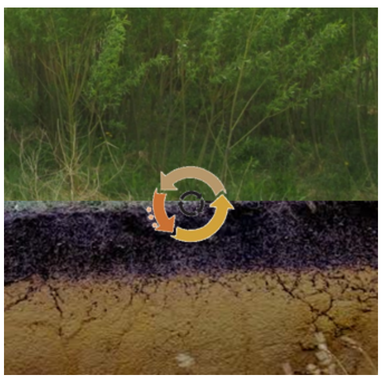
Metal Concentrations, Leaf (dry wt %)		
	Plot 1	Plot 2
Cu	0.001	0.001
Ni	0.001	0.003

Why Grow Willows?

- Current cropping is with hay for dust mitigation – little value

Building cover → Biomass production → Ecosystem recovery

Renewable Energy



- tolerate conditions
- replenish cover

8 to 15 dry t ha^{-1} yr^{-1} over 25 years

Average hay yield:
7.5 dry t ha^{-1} yr^{-1}
(M. Payne, 2018)

- Low maintenance
- Selection of hybrids
- One (*Salix viminalis*) did not survive

Low fuel price

Heating Fuels	$ / kW-hr
Willow (30% H)	**0.02**
Natural gas	0.04
Wood pellets (10% H)	0.05
Fuel oil (no. 6)	0.06
Electricity	0.08
Propane	0.08-0.11
Light fuel oil (no. 2)	0.09-0.11

Hybrid Willows – Biomass for Energy

- Preliminary feasibility study conducted 2017-2018
- EcoWillow 2.0 model (SUNY-ESF)
  - estimated plot size: 1300 ha
  - included all up-front and maintenance costs (cuttings, labour, 1st year herbicide, etc.)
  - did not include fertilizer or ash-disposal costs, nor carbon credits
- Compared 3 modes of power production
  - Pyrolysis (electricity + bio-oil)
  - Gasification (electricity + syngas)
  - Combustion (electricity only)

Capital, Operating and Equipment Costs

	Pyrolysis	Gasification	Combustion	Units
Size	2	2	3.6	MW
Capital	9.5	7.5	12.9	Million $
Hours	7884	7884	7884	hr/yr
Equipment lifetime	20	20	20	yr
Residual value 20%	1.9	1.5	2.6	Million $
Depreciation	380,000	300,000	516,000	$/yr
Power generated	15,768	15,768	28,382	MW-hr/yr
Cost per MW	24.091	19.026	18.180	$/MW
Maintenance 3% capital	285,000	225,000	387,000	$/yr
Maintenance cost	18.075	14.269	13.635	$/MW-hr
Total Equipment Cost	0.042	0.033	0.032	$/kW-hr

Equipment and Fuel Costs

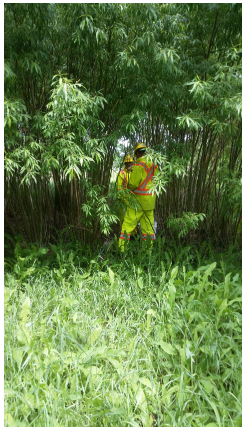
	Pyrolysis	Gasification	Combustion	Units
Total planting cost	2.7	2.7	2.7	Million $
Total power capital cost	9.5	7.5	12.9	Million $
Fuel cost	0.013	0.047	0.010	$/kW-hr
Equipment cost	0.042	0.033	0.032	$/kW-hr
Total electricity production	0.176	0.080	0.042	$/kW-hr
Production cost	2,800,000	1,260,000	1,200,000	$/yr
Revenue from electricity	1,300,000	1,260,000	2,300,000	$/yr
Net revenue	-1,500,000	0	1,100,000	$/yr
IRR	N/A	N/A	5%	

Preliminary Feasibility – Key Findings

- Pyrolysis and gasification are not economically feasible options
- Direct combustion of field-dried biomass is an option
  - Biomass boiler + organic rankine cycle (ORC) system
  - Electricity at half the price of Ontario grid
  - < 400 ha of willow will produce enough electricity to power a typical water treatment plant
  - $800/ha/year (about $1 M) in revenue
  - 10 MW of waste heat (use in other operations?)
  - 250 tonnes of ash/year (liming agent?)

Conclusions

- Revegetation with hybrid willows is also promising:
  - organic layer provides immediate dust control
  - rapid reclamation improves ecosystem recovery and social license
  - high biomass production helps to regenerate the organic cover
  - biomass combustion can generate electrical energy and heat
  - economic value from tailings (energy production, carbon credits)


Future Research

- Required thickness of cover
  - oxygen limitation and prevention of AMD
- Municipal biosolids
  - quality and degradability (thickness)
- Infiltration of nutrients into the tailings
  - metal mobilization by organic acid chelation
  - sulfide oxidation coupled to nitrate reduction
- Application on abandoned tailings
- Metal uptake by vegetation

Next Steps

- Expand the project to include different sites:
  - active or abandoned tailings
  - different provinces, territories and regions

✓ Establish contacts within the organic residuals space
  ✓ there is interest in partnering

- Determine best practices and regulatory implications

- Are you considering use of organic residuals?

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